1 second SRTM Derived

Digital Elevation Models User Guide

1 second DSM, DEM & DEM-S
3 second DSM, DEM & DEM-S

Version 1.0.3

August 2010

1 second products for Government Use Only

Supply Details:
Sales & Distribution
Geoscience Australia
GPO Box 378
Canberra ACT 2601
Email: sales@ga.gov.au
Phone: +61 2 6249 9966
Freecall (Aus only): 1800 800 173
Fax: +61 2 6249 9960

Australian Government
Geoscience Australia

National Research FLAGSHIPS
Water for a Healthy Country

CSIRO

General Information:
Phil Tickle
Geoscience Australia
Phone: +61 2 6253 9299
Email: Phil.Tickle@ga.gov.au

Technical Details:
John Gallant
CSIRO Land & Water
Phone: +61 2 6246 5734
Email: John.Gallant@csiro.au

Document Revisions

Revision Date	Reason for update	Revision approved by	Revised Version number
23/12/2009	User Guide first published.	PT	1.0.0
01/02/2010	Typing error in definitions in Nomenclature section.	NW	1.0.1
24/02/2010	Renaming of DEM and DSM mosaics (to a non-numeric starting grid name to not violate ESRI naming limitations).	NW	1.0.2
30/08/2010	Inclusion of 1 second and 3 second DEM-S. Removal of 1 second cover letter and licence to separate document.	NW	1.0.3

1 second SRTM Derived Digital Elevation Models
User Guide – Version 1.0.3

Product Description

Contact Information

Custodian

Geoscience Australia
Cnr Jerrabomberra Avenue & Hindmarsh Drive
Symonston ACT 2609
Australia

GPO Box 378
Canberra ACT 2601
Australia
elevation@ga.gov.au

Supply Details

Sales & Distribution
Geoscience Australia
GPO Box 378
Canberra ACT 2601

Phone: +61 2 6249 9966
Freecall (Aus only): 1800 800 173
Fax: +61 2 6249 9960
Email: sales@ga.gov.au

Authors

Geoscience Australia – Phil Tickle, Nerida Wilson, Chris Inskeep
CSIRO Land & Water – John Gallant, Trevor Dowling, Arthur Read

Licensing

Licence - 1 second Products (Government Use Only)

The 1 second SRTM products are strictly for **Government use only**. It is important to note that the Level-2 (~1 second or 30m) data are being provided with specific licensing and release constraints agreed to by Australia's Defence Imagery and Geospatial Organisation (DIGO) and the United States Department of Defence. It is therefore crucial that these conditions are adhered to, both in terms of the source data and in the derivation of future products.

The release constraints are based on an assessment of the risk to national security of making the data available, the uniqueness of the information, the requirement to protect source capability and an assessment of the net benefit – societal and otherwise – of disseminating the data compared to restricting access. Subject to developments in technology and capabilities, these release constraints will likely be revisited in the future.

A licence agreement is required to obtain the SRTM derived 1 second products. The data is available to government agencies and their collaborators and contractors who sign a copy of the licence and return it to Geoscience Australia. The 1 second data is not available to universities or students unless they are working on a government project. <u>The licence agreement will cover all versions of products derived from the SRTM data once signed</u>. Under the agreement with DIGO, Geoscience Australia is required to keep a record of all government agencies that have received the data. The data is subject to Commonwealth of Australia Copyright.

Creative Commons – 3 second Products

The 3 second SRTM Smoothed Digital Elevation Model (DEM-S) is released under Creative Commons Attribution 3.0 Australia licence. This means the data can be shared (copy, distributed and transmitted) or adapted providing you acknowledge Geoscience Australia as the author or licensor.

Data Schema

Data Format

<u>1 second Products</u>

Data is stored as a continuous 32 bit Floating Point ESRI Grids and ESRI shapefiles for some reference data. One second (~30m) Grid tiles are named per the latitude and longitude of the south west corner. A suffix of 'dsm1_0', 'dem1_0' or 'dems' has been applied to the tile names to differentiate between the elevation models and the version number (in this case version 1.0).

<u>3 second Products</u>

The data can be provided in several file formats depending on the delivery method.

The data can be downloaded from the National Elevation Data Framework (NEDF) web portal at http://nedf.ga.gov.au/geoportal/catalog/main/home.page in many formats in national coverage or tile format (to begin with ESRI Grid or ESRI ASCII). It is recommended that you use this method to access the data format you require.

If ordering the data through the Geoscience Australia Sales Centre the data will be supplied as a national product in ESRI Grid format.

The 3 second DEM and DSM is available in integer format and the 3 second DEM-S is in 32 bit floating point no matter which delivery method.

Further information on loading data into various software packages is explained in Appendix D.

Data Extent

Australia (mainland and near-shore islands).

North bounding latitude: -10°

South bounding latitude: -44°

East bounding longitude: 154°

West bounding longitude: 113°

The following tiles containing fragment or pieces of islands were not applied at 1 second resolution SRTM and therefore are missing from the 1 and 3 second products.

E112 S26	E120 S35	E124 S15	E133 S11	E142 S10	E150 S22
E113 S29	E121 S35	E125 S14	E134 S35	E143 S10	E152 S24
E118 S20	E123 S16	E132 S11	E141 S10	E146 S17	

Reference System

Horizontal Datum: WGS84.

Vertical Datum: EGM96 (refer to 'Accuracy Assessment' section for further information).

Additional Information

The figures shown in this User Guide were created using the 1 second product with a hill shade applied with elevation values selected to highlight particular features in the dataset.

Introduction

The User Guide provides an informative overview of the various products derived from the 1 second SRTM data including the: Digital Surface Model (DSM); Digital Elevation Model (DEM), Smoothed Digital Elevation Model (DEM–S) and in the future, a hydrologically enforced (DEM–H) product. It describes the characteristics of the data, the differences between the different products, examples of the data in good and poor areas, known problems and comparisons between various elevation data and the SRTM derived products. It does not describe the methods in any detail, so users should refer to the product metadata and the references cited there for further information.

This product has been released in good faith that the user understands the limitations and inherent errors in the data. The data should not be solely relied upon for decision making but rather as a supplementary dataset. The errors associated with these elevation products in time will be minimised and improved for a more accurate national DEM product as this product evolves. Details of known errors in the data are explained in this User Guide. We would urge users to provide feedback on any errors to Geoscience Australia at the following email address: elevation@ga.gov.au

The 1 second resolution (approximately 30m) products are available to government agencies and their collaborators and contractors. Reduced resolution versions of the products at 3 second (~ 90m) and 9 second (~ 250m) resolution are being prepared for public release in 2010. Another available product for public use is the GeoData3 9 second (~250m) DEM which has had hydrological enforcement applied unlike the 3 second DEM and is available through Geoscience Australia Sales Centre.

Overview

The 1 Second DSM and DEM are national elevation data products derived from the Shuttle Radar Topographic Mission (SRTM) data. The SRTM data is not suitable for routine application due to various artefacts and noise.

The data has been (or will be) treated with several processes to produce more usable products:

- A cleaned digital surface model (DSM)
    - regular grid representing ground surface topography and height as well as other features including vegetation and man-made structures
- A bare-earth digital elevation model (DEM)
    - regular grid representing ground surface topography, and where possible, excluding other features such as vegetation and man-made structures.
- A smoothed digital elevation model (DEM–S)
    - A smoothed DEM based on the bare-earth DEM that has been adaptively smoothed to reduce random noise typically associated with the SRTM data in low relief area.
- A hydrologically enforced digital elevation model (DEM–H)
    - A hydrologically enforced DEM is based on the bare-earth DEM that has had drainage lines imposed and been smoothed using the ANUDEM software.

The last product, a hydrologically enforced DEM, is most similar to the DEMs commonly in use around Australia, such as the GEODATA 9 Second DEM and the 25m resolution DEMs produced by state and territory agencies from digitised topographic maps.

The 1 second DEM (in its various incarnations) has quite different characteristics to DEMs derived by interpolation from topographic data. Those DEMs are typically quite smooth and are based on fairly accurate but sparse source data, usually contours and spot heights supplemented by drainage lines. The SRTM data is derived from radar measurements that are dense - there is essentially a measurement at every grid cell - but noisy.

Version 1.0 of the DSM was released in early 2009 and version 1.0 of the DEM was released in late 2009. Version 1.0 of the DEM-S was released in July 2010. These products provide substantial improvements in the quality and consistency of the data relative to the original SRTM data, but are not free from artefacts. Improved products will be released over time.

The hydrologically enforced DEM–H is still in development and is expected to be released in 2010.

The 3 second products were derived from the 1 second data and version 1.0 was released in August 2010. Future release of these products will occur when the 1 second products have been improved.

Nomenclature

There is no universal agreement about the use of the terms digital surface model (DSM), digital elevation model (DEM), and digital terrain model (DTM). The usage adopted for the SRTM-derived 1 second products is that a DSM represents a regular grid of ground surface topography and height as well as other features including vegetation and man-made structures, while a DEM represents a regular grid of ground surface topography, and where possible, excluding other features such as vegetation and man-made structures. In some areas the term DTM is used for the land surface model, with the DEM having a more generic meaning as a DTM or DSM, but in Australia the term DEM is generally accepted to mean a land surface model, such as the GEODATA 9 second DEM, and we have chosen to continue with that term.

For further information users should refer to the Intergovernmental Committee on Surveying and Mapping Guidelines for Digital Elevation Data http://www.icsm.gov.au/icsm/elevation/index.html.

SRTM Background

The SRTM data was collected during a 10 day NASA Space Shuttle mission in February 2000 (Kobrick, 2006). It was processed to produce a 1 arc second digital surface model covering most of the earth's landmass and publicly released as a 3 second resolution product. The 1 second version was provided to CSIRO by Australia's Defence Imagery and Geospatial Organisation (DIGO) with permission to release cleaned up products to government users only.

The data was acquired by interferometric synthetic aperture radar, meaning that the information is contained in the interference patterns between the radar signals collected by two antennas, one of which was inside the Shuttle and the other was on a 60m boom. The Shuttle was oriented to point the antennas at 45° to the ground to optimise the effect of topography on the interference patterns, but this also has the effect of obscuring any steep areas facing away from the Shuttle. This is mostly overcome by collecting overlapping swathes from different orbits, although some canyons and steep areas have no data. Other areas that did not produce a good radar return signal also have no data.

Comparison of SRTM with reference data (Rodriguez *et al*, 2006) showed that 90% of tested heights were within 6m of the reference heights. In much of the clear flat areas of Australia the height errors are less than 3m, although there are some areas where the errors are much larger. Trees and buildings produce offsets in the elevation much larger than these height errors, since the radar frequency used by SRTM does not penetrate them.

Processing of the SRTM data

The processing of the SRTM DSM has produced a series of products:

- The cleaned digital surface model (DSM) is the 1 second SRTM with stripes removed and voids filled.
- The bare-earth DEM is based on the cleaned DSM and has had tree offsets removed using automated methods.
- The DEM-S is based on the bare-earth DEM and has been adaptively smoothed.
- The hydrologically enforced DEM–H is based on the bare-earth DEM and has had drainage lines imposed and been smoothed using the ANUDEM software.
- Resampling of 1 second products to produce publicly available 3 second products (DEM, DSM and DEM-S).

More about the DEM-H products will be described when they are released in the future.

The main processing of the SRTM products has included:

- Removal of stripes
- Voids filling
- Tree offsets removed using automated methods.
- DEM being adaptively smoothed
- Water masking (to flatten water bodies affected by processing)

Stripe removal

Diagonal stripes exist across most of the SRTM DSM and are most visible in low relief landscapes. The orientation of the stripes generally relates to the orbital path of the Space Shuttle. The stripes are about 800m apart and their amplitude is typically around 1m, but up to 4m in places, and can vary quite abruptly.

The stripes were treated using a 2-dimensional Fourier Transform method that detects features with a consistent orientation and spacing. Stripes were detected and removed throughout Australia except where high relief masked their presence. One of the ancillary data layers provided with the product shows the maximum magnitude of striping removed across the continent (Figure 1).

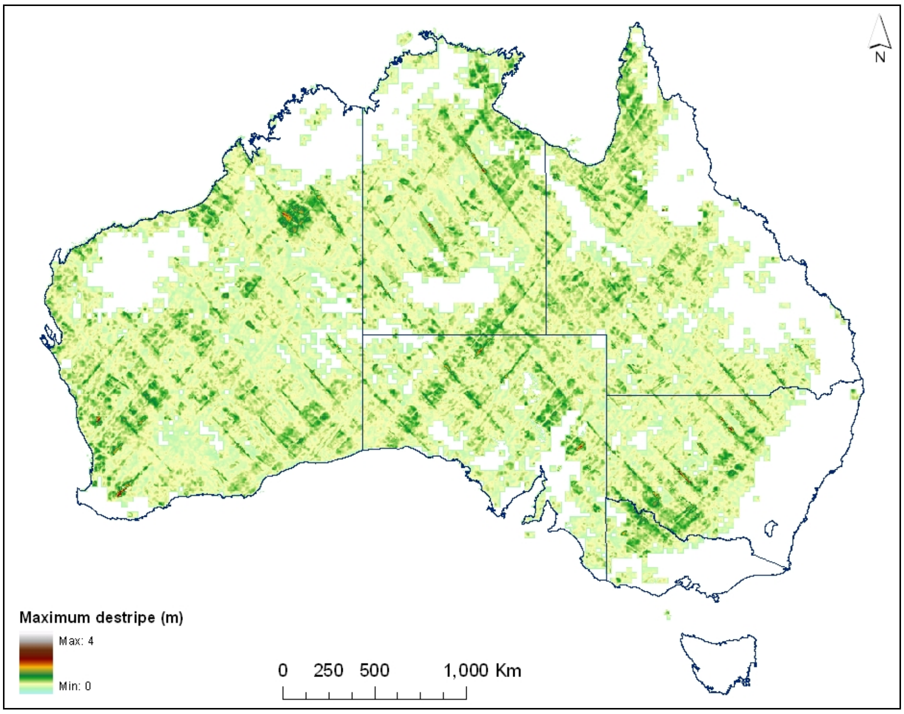


Figure 1. Magnitude and distribution of stripe cleaning.

Stripe removal was effective in most areas, but in some locations where there were abrupt changes in the stripe amplitude the stripes are still apparent (Figures 2 & 3).

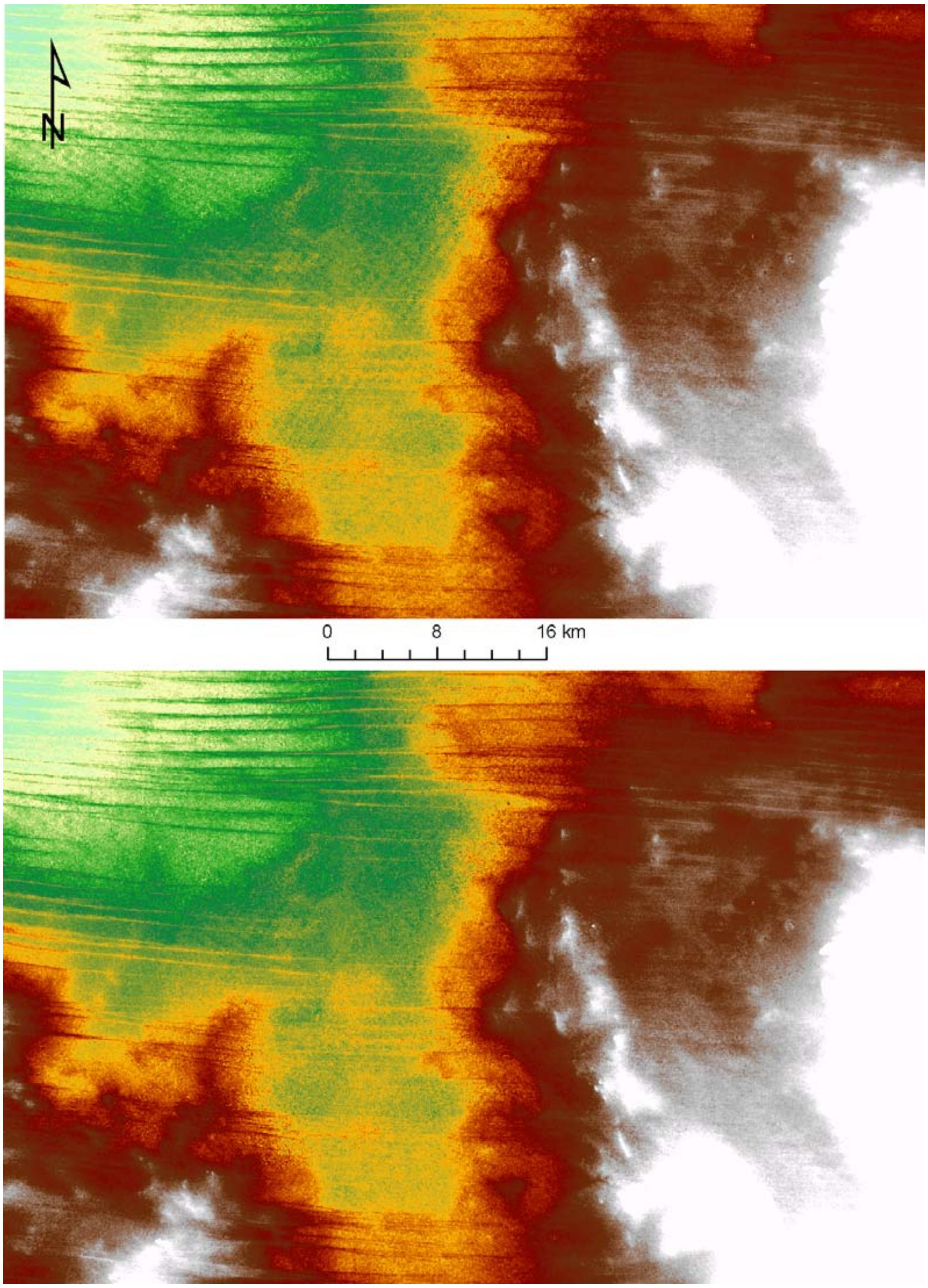


Figure 2. Example of good stripe removal. Southesk Tablelands in Great Sandy Desert, WA, 126.3E 20.2S. Elevation range 220 – 320m.

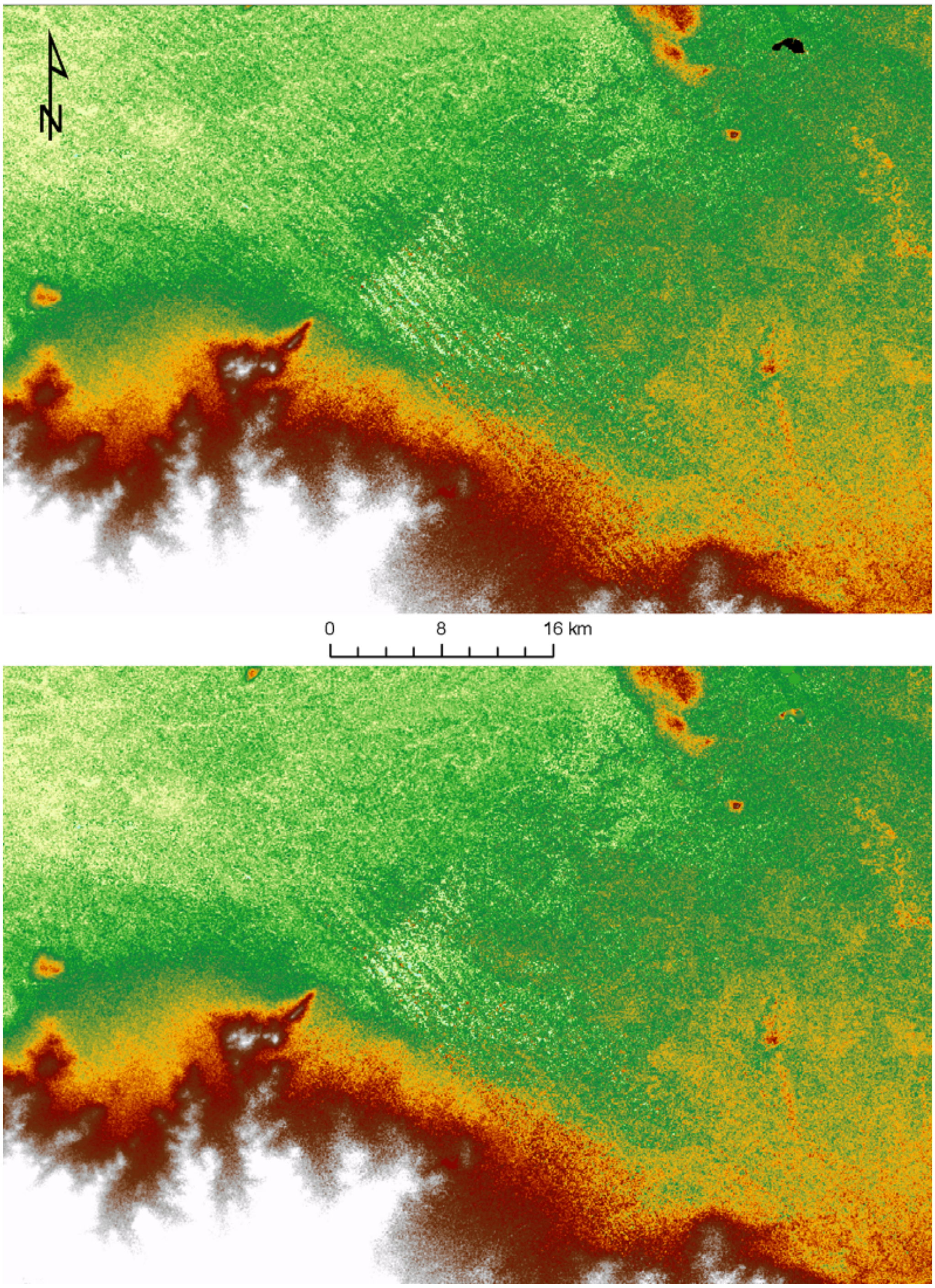


Figure 3. Example of poor stripe removal; there are also some voids among the stripes. Bogan River near Brewarrina, NSW, 146.7E 30.2S. Elevation range 105 – 160m.

Void filling

The SRTM DSM contains voids - areas without data - where the surface did not produce a good radar signal. There are several reasons for these voids:

- Steep areas like canyons where the radar could not see the ground because of its 45° look angle (Figure 4);
- Water bodies that did not reflect a radar signal back to the Shuttle (Figure 5);
- Dry sandy areas that did not reflect a radar signal back to the Shuttle (Figure 6).

Voids are filled by replacing the missing data with elevations from another source, in this case the Geodata 9 second DEM. While this DEM is much lower resolution than the SRTM data, it provides a much better representation of the landscape in the steep areas than just filling in the missing areas by interpolation. Since completing the void filling, the ASTER G-DEM (ERSDAC, 2009) has been released and this is being considered as an alternate source of filling voids in the steep areas.

The void filling method matches elevations around the edge of the void, which avoids abrupt elevation changes at the void edges. Some void fills are affected by erratic elevation values around the edge of the void, particularly in salt lake areas in Central Australia (Figure 5).

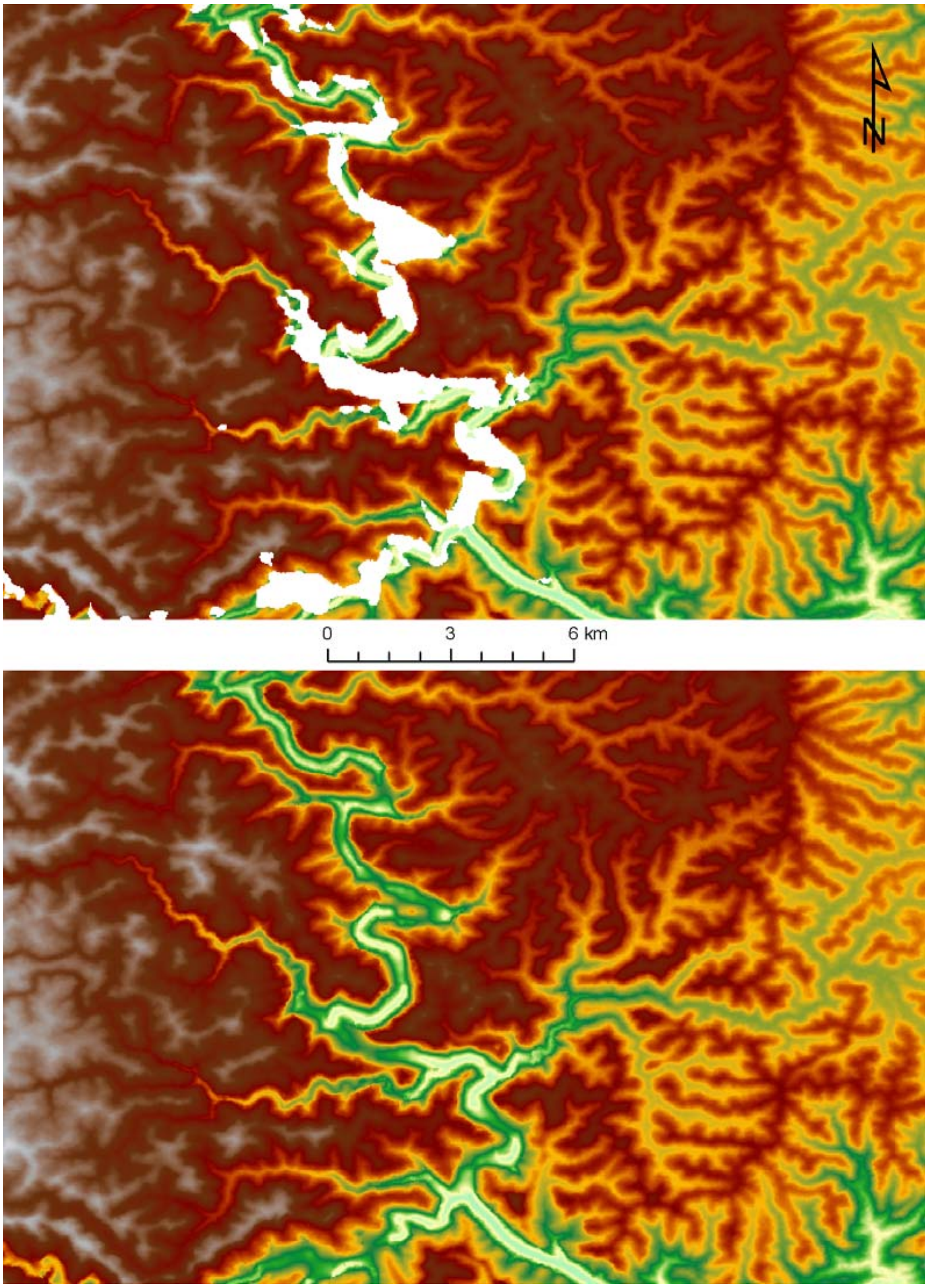


Figure 4. Void filling in canyon area, a fairly good result although canyon bottom has not quite been captured properly. Colo River, Wollemi National Park, NSW, 150.6E 33.3S. Elevation range 0 – 800m.

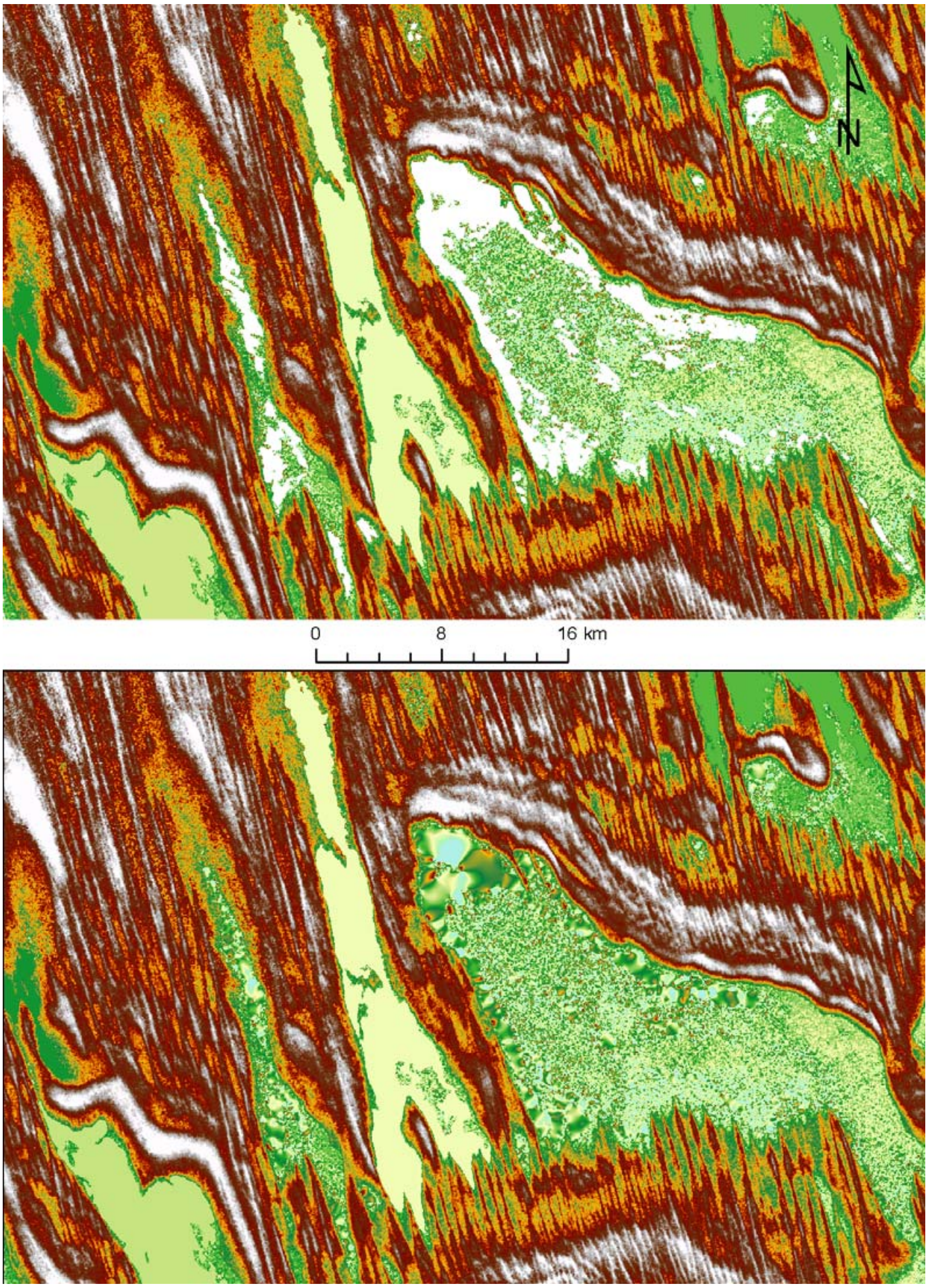


Figure 5. Voids filled in a lake bed; the elevations replacing the void are variable due to the noisy data around the edge of the void. Poolowanna Lake, Simpson Desert, SA, 137.6E 26.7S.
Elevation range -20 to 70m.

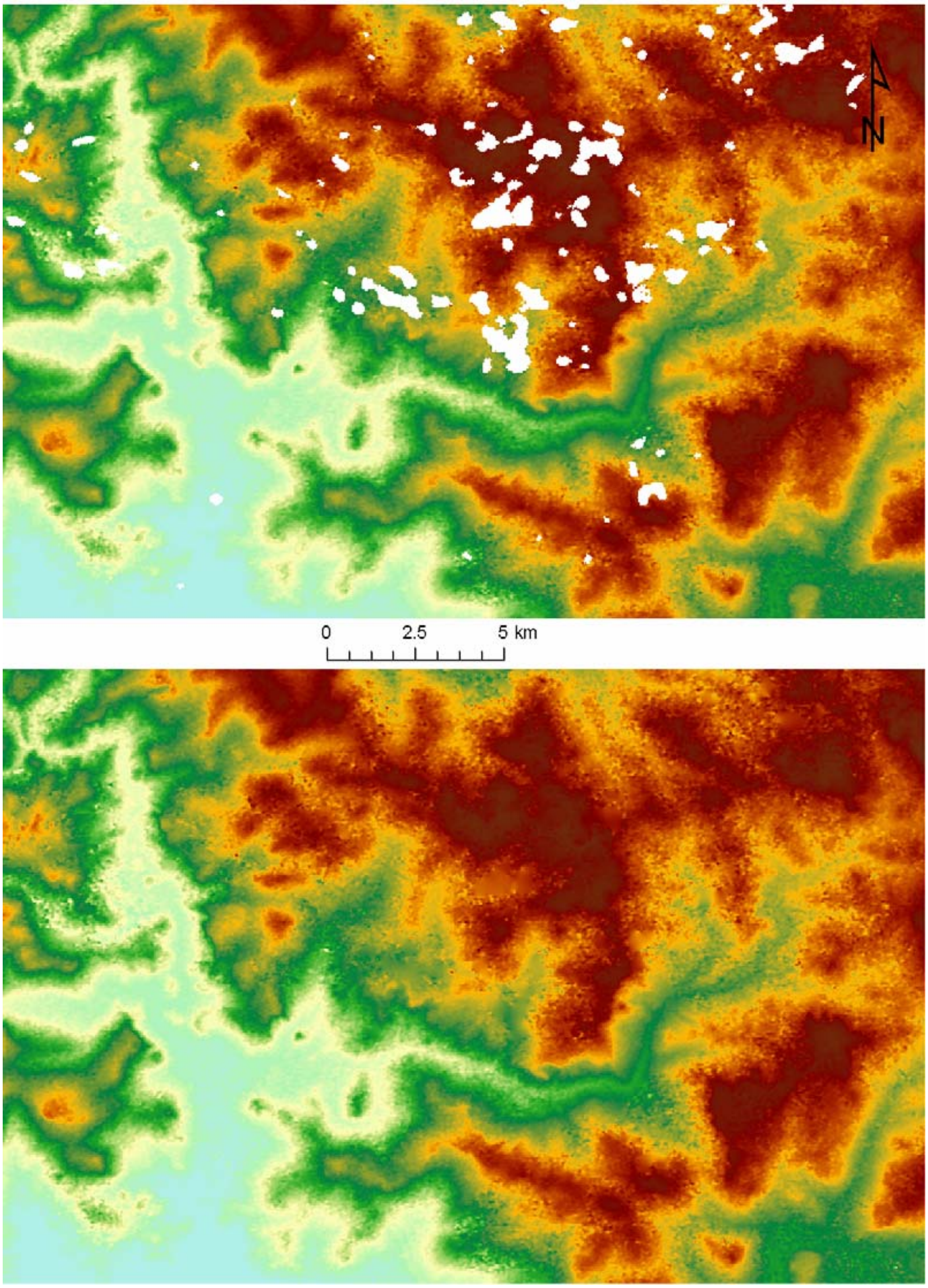


Figure 6. Voids that are probably due to low reflectivity in dry sandy soils. Coomallo Hill, WA, 115.4E 30.2S. Elevation range 100 – 400m.

Vegetation offset removal

The radar used for the SRTM DSM does not penetrate vegetation, so areas with a high tree density are visible in the DSM as raised patches. Lower and less dense vegetation including crops do not appear to cause any offset.

The treatment of vegetation offsets to produce the DEM relies heavily on Landsat-based mapping of woody vegetation to define where the offsets are likely to occur. The mapped extents of woody vegetation were adjusted using an edge-matching process to better represent the extents of areas affected by vegetation offsets in the SRTM DSM. Vegetation treatment was undertaken across about 40% of

Australia. The extent of treatment as shown in Figure 7 below is provided as an ancillary dataset.

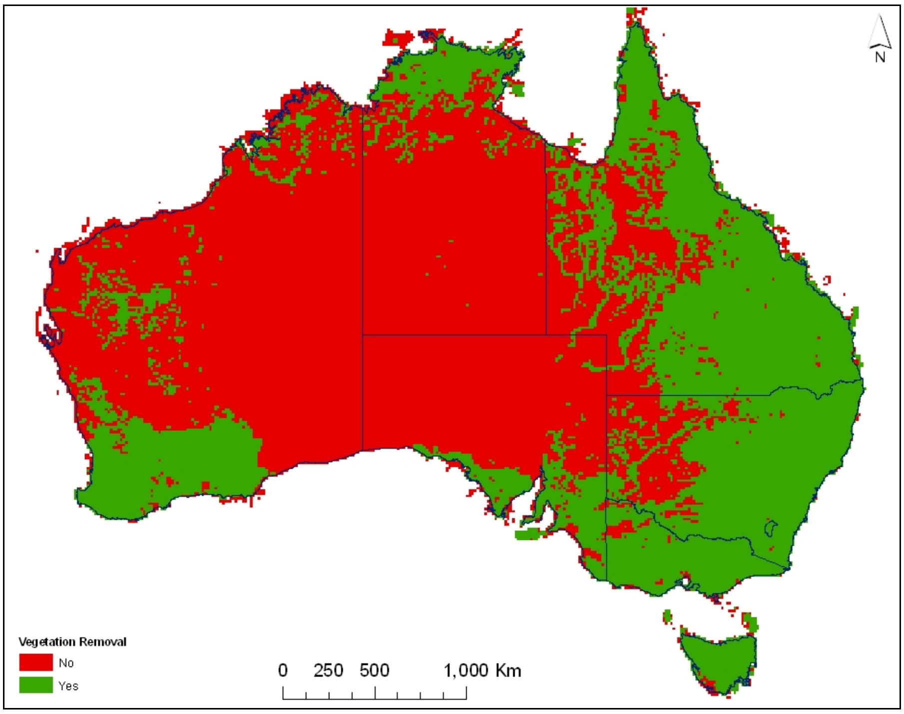


Figure 7. Distribution of vegetation removal in the SRTM.

The tree offsets are treated by detecting affected areas, measuring the height offset around the edges, interpolating the height offset across the tree vegetated areas and subtracting the offset from the DSM (Figure 8).

The heights of the offsets are estimated by measuring height differences across the boundaries of the vegetation patches. The method provides good estimates of the offsets in flat landscapes with well-mapped vegetation boundaries. The effect of sloping terrain is accounted for in the estimation of the offsets, but the results are less reliable in hilly terrain where the mapped vegetation extents do not match the extents of vegetation offsets as seen by the SRTM instrument. The estimation of the vegetation offsets can also be under- or over-estimated if vegetation and topographic patterns coincide, such as trees on hilltops or dune ridges, or in inset floodplains or swamps.

The height offsets at vegetation edges are interpolated within vegetation patches to estimate the effects within the patches. The best results tend to be in small patches such as remnant tree patches. In continuously forested areas with few edges for estimating the offsets the heights are likely to be less reliable, and there is no information at all on variations of the height offset within continuous forests.

The removal of vegetation has been quite effective overall but there are many areas that contain either untreated or incompletely treated vegetation effects such as the area shown in Figure 9.

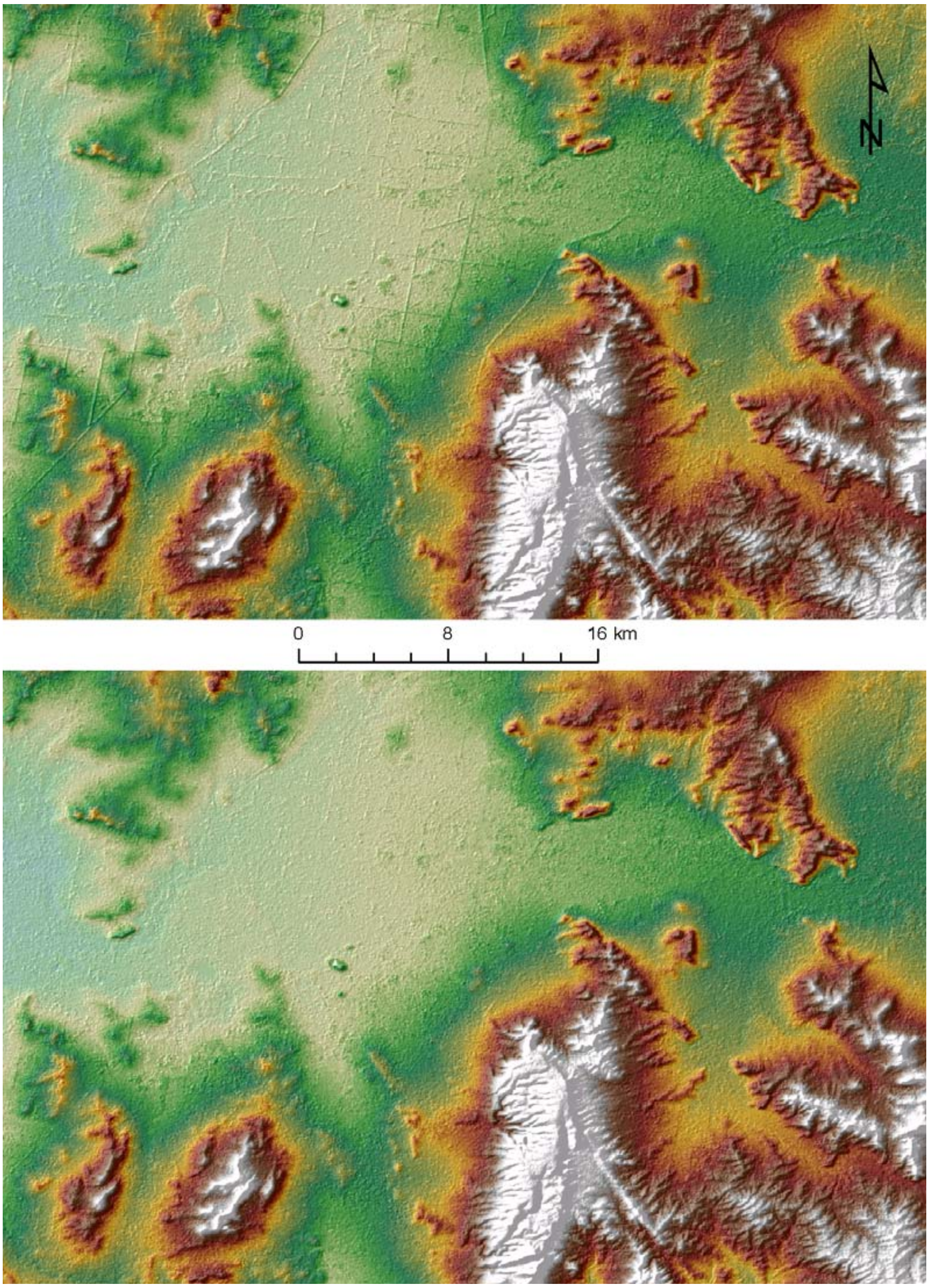


Figure 8. An example of effective removal of vegetation offset. Culcairn, NSW, 147.0E 35.7S. Elevation range 150 – 600m.

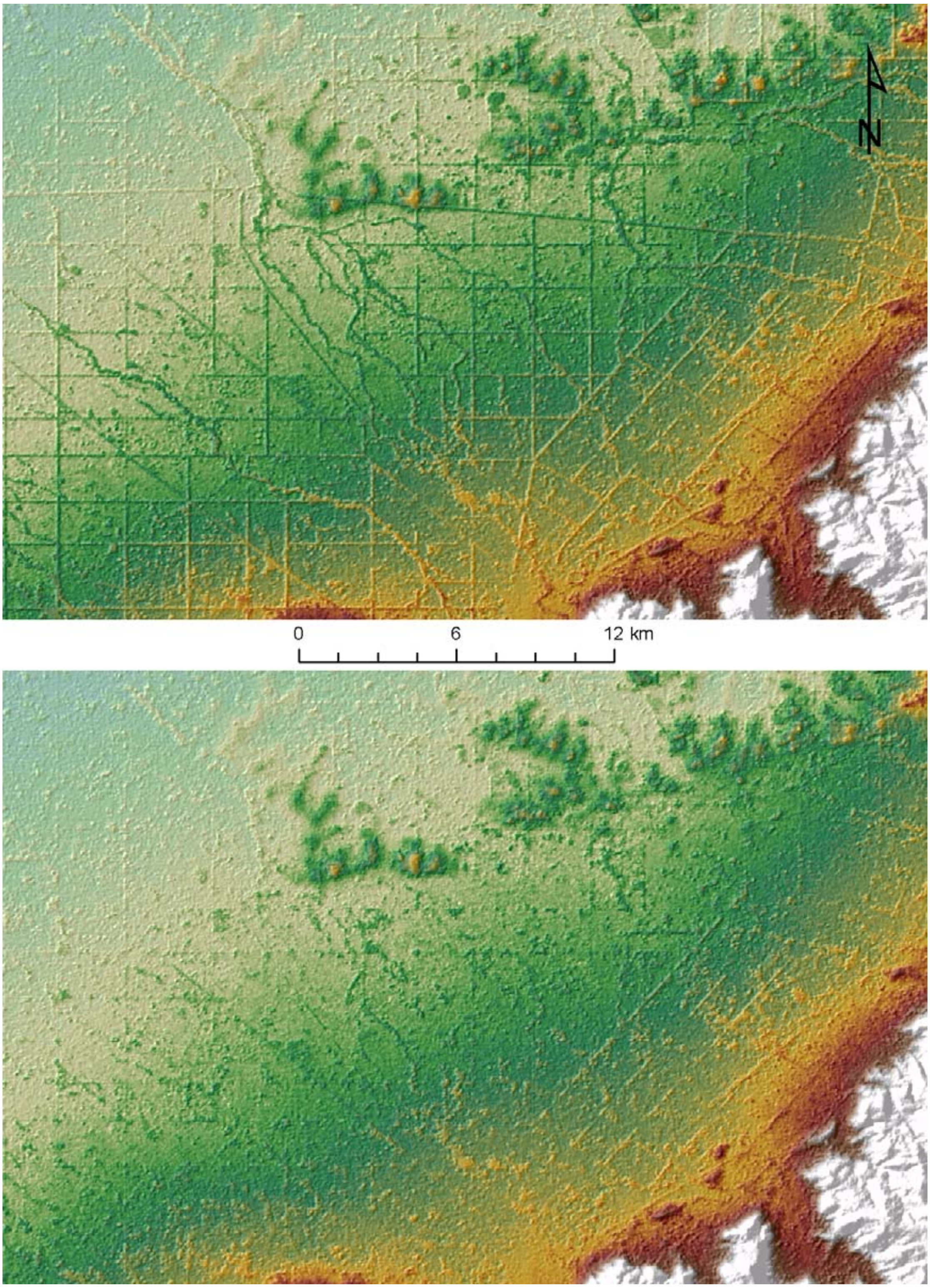


Figure 9. Poor vegetation removal - much improved but many vegetation features remain.
Euroa, VIC, 145.5E 36.7S. Elevation range 120 – 240m.

Smoothing

The 1 second DEM after vegetation removal still contains the random noise present in the original SRTM data. The noise typically alters elevations by 2-3m but in some cases by as much as 10m. In high relief areas where elevations change by many metres from one grid cell to the next, this noise is of little consequence. In low relief areas the noise is usually larger than the actual height differences from one cell to the next and corrupts calculated surface properties like slope and flow direction that depend on local height differences. The true topographic height variations become apparent over longer distances as the variations due to noise are averaged out.

Averaging over larger areas effectively eliminates noise but also smooths out real topography, while averaging over small areas does not produce enough smoothing to eliminate noise in relatively flat areas. The smoothing approach used to produce DEM-S adapts the scale of smoothing in response to local relief and noise levels. Broader scale averaging is used where the noise is large relative to the local relief, while steep areas are left untouched or smoothed only slightly. The effect of the smoothing is therefore most apparent in the flattest and noisiest areas.

The adaptive smoothing process was designed to smooth flat areas to a greater degree than steep areas, and to respond to the degree of noise so that very noisy flat areas are smoothed more than less noisy flat areas. The process operated over multiple resolutions, allowing smoothing over quite large distances in areas of very low relief. The smoothing was performed on overlapping tiles, with sufficient overlap that cells used in the final product were not impacted by edge effects.

In essence, the smoothing process operated by comparing the variance of elevations in a 3x3 group of cells with the mean noise variance in the group. If the elevation variance was larger than the mean noise it was considered to be due to real topographic variation and the elevations were left unchanged, while if it was smaller it was considered to be due to noise and the elevations were replaced by the mean elevation in the group. This was applied at successively coarser resolutions, producing smoothing over large areas where the topographic variation was small compared to the noise levels. The algorithm actually used statistical tests to make the decisions, and combined the multiple estimates of elevation at different resolutions using variance weighting.

Differences due to smoothing can be as large as ±110m, although the maximum change is less than ±50m in 87% of tiles. The standard deviation of elevation change due to smoothing is less than 1.5 m in 84% of tiles. Mean elevation difference due to smoothing is less than 0.2m across all tiles.

Figure 10 shows the changes made by the adaptive smoothing in an area of coastal NSW containing flat plateaus, flat valley floors and steep escarpments. The smoothing has removed random variations in the flatter areas and left the steep areas essentially unchanged. In the moderate relief areas there is some smoothing of topography with valleys raised and ridges lowered by a few metres.

Figure 11 shows the profound impact of smoothing on calculated slope. This area of Western Australia has subtle relief and relatively high noise levels: the noise amplitude is 3-4m in the noisier area and about 1m in the less noisy area. Before smoothing the calculated slopes are heavily impacted by noise and there is little topographic structure apparent in the slope image. After smoothing the topographic structure is clearly apparent.

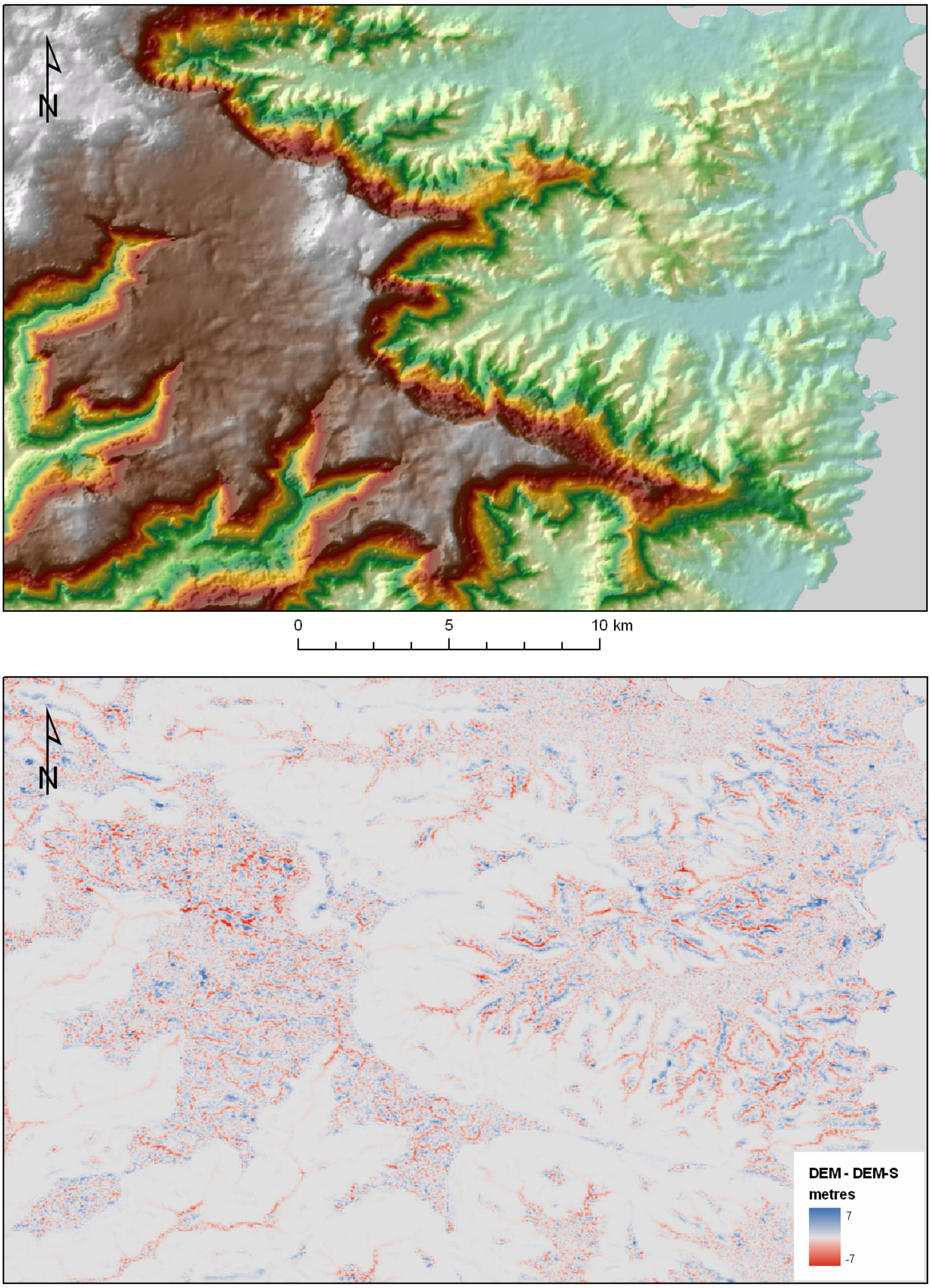


Figure 10. Smoothed DEM-S (top). The bottom image shows the difference between the DEM and smoothed DEM-S, with red showing areas that have been raised due to smoothing and blue those that have been lowered. The differences in the low-relief uplands and lowlands show random patterns of noise that have been removed. In the moderate relief areas some topographic structure has been lost due to smoothing, while in the steepest areas there has been very little change. Jamberoo, NSW, 150.7E 34.6S. Elevation range is 0 – 750m.

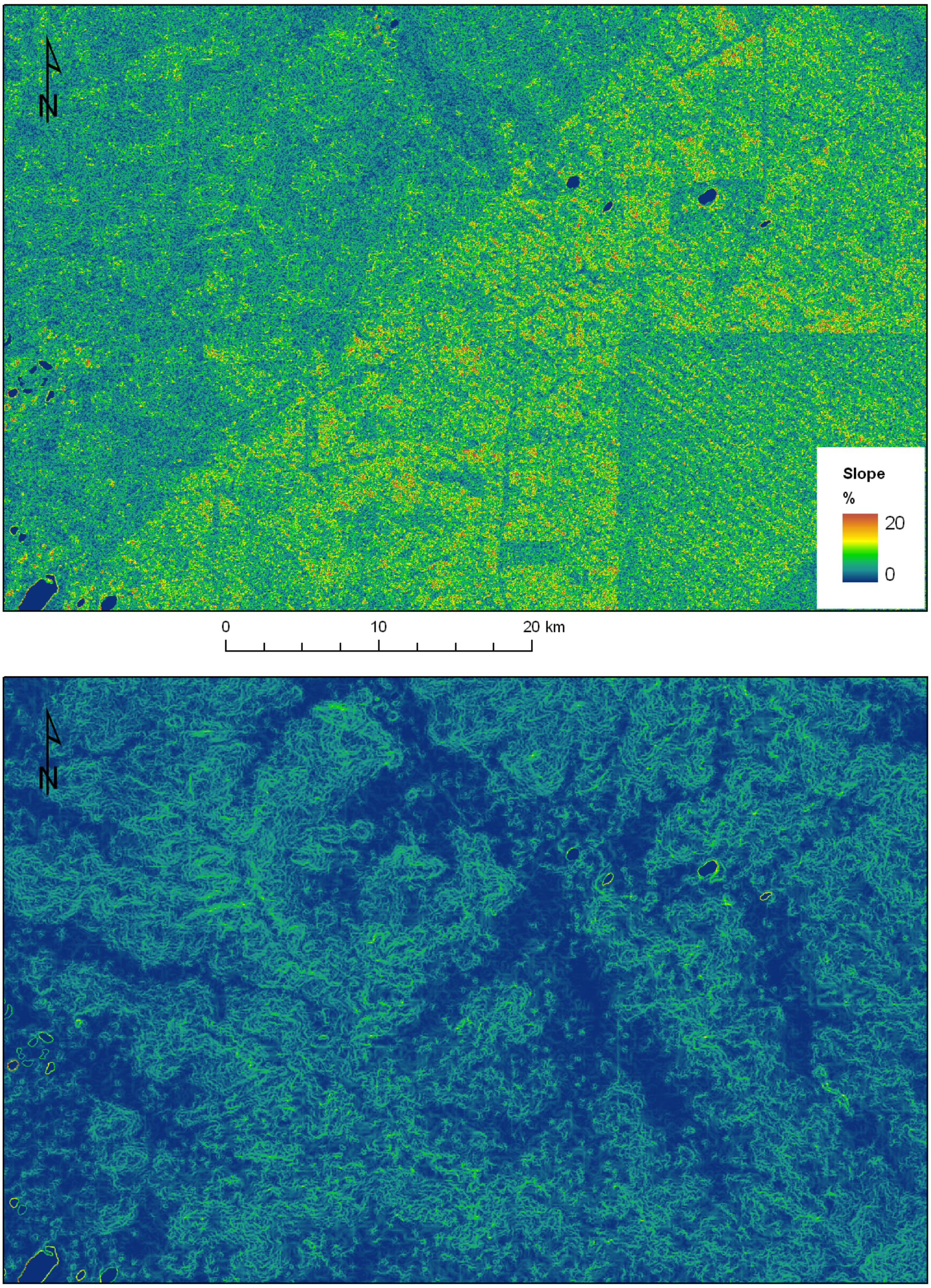


Figure 11. Slope before (top) and after smoothing (bottom); the slope colour scale is the same in both cases. The broad diagonal stripe of higher slopes is due to particularly high noise levels along in that area, almost completely obscuring the topographic structure in the slope map. After smoothing, the flat valley floor in the middle of the area is apparent. Lake Bryde area, WA, 118.8E 33.4S. Elevation range 280 – 390 m.

Dataset Examples

This section shows some examples of the 1 second bare-earth DEM from a range of landscapes around Australia, highlighting the capabilities of this DEM (Figures 12 to 18). The examples focus on low relief landforms, where the SRTM-based 1 second DEM is significantly superior to DEMs based on interpolated contour data, and in the arid zone previously only covered by the 9 second DEM.

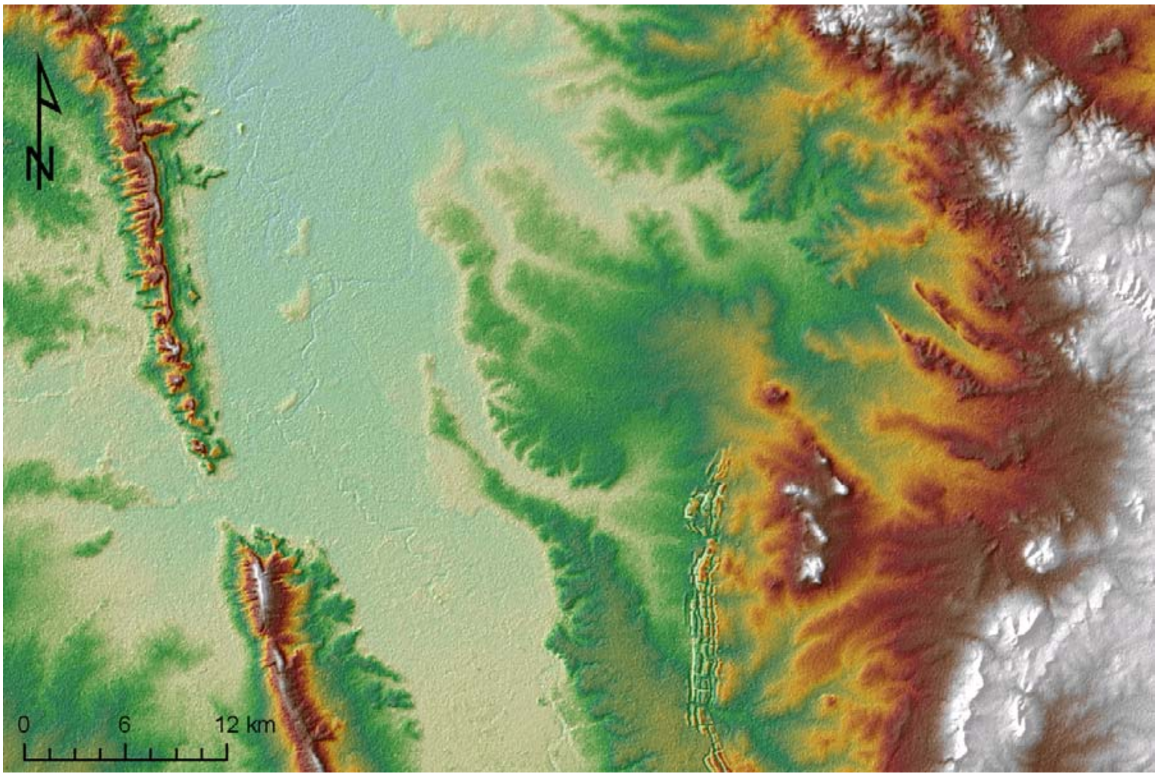


Figure 12. The linear features in the bottom centre are open cut coal mines. Moura, QLD 150.0E 24.5S. Elevation range 220 – 320m.

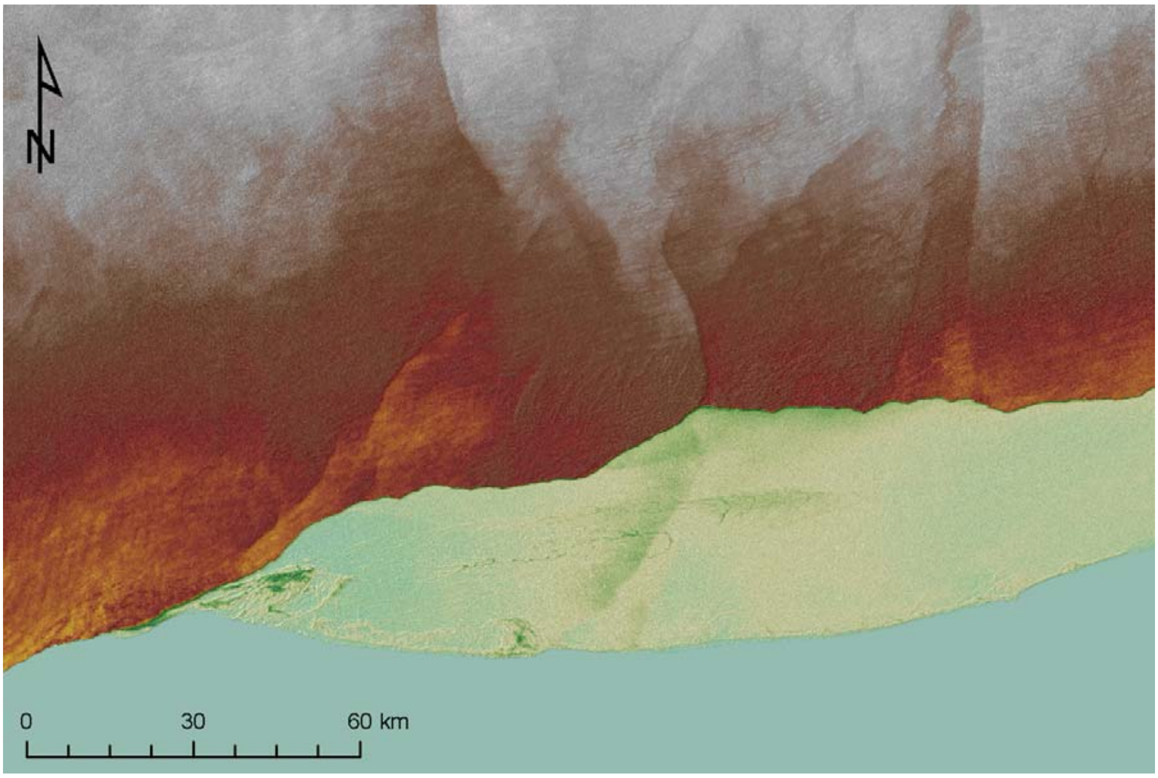


Figure 13. Escarpment at the southern edge of the Nullarbor Plain. Madura, WA 126.8E 31.9S.
Elevation range 0 – 170m.

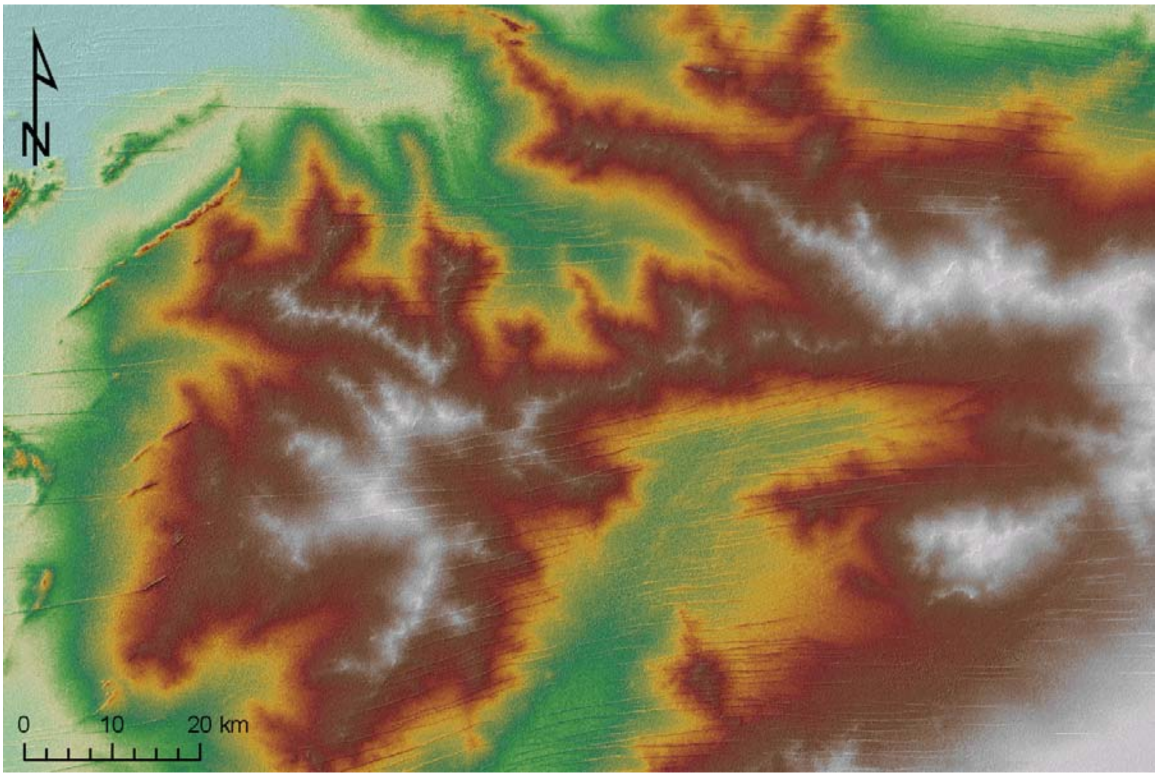


Figure 14. Wilbrunga Range, Tanami Desert, NT 129.5E 21.5S. Elevation range 350 – 480m.

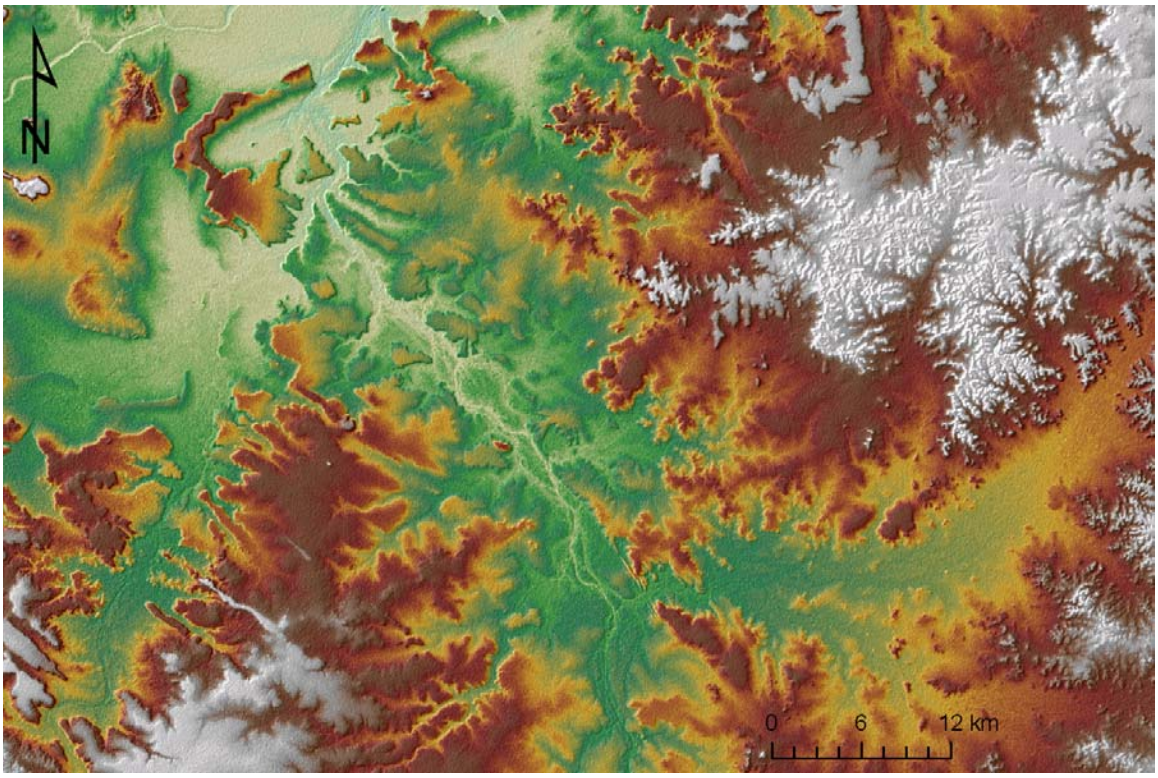


Figure 15. Victoria River, WA, 131.2E 16.6S. Elevation range 70 – 200m.

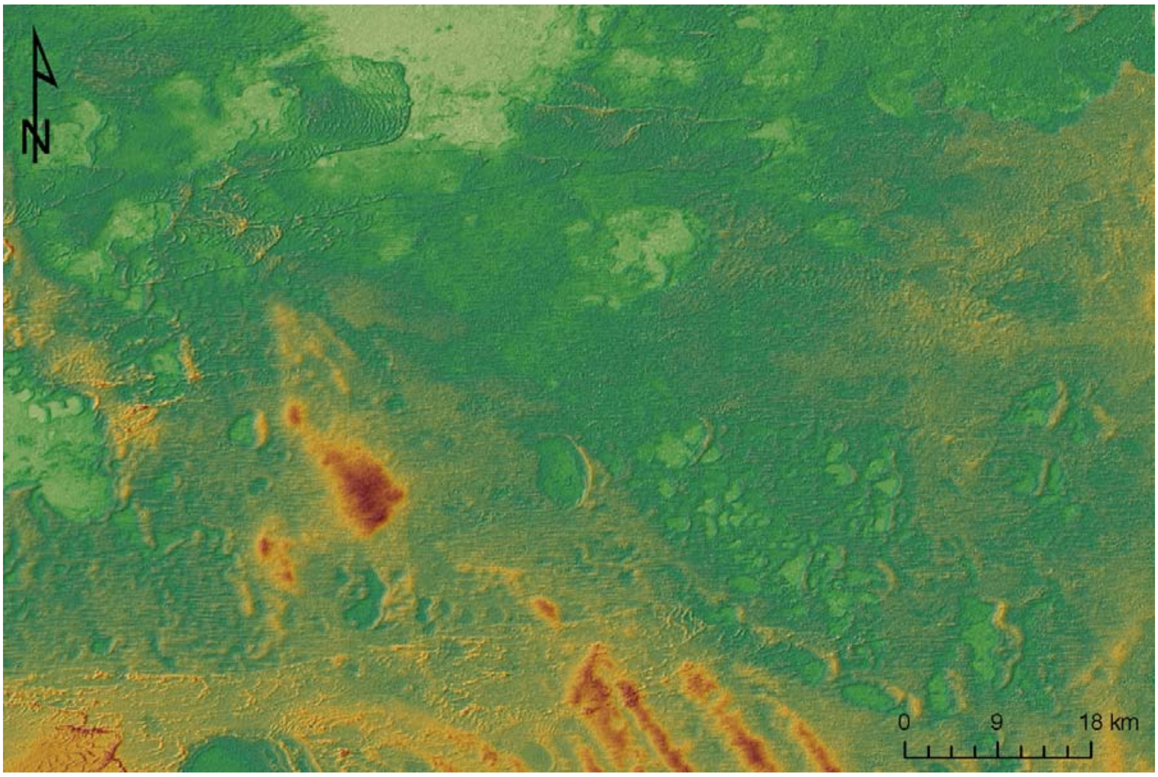


Figure 16. Ouyen, VIC, 142.2E 35.1S. Elevation range 30 – 120m.

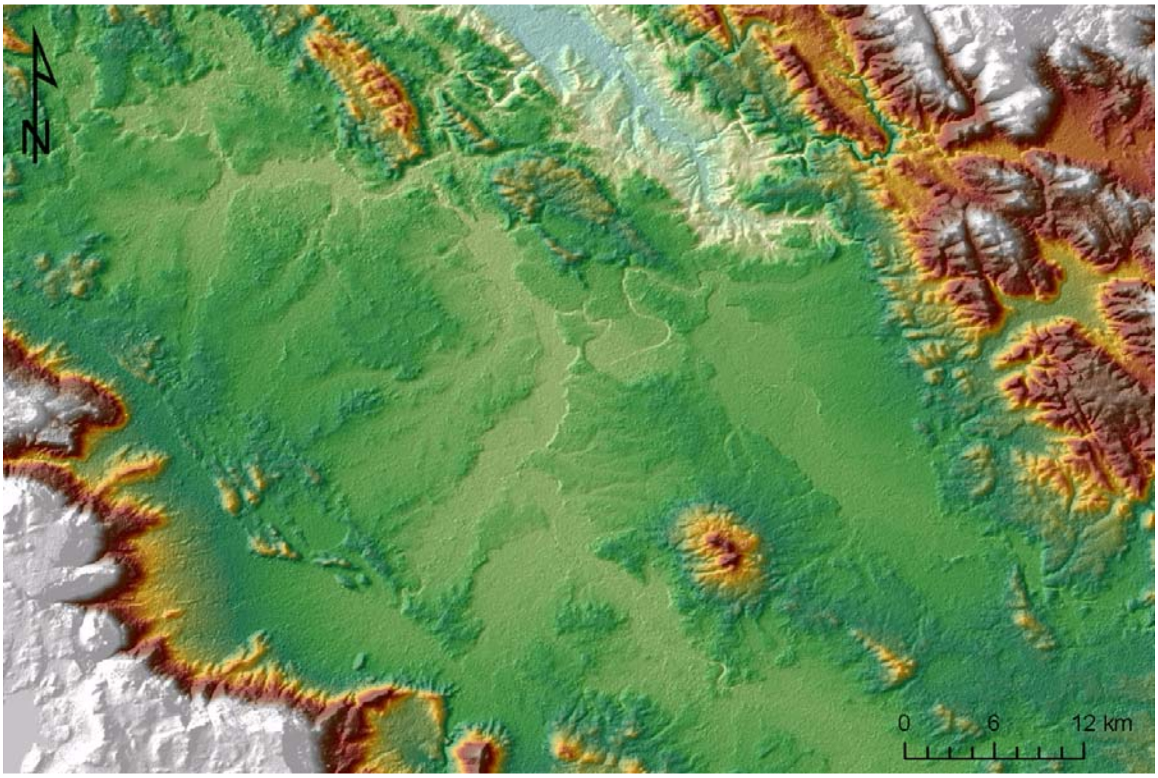


Figure 17. Longford, TAS, 147.2E 41.6S. Elevation range 0 – 700m.

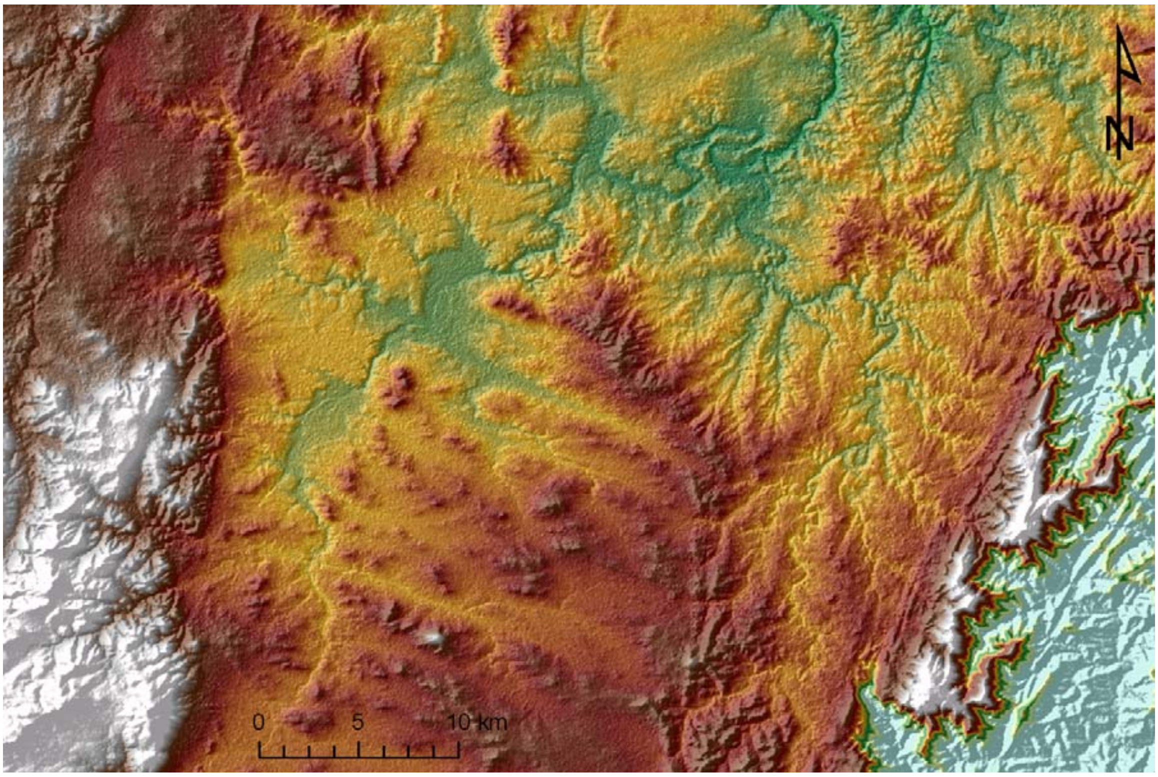


Figure 18. Braidwood, NSW, 149.8E 35.3S. Elevation range 400 – 900m.

Known Issues

All DEMs are imperfect representations of the earths land surface with their particular foibles, and the products derived from the 1 second SRTM are no exception. There are a number of known issues with the products, described below. These problems are being addressed in various ways and subsequent releases of the products will improve or resolve these issues.

Residual stripes

Some areas of the DSM and derived DEMs contain stripes that could not be removed using CSIRO custom-made destriping tool. An example is shown above in the Stripe Removal section (Figures 2 & 3). Residual stripes are relatively rare. These stripes will significantly affect measures of surface shape such as slope, aspect, flow direction and curvature.

Broad scale stripes

In a few areas, notably the Hay Plain in southern NSW (Figure 17), there are gentle undulations similar to the stripes but with much longer wavelength - about 10km, rather than the 800m of the widespread stripes - and amplitude of up to 4m. These have not yet been treated. Due to the very low gradient of the terrain in the Hay Plain, as low as 1m per 10km, these stripes will impact surface shape and flow patterns at the 10km scale.

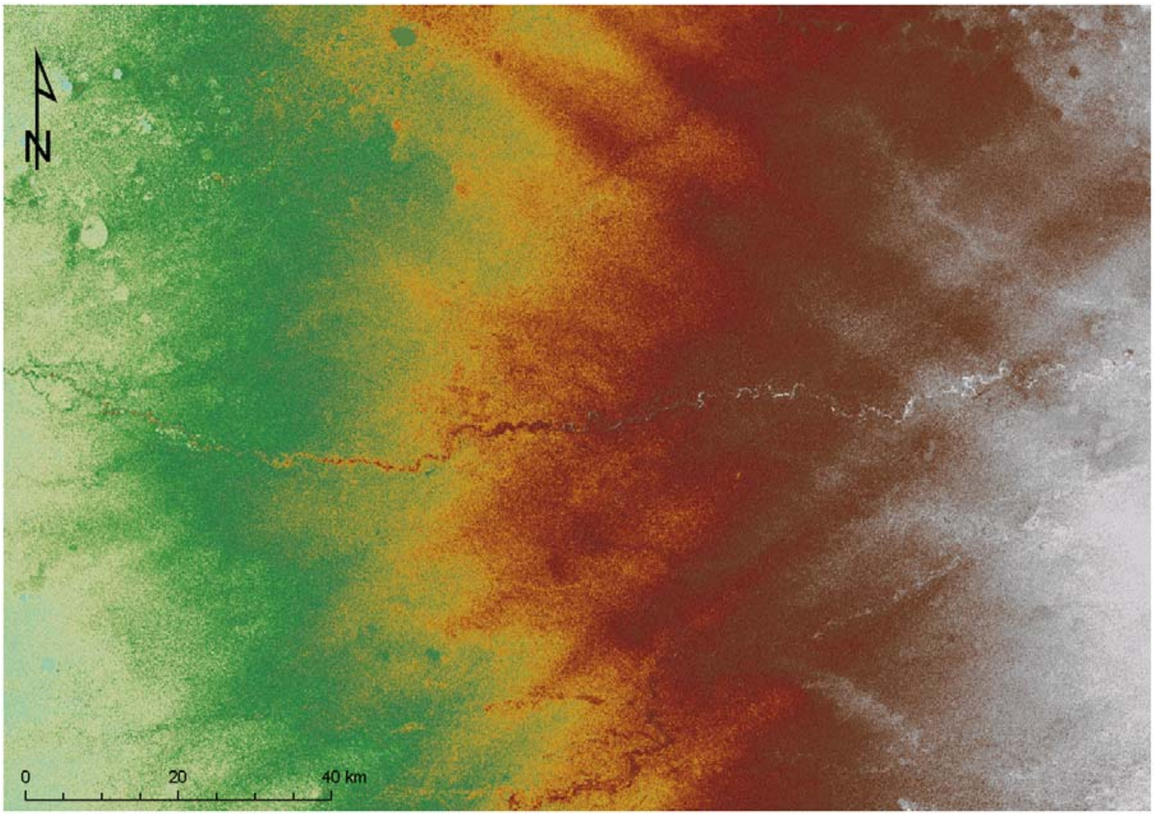


Figure 19. Broad striping in Hay Plain, NSW 144.8E 34.5S. Elevation range 70 – 110m.

Steps

There are several places where there are steps in elevation along straight lines extending many kilometres. These lines are oriented along orbital paths in the same way as the fine scale stripes. The most obvious example is north of Balranald in south-western NSW where a step of up to 7m extends along a 30km line (Figure 18). Areas with steps also tend to have a higher noise level, which obscures the details of the step, but the steps appear to be gradual rather than abrupt with the elevation change occurring over a distance of about 1km. Another clear example extends from south of St George, QLD, 148.47E 28.26S to Mungindi near the NSW-QLD border, 149.18E 29.10S. These steps will affect measures of local shape such as slope, aspect, flow direction and curvature. They may also disrupt drainage patterns.

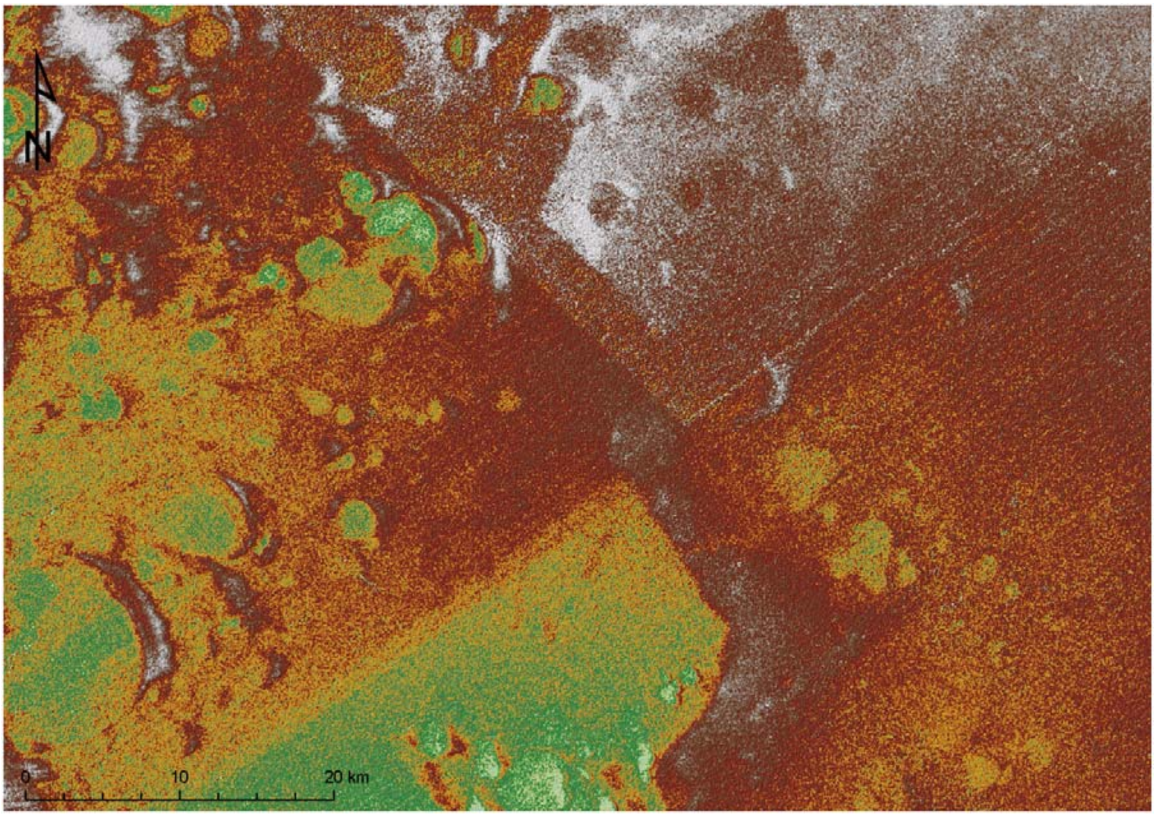


Figure 20. Step north of Balranald, NSW, 144.0E 33.8S. Elevation range 60 – 90m.

Large offsets

One example of large offsets in elevation has been discovered, affecting the Grose Valley in the Blue Mountains of NSW (Figure 19). This valley is surrounded by cliffs which resulted in voids around most of the valley floor. The edges of the valley floor have been erroneously assigned heights consistent with the surrounding plateau, ignoring the cliffs, so it is about 200m too high. No other errors approaching this magnitude have been detected.

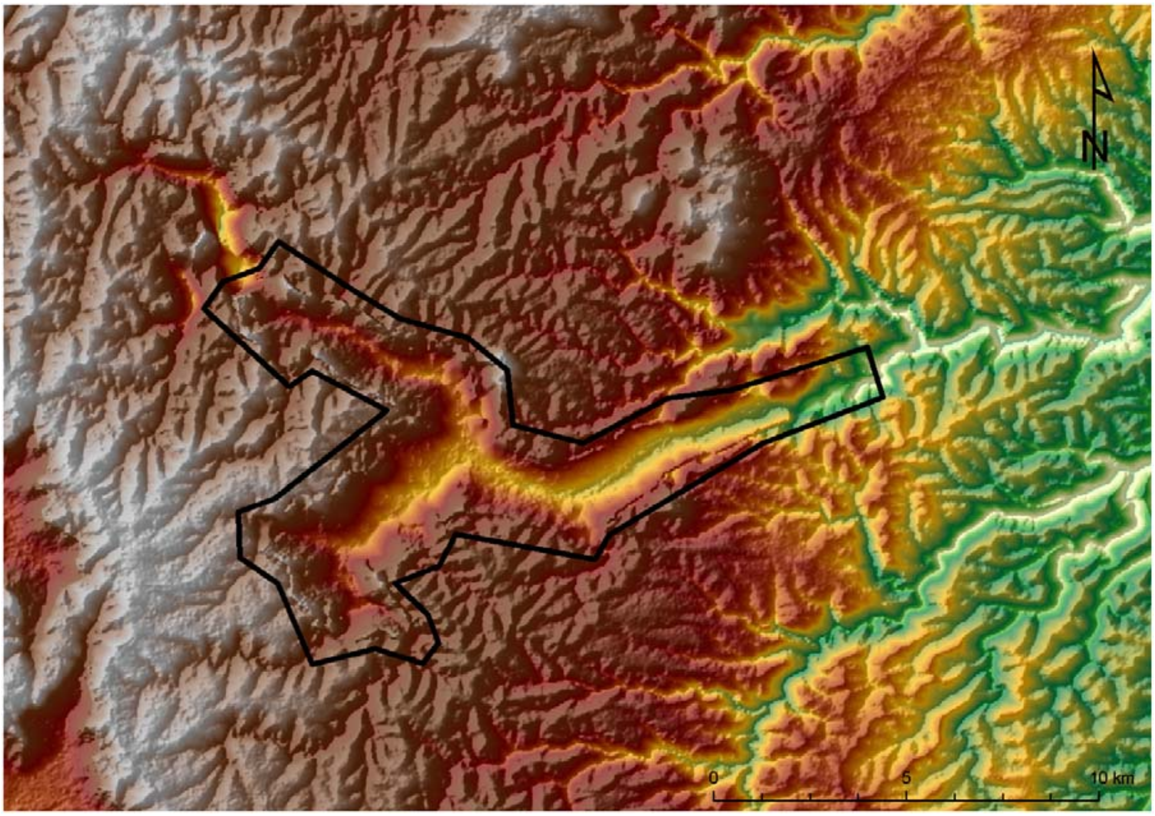


Figure 21. The black polygon encloses the affected area. Grose Valley, NSW, 150.345E 33.602S. Elevation range 100 – 1200m.

Noise

The SRTM DSM is affected by intrinsic noise due to the nature of the radar acquisition and processing (Figure 22, also visible in many other images). The noise has no directional character, and has a short range correlation over a distance of about 100m, appearing as humps and hollows in flat areas. This noise typically has amplitude of 2-3m but can be much larger, up to about 10m.

In areas of low relief, this noise significantly impacts measures of local shape such as slope, aspect, flow direction and curvature. It creates a multitude of small sinks and peaks, although there are often real sinks in those landscapes too. In steep areas it is essentially inconsequential.

The smoothed version of the dataset currently under development (DEM-S) will remove a significant proportion of this noise.

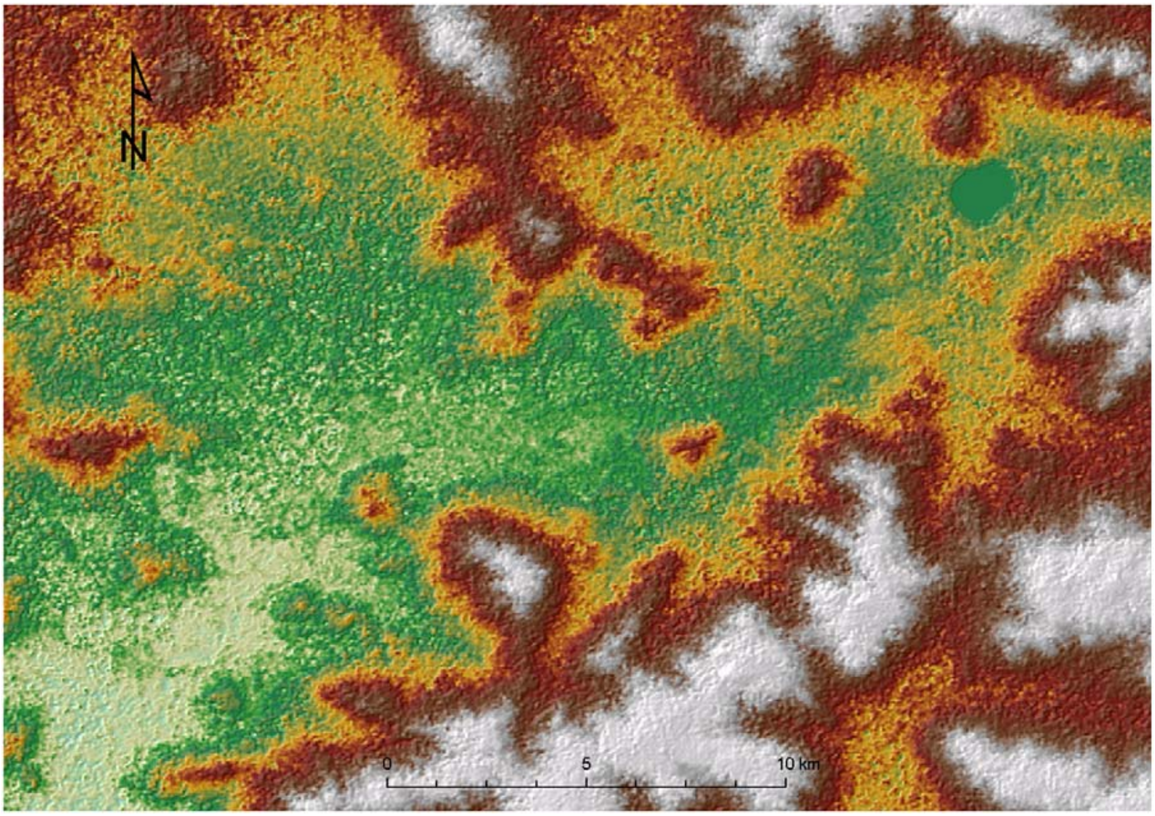


Figure 22. Typical noise in 1 second SRTM DEM - Arthur River near Narrogin, WA, 117.38E 33.05S. Elevation range 270 – 350m.

Incomplete removal of vegetation offsets

In some areas offsets due to trees have not been completely treated. Some patches are completely untreated because they were not mapped as trees in the vegetation mapping, while other areas are partially treated due to poor estimation of vegetation height offset. One example is shown in the vegetation removal section above. Actively managed forests such as pine plantations are particularly subject to this problem because the contrasts in height are obvious and mismatches in the date of the forest cover mapping create substantial errors.

Figure 23 shows a pine forest area in southwest Victoria where some patches have been adequately treated but many obvious offsets remain. This is one of the worst examples of this effect and most instances are much subtler than this. In low relief areas residual vegetation offsets will significantly affect measures of local shape such as slope, aspect, flow direction and curvature.

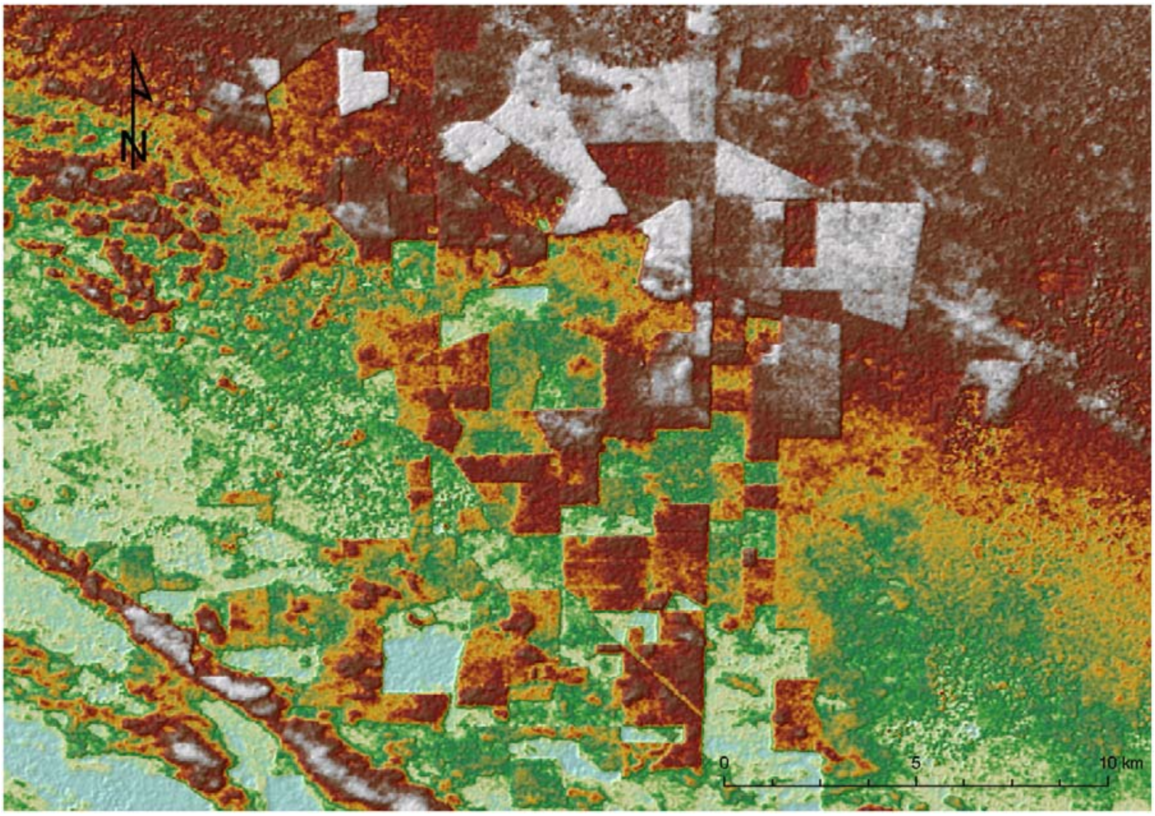


Figure 23. Pine Forests in Victoria not completely removed, 140.959E 37.866S.
Elevation range 30 – 80m.

Vegetation height over-estimated

In a small number of areas the offsets due to trees have been over-estimated. Figure 24 shows the lower end of the Glenelg River before and after removal of vegetation offset. The areas around the river are covered in (mostly) low vegetation, probably with little impact on the DSM. Unfortunately the edge of the vegetated area corresponds to the edge of the river gorge so the difference in height between vegetated and unvegetated areas includes the depth of the gorge. The adjustment for this apparent vegetation offset almost eliminates the gorge itself.

Where the over-estimation is associated with regularly shaped patches of trees, the effect can be seen as shallow depressions bounded by relatively straight lines corresponding to the edges of the mapped area of trees. Vegetated dunes can also be subject to this problem and results in either attenuation or removal of the dune features in the DEM. Small tree-covered hills in cleared landscapes may also be affected by this problem.

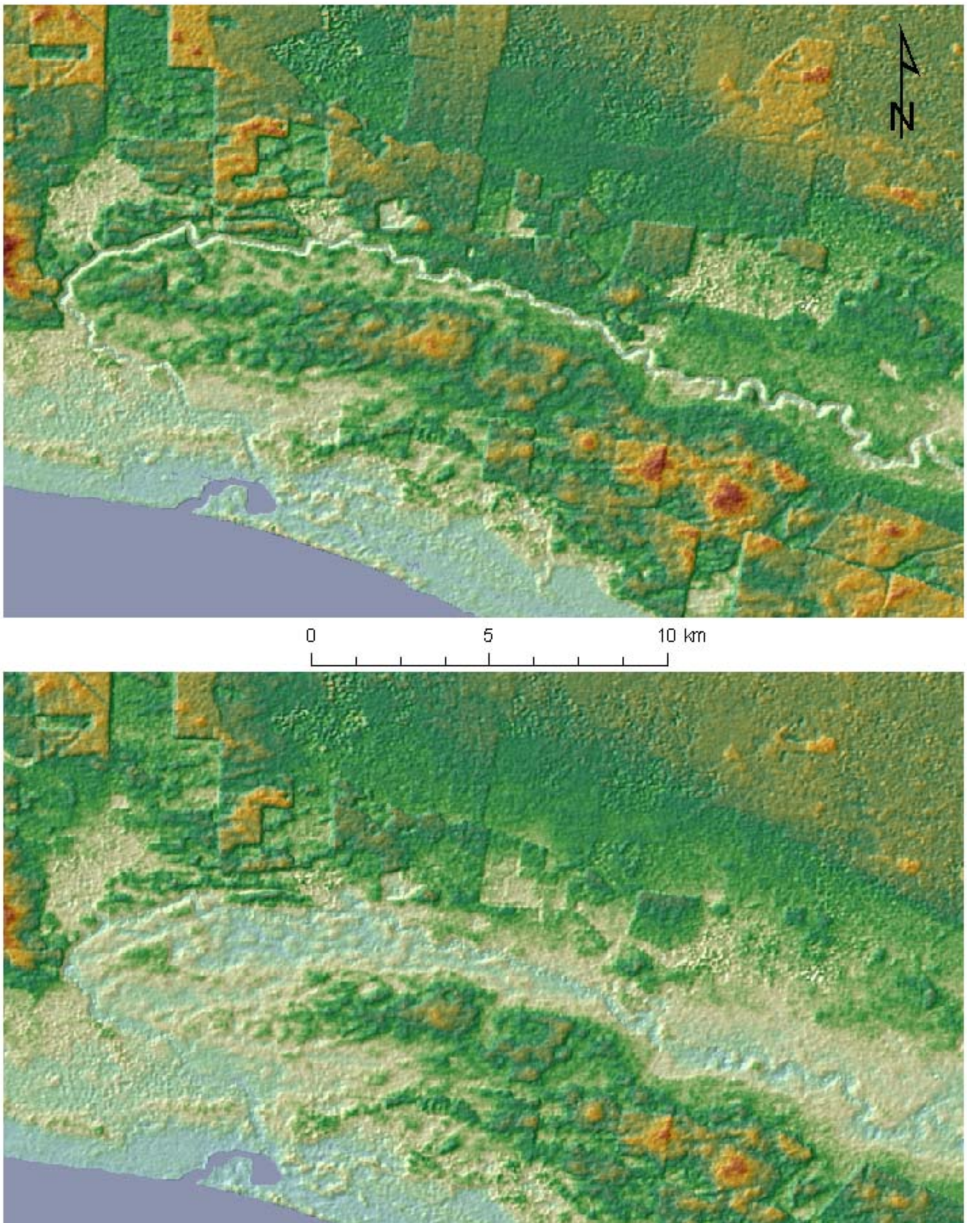


Figure 24. The outlet of the Glenelg River, Victoria, around 141.00E 38.00S (adjacent to the area of Figure 23). The gorge has almost disappeared because the cliffs have been mistakenly identified as vegetation offsets. Elevation range 0 – 150m.

Incomplete removal of urban and built infrastructure

Buildings and structures above the ground are seen by the SRTM radar if they are sufficiently large or dense, in the same way as vegetation. No attempt has been made in this version to remove these features. The most visible examples are major city centres and power line towers; less dense urban areas are mostly free of such offsets (Figures 25 to 27).

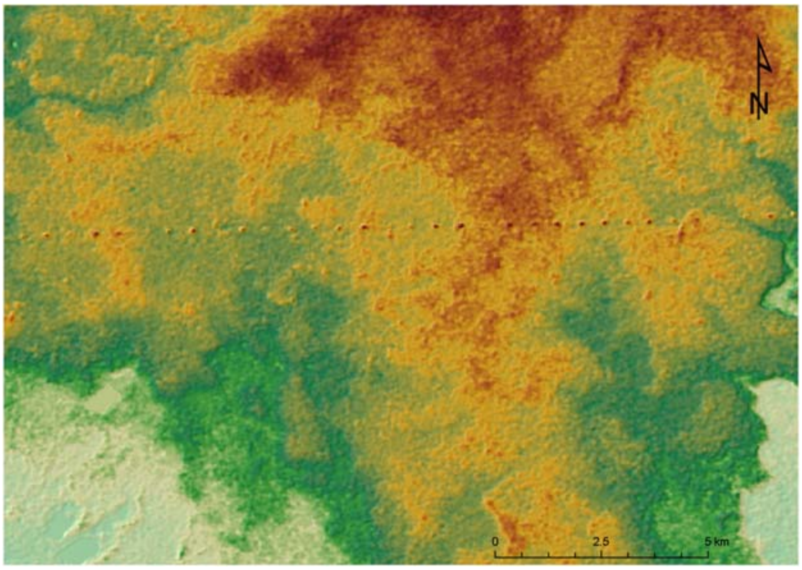


Figure 25. Power line transmission towers near Mortlake, western Victoria, appearing as bumps up to 20m high. 142.92E 38.05S. Elevation range 120 – 200m.

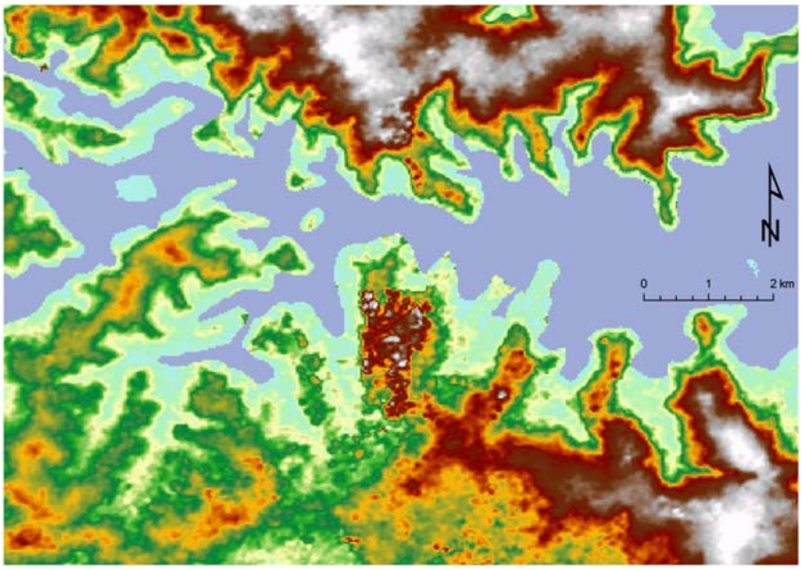


Figure 26. Central Sydney showing significant visible offsets of up to 30m in the CBD area and isolated features elsewhere. 141.21E 33.87S. Elevation range 0 – 100m.

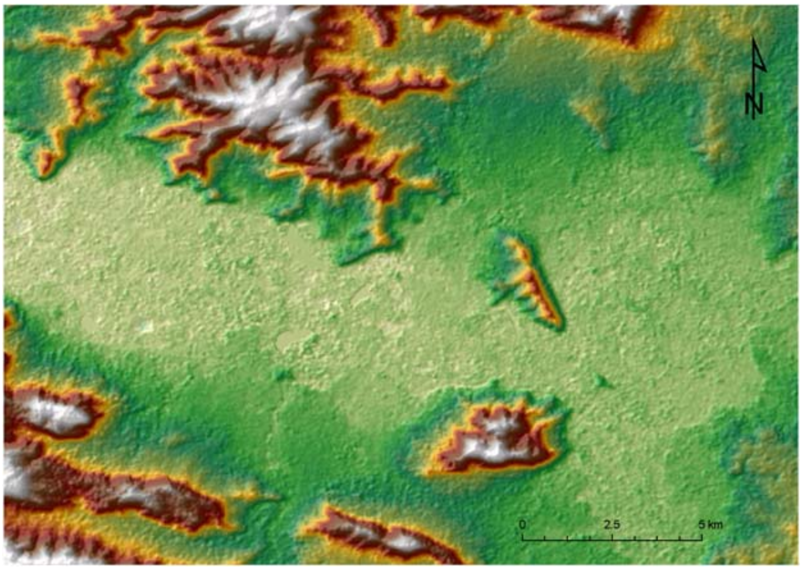


Figure 27. Albury-Wodonga area showing very few artefacts due to urban structures. 146.9E 36.1S. Elevation range 100 – 400m.

Elevation incorrectly set to zero near coasts

In some areas elevations have been set to zero where they should be above sea level by 1 – 2m. Figure 28 shows zero elevations as light blue and a number of land areas also are light blue. Satellite imagery suggests these areas are probably inundated at high tide.

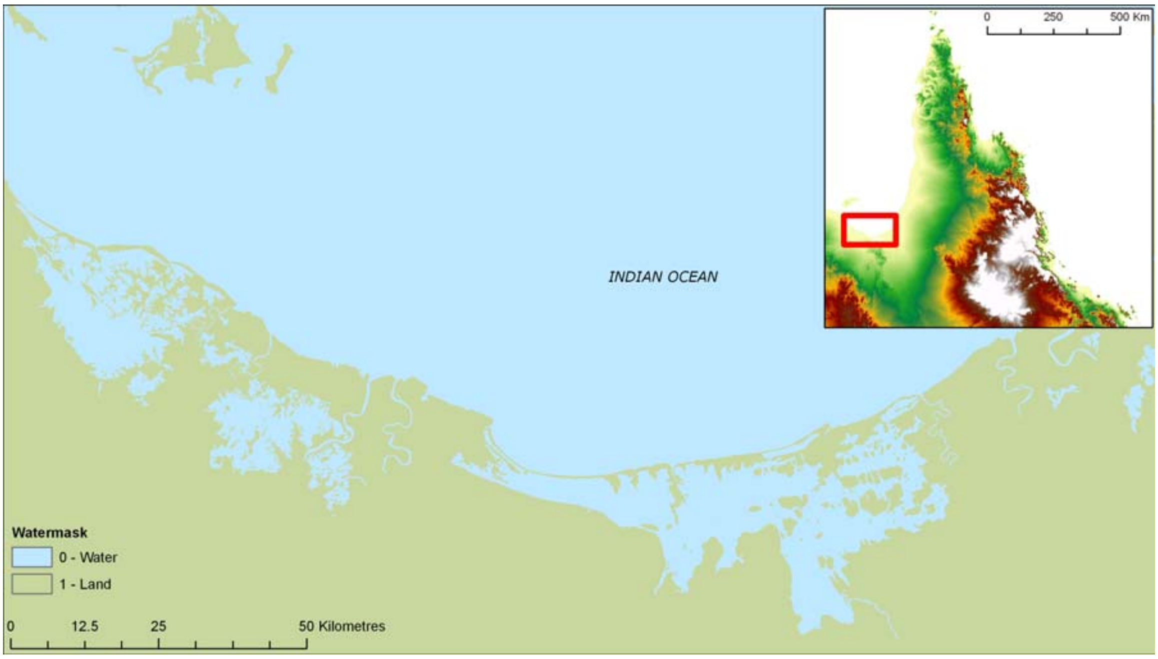


Figure 28. Elevation at Sea level. QLD 140.096E 17.566S.

Evaluation of 1 Second Products

Accuracy Assessment

The SRTM data is part of a global dataset released by US Defence Department in the WGS84 projection with a height datum in the Earth Geopotential Model 1996 (EGM96). The difference between EGM96 and the Australian Height Datum 1971 (AHD71) is between -0.8m and 1.2m which is generally less than the uncertainty in the SRTM heights.

Given the minor difference between EGM96 and AHD71 relative to the vertical accuracy of the data, and to maintain consistency with the global dataset, we have therefore decided not to make any corrections between EGM96 and AHD71 in Version 1 of the derived datasets. In future versions the minor correction to the AHD71 vertical height datum will be undertaken following more thorough analysis of higher quality datasets. For most purposes, the SRTM data can therefore be considered to be AHD heights.

In order to quantify the absolute vertical accuracy of the datasets relative to AHD71 analyses have been undertaken at national, state and local levels. A number of existing elevation products were used to compare the vertical accuracy of the surface including permanent survey mark data (PSM), sample contour data for the Atherton Tableland area, a LiDAR-derived DEM for Lower Darling and the Victorian DEM state-wide product (VicMap Elevation DTM 20m). Each of these analyses are described below.

The accuracy assessment was completed on the base product, the 1 second DEM. Analysis should little notable difference to include information on the accuracy of the DSM and DEM-S. Relative elevation accuracy between adjacent cells is improved in DEM-S due to the reduction in noise levels; this has not been quantified but is evident in the comparison of slopes calculated before and after smoothing as shown in this User Guide (refer to the Smoothing section).

Permanent Survey Mark Data

A total of 1198 Permanent Survey Marks (PSM) made available through State land survey agencies were used to assess the overall vertical accuracy of the data at the national level. The PSM data uses AHD71 for the vertical datum and GDA94 for the horizontal datum. Figure 29 shows the spatial distribution of points and the height differences relative to AHD71 for the 1 second DEM. Figure 30 shows the histogram of differences.

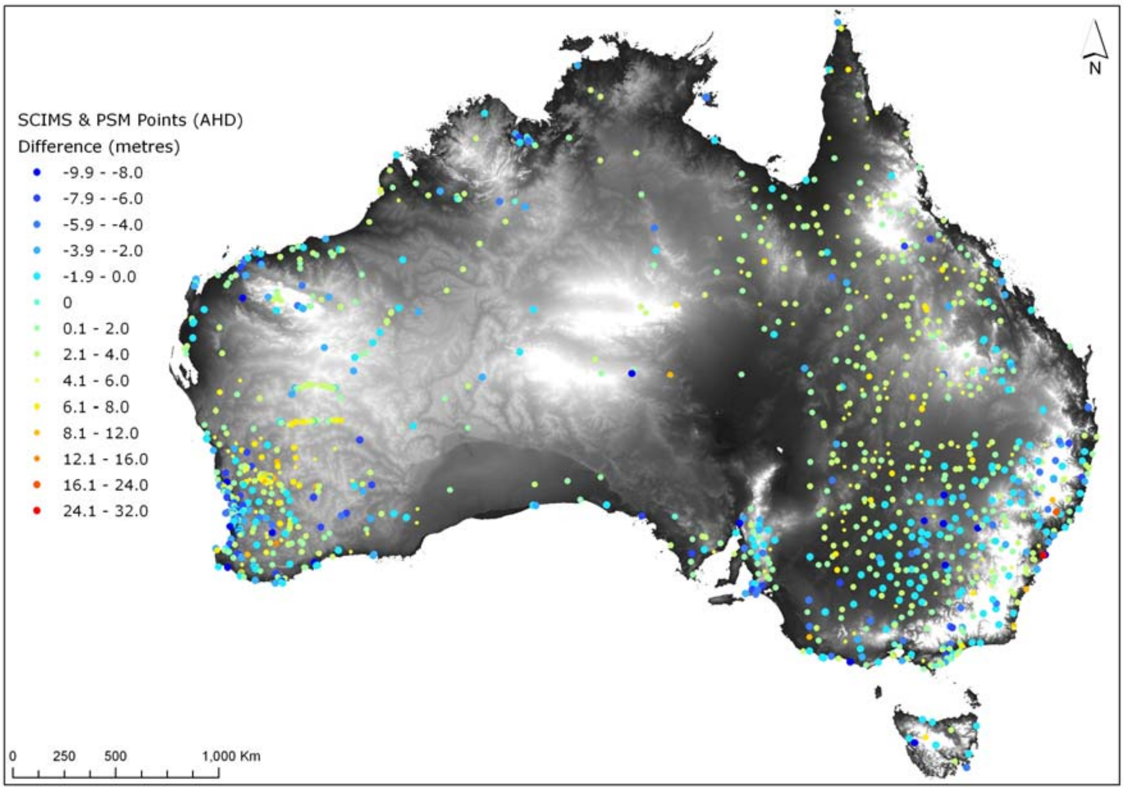


Figure 29. Height difference relative to the AHD71 vertical datum between the DEM and the PSM points.

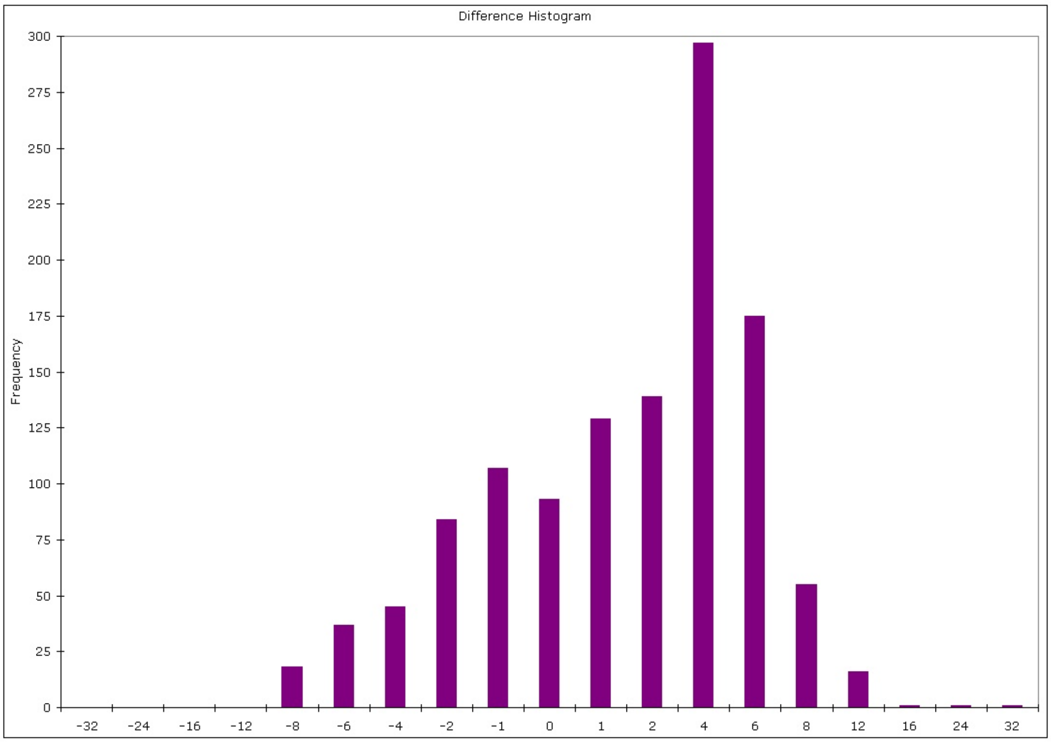


Figure 30. Height difference distribution between the DEM and the PSM points relative to the AHD71 vertical datum.

The following results were observed relative to the AHD71 vertical datum:

Mean	1.287
Median	1.668
St. Dev	3.649
Min	-9.882
Max	31.285
RMSE	3.868

DEM – PSM points height statistics

It is important to note that the PSM data are generally associated with open (non-vegetated) and relatively flat terrain, and as such this national accuracy assessment should not be used in densely vegetated or high relief areas. Results of this comparison show the absolute accuracy of the data as tested to be 7.582m at the 95th percentile with a RMS error of 3.868 in open, flat terrain. 99 percent of points are within a height difference of less than 9.602m. There are eight points with a height difference of more than 10 m, most of which occur in high elevations in densely vegetated slopes where vegetation removal is likely to be the cause of the difference.

Tablelands Regional Council Contour Data

The Tablelands Regional Council (QLD) provided contour data, at a 2 metre interval based on the AHD71 vertical datum, covering an area south of Lake Tinaroo in the Atherton Tablelands (Figure 31).

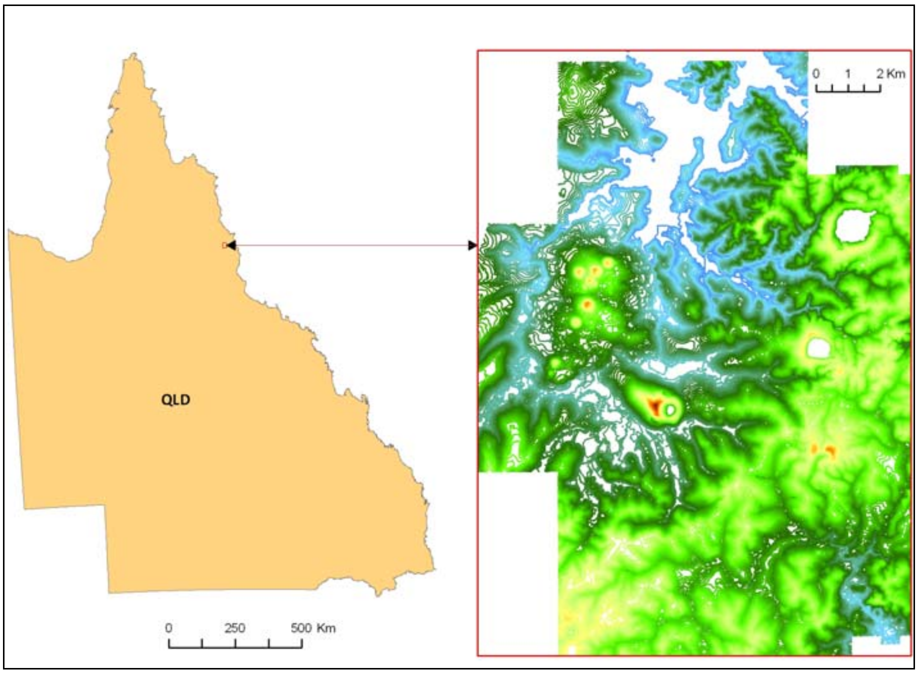


Figure 31. Location of Atherton Tablelands 2 m Contour Data.

The contours were used to create a surface which was then compared with the 1 second DEM, producing the difference surface shown in Figure 32. The statistical differences between the surfaces were as follows:

Mean	2.985
St. Dev.	5.942
Min.	-26.369
Max.	44.750

DEM - Atherton Difference Surface Statistics

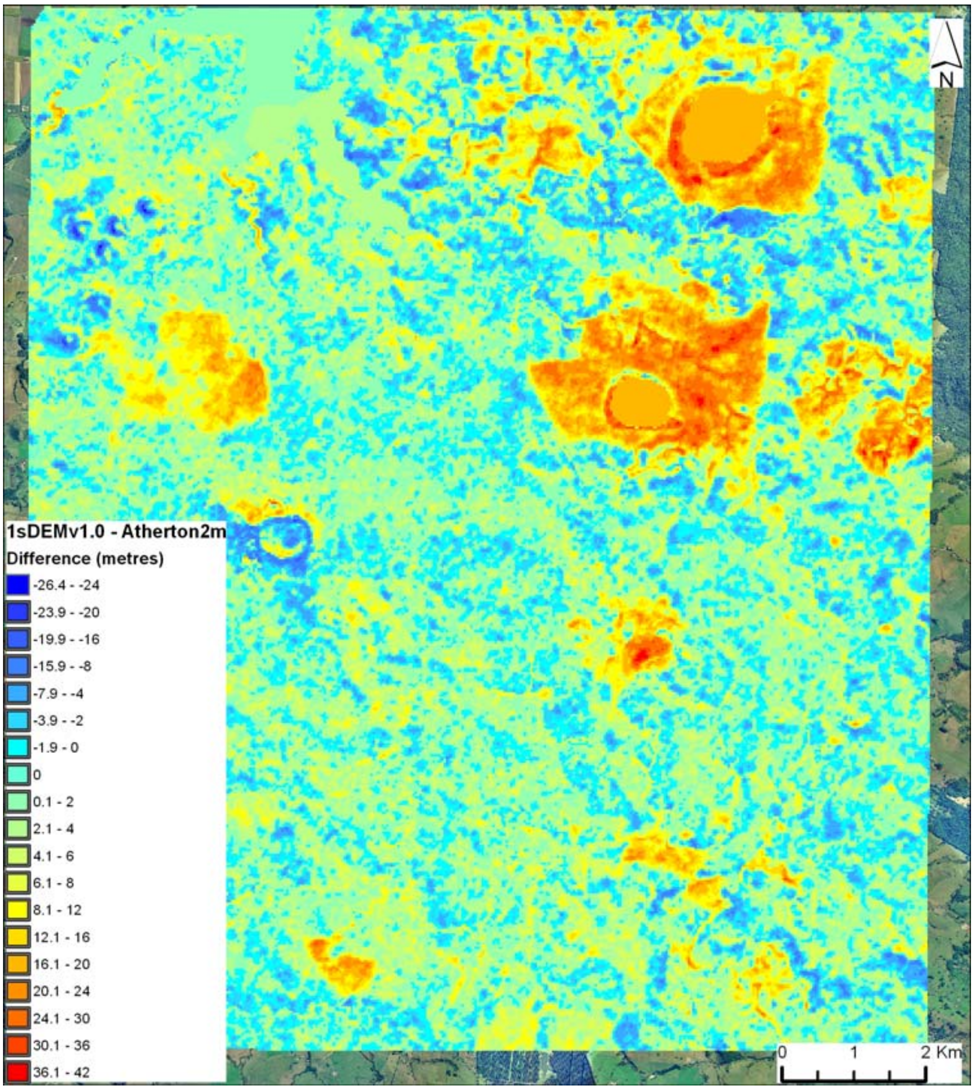


Figure 32. Atherton difference grid 145.604E, 17.303S.

7881 points were randomly generated across the surface for statistical analysis. Figure 33 shows the histogram of the differences. The following statistics were then obtained:

Mean	3.001
St. Dev.	5.863
Min.	-22.408
Max.	39.580
RMSE	6.586

Atherton Sample Points Statistics

The 1 second DEM and Atherton data provide similar heights normally in the range of -3m to +6m except in densely vegetated areas or lakes where the DEM has underestimated the heights by 8-40m. This results in the mean difference being much higher than the average height difference over non vegetated areas which is closer to 0-2m for the majority of the sample area.

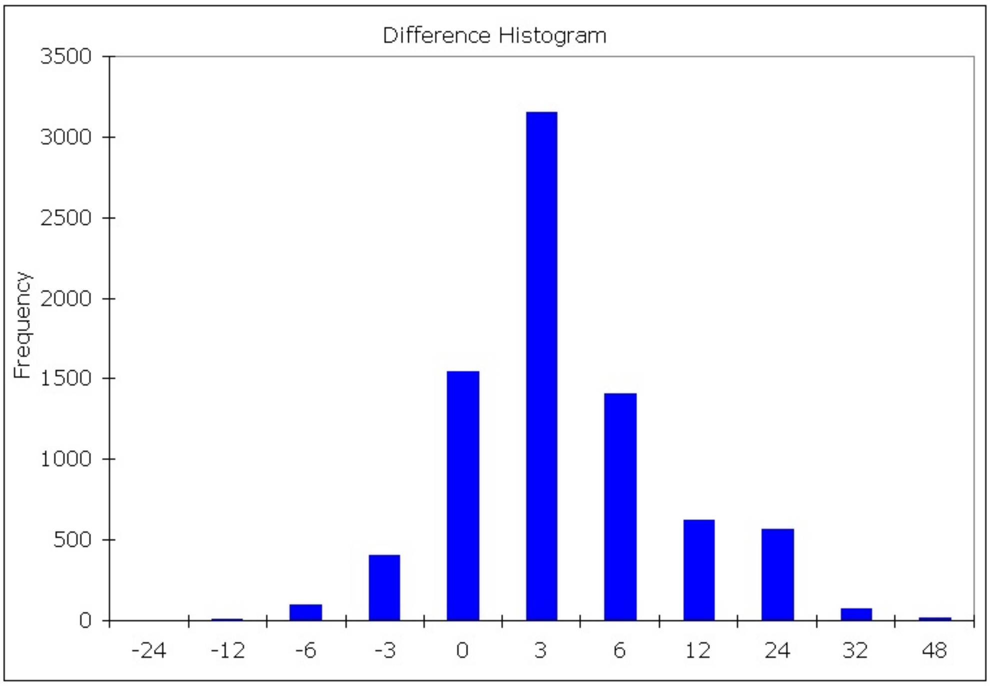


Figure 33. Difference Histogram between Atherton Tablelands elevations and SRTM heights.

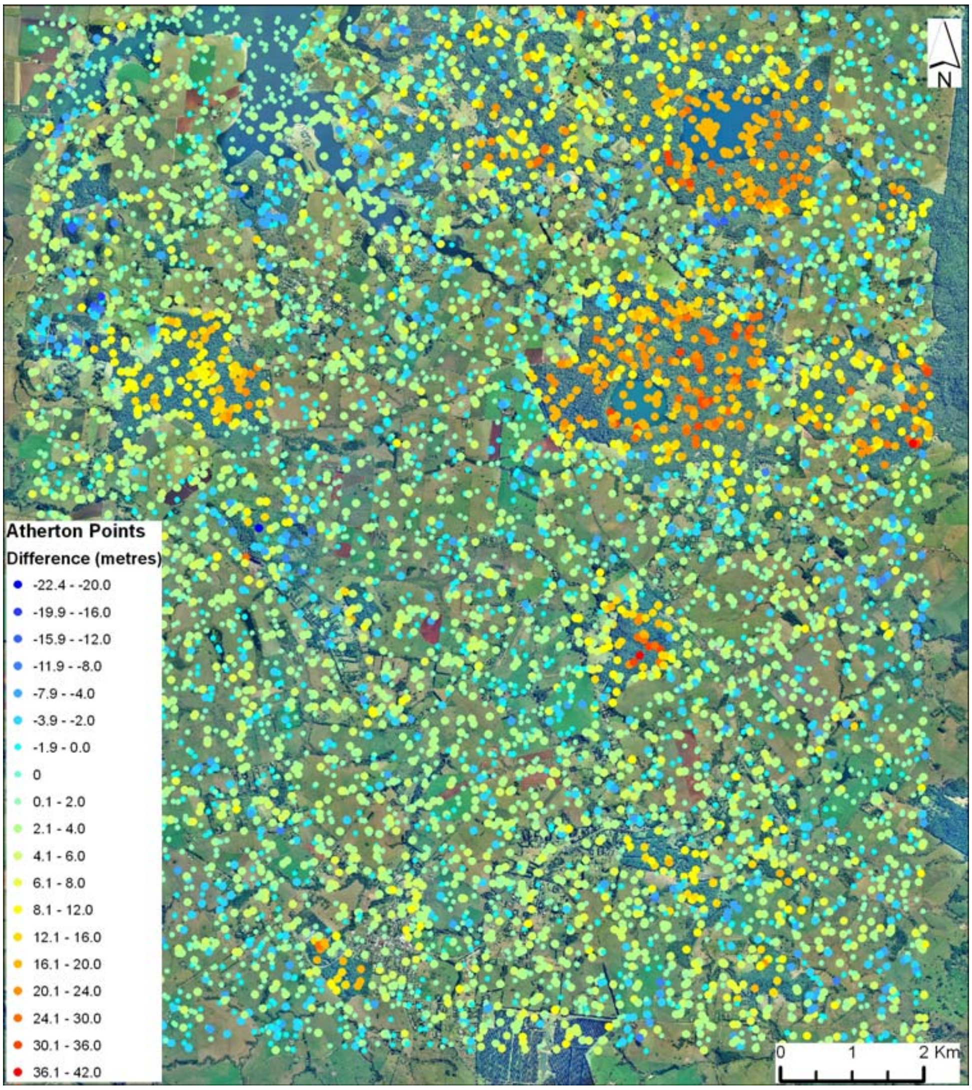


Figure 34. Atherton Grid difference points, 145.604E, 17.303S.

The areas of large difference between the 1 second DEM and the Atherton surface (Figure 34) are primarily forested areas and water surfaces (Lake Eacham and Lake Barrine, both lakes in volcanic craters). The differences on the water surfaces are most likely due to incorrect water surface heights assigned to the SRTM data, although variations in height over time may also be involved. The height differences in forested areas indicates that the vegetation offset has been significantly underestimated in those areas.

Comparison with Other Elevation Datasets

VicMap Elevation

The VicMap 20m DTM coverage extends across the whole of Victoria and 10km into bordering states (Figure 35).The dataset consists of a wide variety of input source data varying in currency from 1974 to 2006. The DTM is hydrologically enforced to define the natural surface drainage and hydrological flow.

The spatial accuracy for Vicmap Elevation DTM 20m and DTM 10m is inherited from the spatial accuracies of its many source datasets. The most consistently used and therefore the base for positional accuracy is the Vicmap Elevation 10-20m Contours & Relief. Therefore the positional accuracy for Vicmap Elevation DTM 20m and DTM 10m is 12.5m horizontally and 5m (AHD71) vertically respectively or better, barring errors in those data.

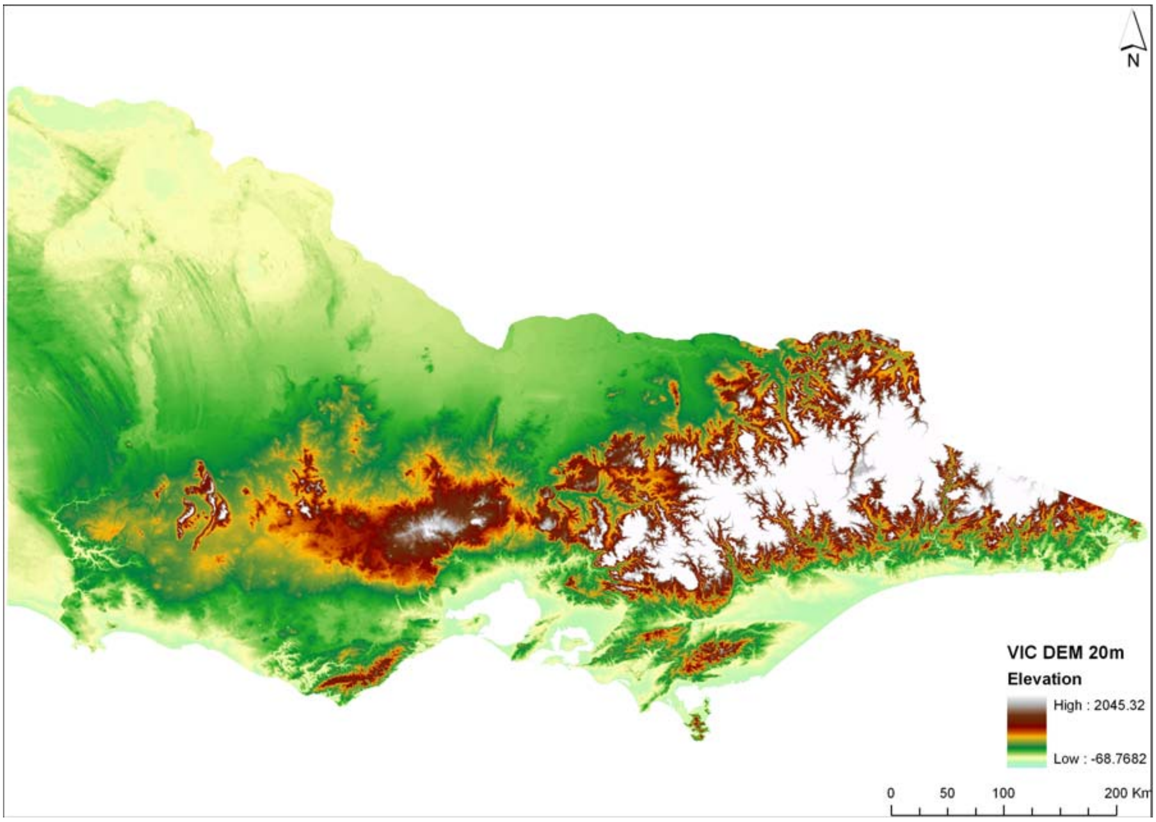


Figure 35. Extent of Vicmap DTM 20 m 141.306E, 38.049S.

The Vicmap DTM was subtracted from the SRTM-derived DEM to produce a difference surface (Figure 36). The differences are due to a number of factors (numbers correspond to approx location on figure below):

1 Riparian vegetation along the Murray is a known area of inadequate vegetation removal in the 1 second DEM and has an over estimated elevation by 4-16m.

2 Some areas mapped as woody vegetation (particularly the forests in north-west Victoria) have been lowered too much by the vegetation offset removal – the height of vegetation has been over-estimated.

3 These rectangular patterns of difference have not been explained but do not appear to be an SRTM artefact. It is thought that this is a photogrammetric

error that has been passed onto the Vicmap DTM as this effect was also seen in the 9 second Geodata DEM.

4 Residual striping from the SRTM data is visible in the north western part of the state. These are being carried through into the difference surface from the SRTM DEM and are typically of a magnitude of around 1-2m.

5 The Orange – Red colour (16-24m) occurs in areas where the vegetation has not been sufficiently removed or treated. This can occur for a range of reasons:

- Riparian and remnant vegetation which was not adequately mapped and therefore hard to remove from the SRTM-derived DEM,
- Continuously forested hilly areas where the vegetation offset has been systematically under-estimated,
- Areas of narrow gorges or cliffs where due to the angle of the SRTM no readings were recorded for the valley floor, and this results in a more generalized valley.
- Lake and water levels for the SRTM are set to highest water mark, this was the same for Vicmap DTM unless they had other readings lower than the high water mark

6 This area is an artefact in the Vicmap DEM which is the result of a contour used to create that Vicmap DTM that should not have existed or was mislabelled.

The extremes (shown in pink and purple in above figure) in the difference surface are minor and are insignificant. The negative range of differences are randomly scattered in minute areas and the positive ranges are the same. These do show that some lakes have been over estimated by the SRTM DEM particular Lake Dartmouth northeast of Mount Beauty (147.545E, 36.574S).

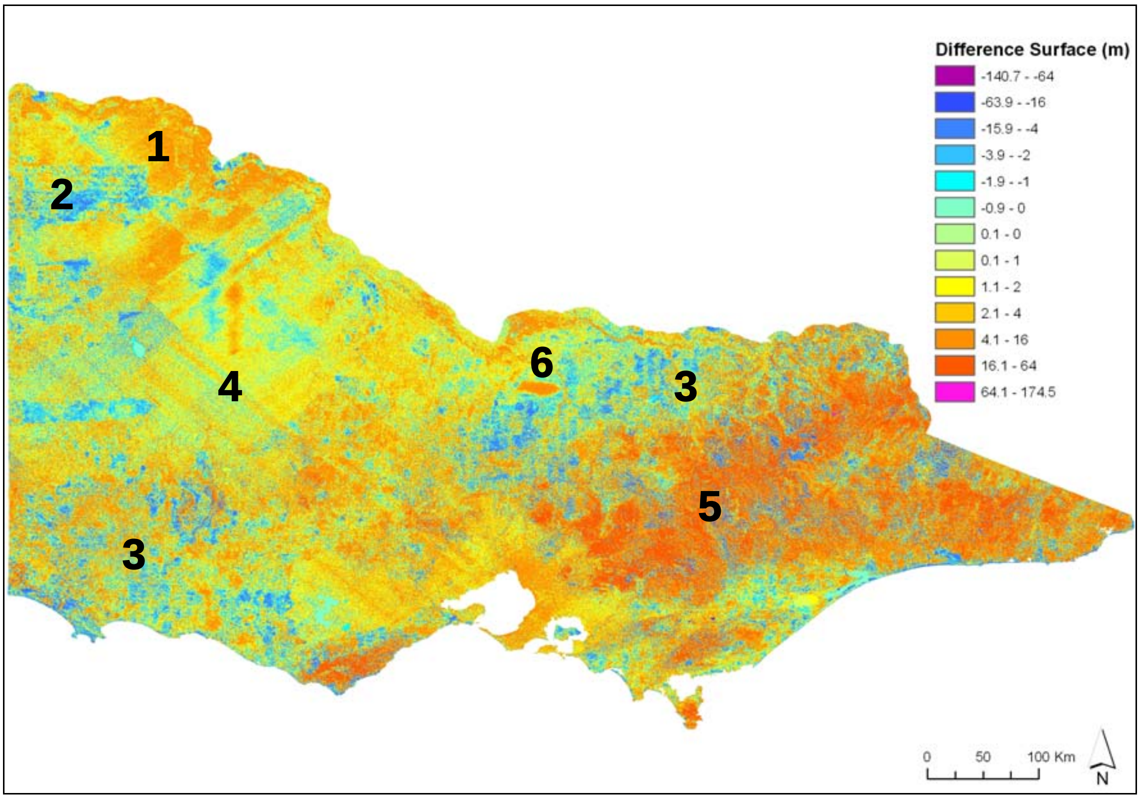


Figure 36. DEM – Vicmap DTM Difference Surface 141.306E, 38.049S.

Significant differences were observed between the Vicmap DTM and the SRTM-derived DEM (see table below). 4193 points were randomly created across the surface for a more in-depth analysis. The following statistics were obtained from the sample points:

Mean	3.145
St. Dev.	7.225
Min.	-40.595
Max.	50.682
RMSE	7.879

DEM – Vicmap DTM Sample Points Statistics

This produced the following difference histogram (Figure 37).

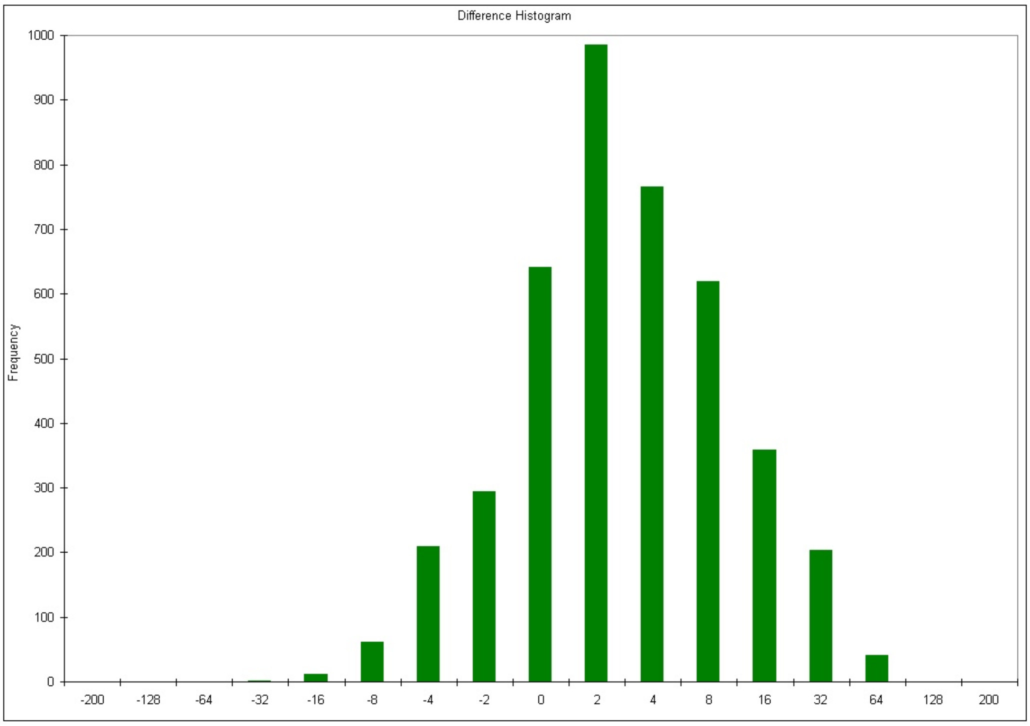


Figure 37. DEM – Vicmap DTM Sample Points Histogram.

Lower Darling LiDAR

The Lower Darling LiDAR comparison comprises a 5m grid bare earth DEM derived from LiDAR data acquired in mid-2009 (Figure 38) and the SRTM 1 second derived DEM. Non-ground points such as vegetation and man-made structures were removed from the DEM, so that it defines the “bare-earth” ground surface. The vertical accuracy of the lidar mass point data was verified at <15cm (95% confidence).

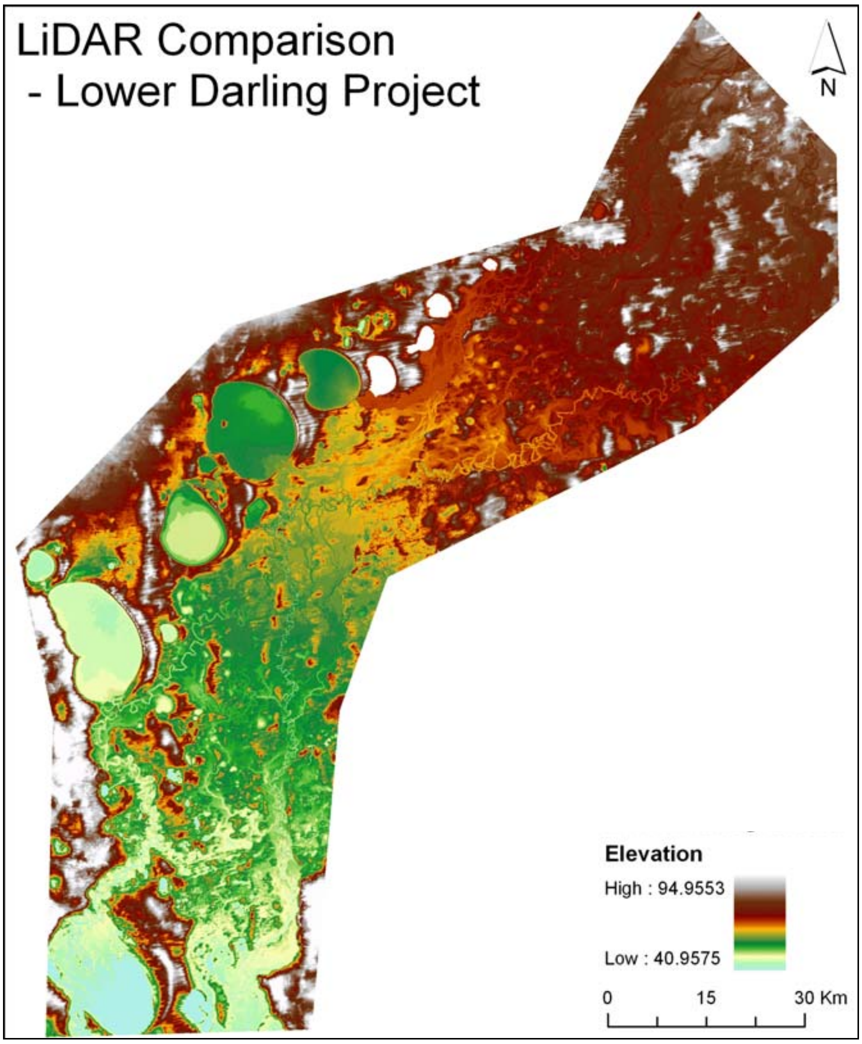


Figure 38. Lower Darling 5 m Grid 142.625E, 32.477S.

Mean	3.747
St. Dev.	1.991
Min	-47.972
Max	33.175

Lower Darling LiDAR statistics

A difference surface (Figure 39) was created by subtracting the LiDAR generated 5m Grid from the DEM. The difference surface shows some significant differences between the LiDAR and the SRTM DEM. There are some offsets due to riparian vegetation that have not been removed from the STRM-derived DEM. There is also some striping identifiable that appears in the difference surface. Differences in water surface heights in lakes are to be expected from data obtained at different times.

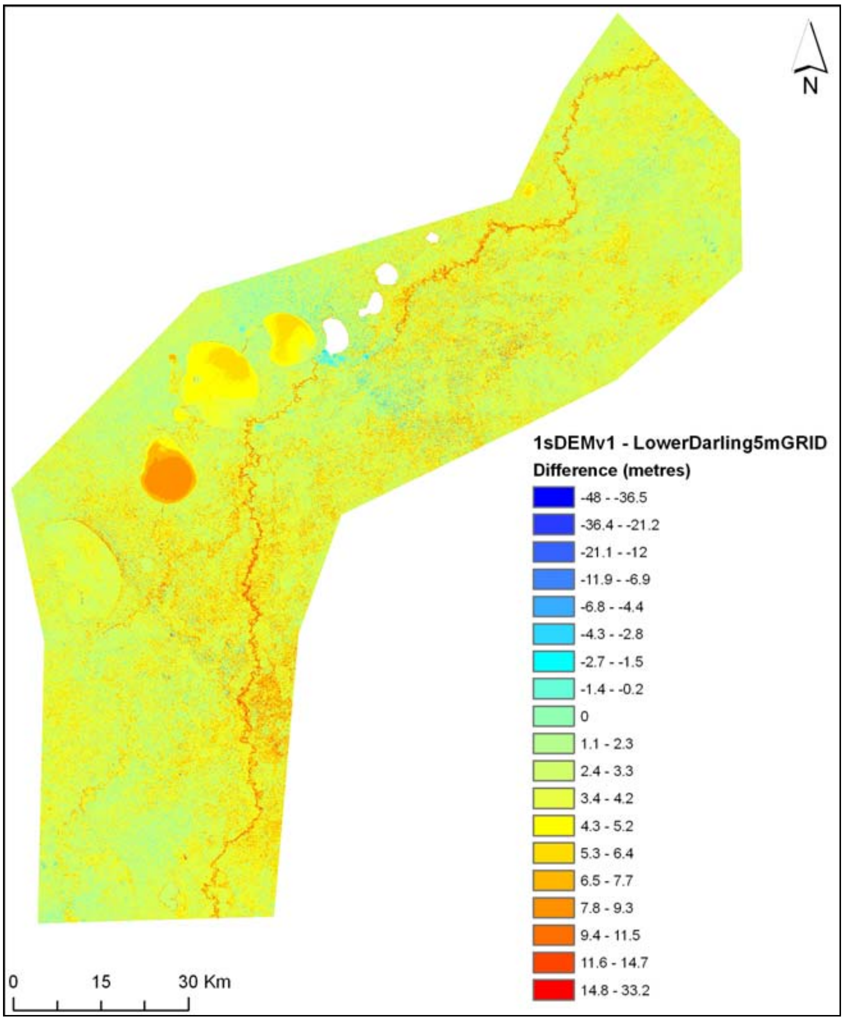


Figure 39. Lower Darling Difference Grid (DEM – LiDAR) 142.625E, 32.477S.

10,000 points were randomly selected across the project area to extract values for further statistical analysis (Figure 40). The following results were obtained:

Mean	3.717
Min	-5.270
Max	18.563
St. Dev.	1.990
RMSE	4.216

Statistics of Lower Darling LiDAR comparison

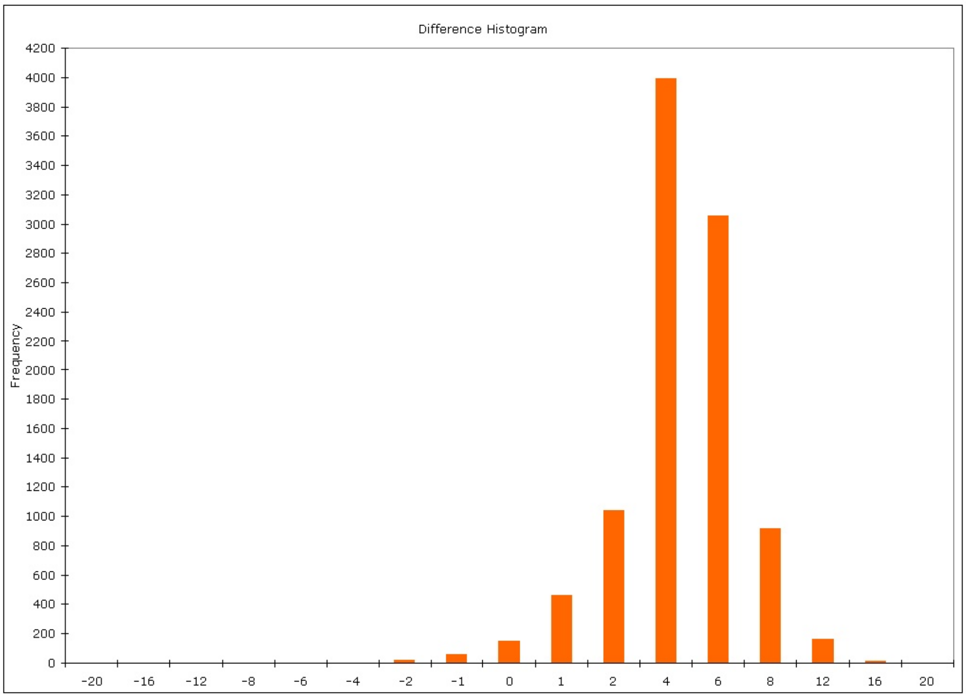


Figure 40. Histogram of Difference in Elevation between Lower Darling LiDAR and SRTM DEM.

A few significant differences were observed between the Lower Darling LiDAR generated DEM and the SRTM-derived DEM. The largest differences relate to riparian vegetation that the SRTM DEM has neglected to identify and rectify. Also the striping identifiable in the SRTM has also been identified in the difference surface (see section on Striping).

Derivation of the 3 Second Products

Processing of the 3 Second Products

The processing described in 'Processing of the SRTM Data' was completed on the 1 second data as the parent datasets. As the 3 second is a derived product they have inherent improvements in the 3 second products also. Refer to this section for further information. Below is the coverage of the 3 second DEM-S (Figure 41).

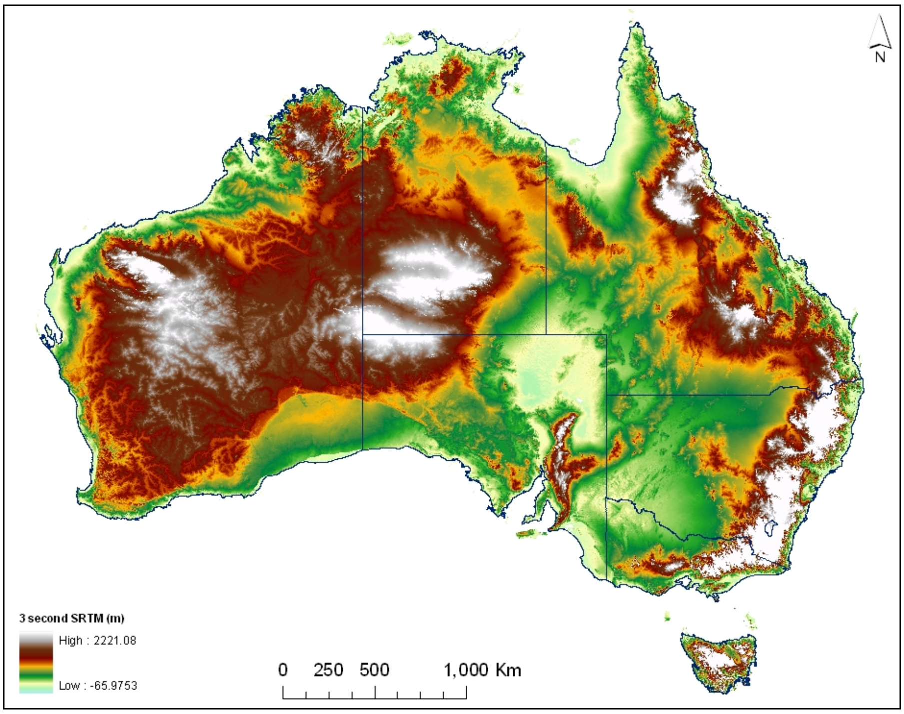


Figure 41. 3 Second National DEM coverage.

Resampling the data to 3 seconds from the 1 second product was completed in ESRI ArcGIS software with the aggregation tool using mean cell values. This tool determines a new cell value based on multiplying the cell resolution by a factor of the input (in this case three) and determines the mean value of input cells with the new extent of the cell (i.e. Mean value of the 3x3 input cells).

Accuracy Assessment

The same PSM comparison was conducted on the 3 second DEM-S using the same 1198 points. It was expected that the 3 second would be approximately three times that of the 1 second product given the resolution of the data and additional smoothing that was applied to the 3 second DEM (and its parent 1 second product).

Results showed the absolute accuracy of the data as tested to be 14.54m at the 95th percentile with a RMS error of 7.029 in open, flat terrain. 99 percent of points are within a height difference of less than 29.97m.

The following results were observed relative to the AHD71 vertical datum:

Mean	-0.539
Median	1.456
St. Dev	7.012
Min	-55.841
Max	22.306
RMSE	7.029

3 second DEM-S – PSM points height statistics

Choosing the Right Product

Given the accuracy of the 3 second product it is advised that you consider the application of the data and which of the three second products to use. This product has been released in good faith that the user understands the limitations and inherent errors in the data. The data should not be solely relied upon for decision making. The 3 second products are not suitable for finer scale applications requiring accuracy less than the specified vertical accuracy of approximately ±15m.

It is recommended that the DEM and DSM are used for visualisation purposes or to do any large scale slope or vegetation analysis. The DEM-S should be used for large scale projects or for software that requires decimal elevation values. Please be aware that the 3 second products have not been hydrologically enforced and shouldn't be used for hydro-modelling. If you require a hydrologically enforced product there is the 9 second GEODATA3 DEM which is available through the Sales Centre although this has a poorer accuracy (~250m). In the future, there are plans for there to be a 3 second DEM-H.

Future Developments

The products described in this User Guide are version 1.0, meaning that they are the relatively new versions of each product. Work is continuing to treat some of the known issues and further releases of the products are planned in 2011.

The 1 second hydrologically enforced (DEM–H) products is expected to be released in 2010-11.

Feedback

This is an evolving product which requires government support and feedback to improve the accuracy of data and refine processing techniques. Please direct feedback to elevation@ga.gov.au.

References

ERSDAC. June 2009. ASTER Global DEM Validation Summary Report. Earth Remote Sensing Data Analysis Centre, Japan. http://www.gdem.aster.ersdac.or.jp/index.jsp

Kobrick, M. 2006. On the toes of giants - how SRTM was born. Photogrammetric Engineering and Remote Sensing.

Rodriguez, E., Morris, C.S., Belz, J.E., Chapin, E.C., Martin, J.M., Daffer, W., Hensley, S. 2005. An assessment of the SRTM Topographic Products. Jet Propulsion Laboratory D-31639, JPL Technical Memorandum. http://www2.jpl.nasa.gov/srtm/SRTM_D31639.pdf

Appendix A – 1 second DSM Metadata

Note: *This metadata describes the dataset in accordance with the ANZLIC (Australia New Zealand Land Information Council) Core Metadata Guidelines Version 2.*

Dataset citation

ANZLIC unique identifier: ANZCW0703013336
Title: 1 second SRTM Derived Digital Surface Model (DSM) version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 1 second Shuttle Radar Topographic Mission (SRTM) derived Digital Surface Model (DSM) Version 1.0 is a 1 arc second (~30m) gridded DSM that represents ground surface topography as well as features above the ground such as vegetation and man-made structures. The dataset was derived from the SRTM data acquired in February 2000, supported by the GEODATA 9 second DEM in void areas and the SRTM Water Body Data. Stripes and voids have been removed from the 1 second SRTM data to provide an enhanced and complete DSM for Australia and near-shore islands. A full description of the methods is in progress (Read *et al.,* in prep).

This 1 second DSM forms the source for the 1 second DEM with vegetation offsets removed (ANZCW0703013355), the smoothed DEM (DEM-S; ANZCW0703014016) released in August 2010 and drainage enforced version that is expected to be released in 2010-11.

ANZLIC search words:

- LAND Topography Models
- ECOLOGY Landscape

Spatial domain:

Geographic extent name: AUSTRALIA EXCLUDING EXTERNAL TERRITORIES - AUS - Australia - Australia
Geographic bounding box:

- **North bounding latitude:** -10°
- **South bounding latitude:** -44 °
- **East bounding longitude:** 154°
- **West bounding longitude:** 113°

Data currency

Beginning date: 2000-2-11
Ending date: 2000-2-22

Dataset status

Progress:
Version 1.0 of the 1 second bare-earth DSM is complete as at 23 December 2009.

Maintenance and update frequency:
Updates and revisions are anticipated to resolve some of the issues identified in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010) and Quality Assessment layers, and to incorporate improvements in the Digital Surface Model. The first update is expected to be complete by June 2010, and further revisions are likely.

Reference system:

Horizontal datum WGS84. Vertical datum EGM96.

Access

Stored data format:

DIGITAL - ArcGIS-grid ArcInfo grid

Available format type:

DIGITAL - ArcGIS-grid ArcInfo grid

Access constraints:

This data is strictly for Government use only.

Data quality

Lineage:

Source data

1. SRTM 1 second Version 2 data (Slater et al., 2006), supplied by Defence Imagery and Geospatial Organisation (DIGO) as 813 1 x 1 degree tiles. Data was produced by NASA from radar data collected by the Shuttle Radar Topographic Mission in February 2000.
2. GEODATA 9 second DEM Version 3 (Geoscience Australia, 2008) used to fill voids.
3. SRTM Water Body Data (SWBD) shapefile accompanying the SRTM data (Slater et al., 2006). This defines the coastline and larger inland waterbodies for the SRTM DSM.

De-striping

SRTM data contains striping artefacts oriented approximately NE-SW and NW-SE that vary in amplitude from about 0.2m to nearly 4m. The wavelength of the striping is approximately 800m. Stripes were detected in the elevation data using a 2-dimensional Fast Fourier Transform. Peaks in the spectra were visually identified and manually delineated using a tool designed specifically for this purpose. Striping occurred everywhere except where relief was high enough to obscure striping. Spectral analysis was performed on sub-tiles to account for spatial variation in the intensity and direction of striping. Fourier transform was applied to overlapping sub-tiles covering 1536 x 1536 cells (0.43 x 0.43 degrees). Central 1024 x 1024 cells were retained, each comprising one sixteenth of a 1 x 1 degree tile (900 x 900 cells) with a 62-cell overlap on each edge to provide smooth transitions between sub-tiles.

Void filling

Voids (areas without data) occur in the data due to low radar reflectance (typically open water or dry sandy soils) or topographic shadowing in high relief areas. Delta Surface Fill Method (Grohman et al., 2006) was adapted for this task, using GEODATA 9 second DEM as infill data source. The 9 second data was refined to 1 second resolution using ANUDEM 5.2 without drainage enforcement. Delta Surface Fill Method calculates height differences between SRTM and infill data to create a "delta" surface with voids where the SRTM has no values, then interpolates across voids. The void is then replaced by infill DEM adjusted by the interpolated delta surface, resulting in an exact match of heights at the edges of each void. Two changes to the Delta Surface Fill Method were made: interpolation of the delta surface was achieved with natural neighbour interpolation (Sibson, 1981; implemented in ArcGIS 9.3) rather than inverse distance weighted interpolation; and a mean plane inside larger voids was not used.

Water bodies

Flat water bodies in the original 1 second data were modified as part of the de-striping process and were re-flattened afterwards. SRTM Water Body Data was converted to a 1 second resolution grid then adjusted to match the extent of equal-height pixels in original SRTM 1 second data. Grid cells within that water mask were set to the original SRTM height.

Edit rules for land surrounding water bodies
SRTM edit rules set all land adjacent to water at least 1m above water level to ensure containment of water (Slater et al., 2006). Following de-striping, void filling and water flattening, the heights of all grid cells adjacent to water was set to at least 1cm above the water surface. The smaller offset (1cm rather than 1m) could be used because the cleaned digital surface model is in floating point format rather than integer format of the original SRTM.

Some small islands within water bodies are represented as voids within the SRTM due to edit rules. These voids are filled as part of void filling process, and their elevations set to a minimum of 1cm above surrounding water surface across the entire void fill.

DSM Ancillary data layers
Four additional data layers provide information about the alterations to the raw SRTM data to produce this DSM:

- A destripe mask indicating which ¼ × ¼ degree tiles have been affected by destriping and which have not been destriped
- A striping magnitude layer showing the amplitude of the striping at 0.01 degree (~ 1km) resolution
- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- A void mask showing cells that were no-data in the raw SRTM and have been filled using the void filling algorithm

Positional accuracy:

The horizontal positional error is the same as for the raw SRTM 1 second data, with 90% of tested locations within 7.2m for Australia. See Rodriguez *et al.* (2006) for more information.

Attribute accuracy:

Elevation accuracy is essentially the same as for the raw SRTM 1 second data, with 90% of tested heights within 9.8m for Australia. Errors in height are still mostly due to random variation (noise) that is spatially uncorrelated beyond distances of about 100m, but there are some broader scale errors. The noise component is typically about +/- 2m but in some areas is much larger. See Rodriguez *et al.* (2006) for more information.

The removal of striping artefacts improves the representation of the landform shape, particularly in low relief areas, but it is not clear whether this also produces an improvement in overall height accuracy. Some striping remains in the data at a much reduced level (mostly less than 0.3m amplitude). Additional artefacts including long-wavelength (~10km) striping have not been corrected.

Height accuracy is likely to be poorer in areas where voids have been filled using the 9 second DEM, particularly in high relief areas.

Logical Consistency:

The DSM represents heights of the land surface or buildings or vegetation above the land surface. Due to random noise, the relative elevation between adjacent grid cells can be in error by several metres. The removal of striping has improved the representation of local landform shape, particularly in low relief areas.

All void areas have been filled and there are no discontinuities due to tile boundaries.

The SRTM editing rules relating to water bodies have been respected in the processing: lakes are flat, rivers decline continuously in a downstream direction and sea surfaces are at 0m elevation. Flattened water bodies occupy the same areas as in the original SRTM 1 second data. Grid cells adjacent to water bodies are at least 1cm above the water surface. Void areas within water bodies (small islands not represented in the original SRTM data) are at least 1cm above the water surface over their entire area.

Completeness:

The DSM covers all of continental Australia and near coastal islands land areas including all islands defined by the available SRTM 1 second elevation and SRTM Water Body Data datasets.

The following tiles containing fragments of mainland or pieces of islands were not supplied at 1 second resolution and are therefore missing from the DSM:

E112 S26	E124 S15	E142 S10
E113 S29	E125 S14	E143 S10
E118 S20	E132 S11	E146 S17
E120 S35	E133 S11	E150 S22
E121 S35	E134 S35	E152 S24
E123 S16	E141 S10	

Note that the coordinates are of the southwestern corner of the tile.

Contact information

Contact organisation: Geoscience Australia (GA)
Contact position: Director, Sales and Distribution, ISB
Mail address: GPO Box 378
Mail address:
Locality: Canberra
State: ACT
Country: Australia
Postcode: 2601
Telephone: +61 2 6249 9966
Facsimile: +61 2 6249 9960
Electronic mail address: sales@ga.gov.au

Metadata information

Metadata Created date: 2009-12-23
Metadata Updated date: 2010-08-30

Additional metadata

Metadata reference XHTML: *NA*
Metadata reference XML: *NA*

Conversion to floating point format
As a by-product of the de-striping process the integer data was converted to floating point format to allow for the continuously varying nature of the striping. Areas where no de-striping was required will contain unaltered integer values, but represented in floating point format for consistency.

Data layers distributed with the data
Five additional data layers provide information about this DSM:
The four DSM ancillary layers and the DSM tile index have been provided with the data.

References

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3.

Geoscience Australia and CSIRO Land & Water (2010) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0. Geoscience Australia.

Grohman, G., Kroenung, G., and Strebeck, J. (2006) Filling SRTM voids: The delta surface fill method. Photogrammetric Engineering and Remote Sensing 72 (3), 213-216.

Read, Gallant and Dowling (in prep) Destriping and void filling methods used in SRTM 1 Second processing. See http://www.clw.csiro.au/publications/waterforahealthycountry/index.html for progress.

Rodríguez, E., Morris, C.S., and Belz, J.E. (2006) A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing 72 (3), 249-260.

Sibson, R. (1981) A brief description of natural neighbour interpolation. In V. Barnet, editor, Interpreting Multivariate Data, pages 21-36. John Wiley & Sons, Chichester.

Slater, J.A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J. (2006) The SRTM data "finishing" process and products. Photogrammetric Engineering and Remote Sensing 72 (3), 237-247.

For technical queries please contact:
John Gallant
CSIRO Land and Water
Clunies Ross St
CANBERRA ACT 2600
e-mail: John.Gallant@csiro.au

Nerida Wilson
Geoscience Australia
GPO Box 378
Canberra ACT 2601
elevation@ga.gov.au

Authors: John Gallant, Trevor Dowling, Arthur Read, Nerida Wilson and Phil Tickle.

Appendix B – 1 second DEM Metadata

Note: *This metadata describes the dataset in accordance with the ANZLIC (Australia New Zealand Land Information Council) Core Metadata Guidelines Version 2.*

Dataset citation

ANZLIC unique identifier: ANZCW0703013355
Title: 1 second SRTM Derived Digital Elevation Model (DEM) version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 1 second Shuttle Radar Topographic Mission (SRTM) derived Digital Elevation Model (DEM) Version 1.0 is a 1 arc second (~30m) gridded DEM. The DEM represents ground surface topography, and excludes vegetation features. The dataset was derived from the 1 second Digital Surface Model (DSM; ANZCW0703013336) by automatically removing vegetation offsets identified using several vegetation maps and directly from the DSM. This product provides substantial improvements in the quality and consistency of the data relative to the original SRTM data, but is not free from artefacts. Man-made structures such as urban areas and power line towers have not been treated. The removal of vegetation effects has produced satisfactory results over most of the continent and areas with defects are identified in the quality assessment layers distributed with the data and described in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010). A full description of the methods is in progress (Read *et al.,* in prep; Gallant *et al.,* in prep).

Smoothed DEM (DEM-S; ANZCW0703014016) was released in August 2010 as a derivative product of the DEM (and the DSM; ANZCW0703013336) and the drainage enforced version is under development, and is expected to be released in 2010-11.

ANZLIC search words:
LAND Topography Models
ECOLOGY Landscape
Spatial domain:

Geographic extent name: AUSTRALIA EXCLUDING EXTERNAL TERRITORIES - AUS - Australia - Australia
Geographic bounding box:
North bounding latitude: -10°
South bounding latitude: -44 °
East bounding longitude: 154°
West bounding longitude: 113°

Data currency

Beginning date: 2000-2-11
Ending date: 2000-2-22

Dataset status

Progress:
Version 1.0 of the 1 second bare-earth DEM is complete as at 23 December 2009.

Maintenance and update frequency:
Updates and revisions are anticipated to resolve some of the issues identified in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010) and Quality

Assessment layers, and to incorporate improvements in the Digital Elevation Model. The first update is expected to be complete by June 2011, and further revisions are likely.

Reference system:
Horizontal datum WGS84. Vertical datum EGM96.

Access

Stored data format:
DIGITAL - ArcGIS-grid ArcInfo grid
Available format type:
DIGITAL - ArcGIS-grid ArcInfo grid
Access constraints:
The data are subject to Commonwealth of Australia Copyright. A licence agreement is required and a licence fee is also applicable for packaged data (included in the purchase price).

This data is strictly for Government use only.

Data quality

Lineage:

Source data
1. SRTM 1 second Version 2 data (Slater et al., 2006), supplied by Defence Imagery and Geospatial Organisation (DIGO) as 813 1 x 1 degree tiles. Data was produced by NASA from radar data collected by the Shuttle Radar Topographic Mission in February 2000.
2. GEODATA 9 second DEM Version 3 (Geoscience Australia, 2008) used to fill voids.
3. SRTM Water Body Data (SWBD) shapefile accompanying the SRTM data (Slater et al., 2006). This defines the coastline and larger inland waterbodies for the DEM and DSM.
4. Vegetation masks and water masks applied to the DEM to remove vegetation.

DSM processing
This DEM was based on the 1 second SRTM derived Digital Surface Model (DSM) that was itself derived from the 1 second Shuttle Radar Topographic Mission data. The DSM was produced by removing stripes, filling voids and re-flattening water bodies. Further details are provided in the DSM metadata (ANZCW0703013336).

The vegetation removal used the DSM *without* voids filled so that vegetation height estimates would not be affected by interpolated heights and so that voids adjacent to vegetated areas could be filled using bare-earth elevations.

Vegetation offset removal
The processing of vegetation offsets to produce the DEM relies on Landsat-based mapping of woody vegetation to define where the offsets are likely to occur. The mapped extents of woody vegetation were adjusted using an edge-matching process to better represent the extents of areas affected by vegetation offsets in the SRTM DSM. Vegetation was processed across approximately 40% of Australia as shown in the vegetation mask ancillary dataset and in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Vegetation offset processing involves detecting vegetation patches, measuring the height offset around the edges, interpolating the height offset across the vegetated areas and subtracting the offset from the DSM. The heights of the offsets are estimated by measuring height differences across the boundaries of the vegetation patches. The method provides good estimates of the offsets in flat landscapes with well-mapped vegetation boundaries. The effect of sloping terrain is accounted for in the estimation of the offsets, but the results are less reliable in hilly terrain. Estimates of the offsets can also be very poor where the mapped vegetation extents do not match the extents of vegetation offsets as seen by the SRTM instrument. The estimation of the vegetation offsets can also be under or over-estimated if vegetation and topographic patterns coincide, such as trees on hilltops or dune ridges, or in inset floodplains or swamps.

The height offsets at vegetation edges are interpolated within vegetation patches to estimate the effects within the patches. The best results tend to be in small patches such as remnant tree patches. In continuously forested areas with few edges for estimating the offsets the heights are likely to be less reliable, and there is no information at all on variations of the height offset within continuous forests.
The removal of vegetation has been quite effective overall but there are many areas that contain either untreated or incompletely treated vegetation effects.

The methods will be fully described in Read, *et al.* (in prep) and Gallant, *et al.* (in prep).

Void filling
Voids (areas without data) occur in the data due to low radar reflectance (typically open water or dry sandy soils) or topographic shadowing in high relief areas. Delta Surface Fill Method (Grohman et al., 2006) was adapted for this task, using GEODATA 9 second DEM as infill data source. The 9 second data was refined to 1 second resolution using ANUDEM 5.2 without drainage enforcement. Delta Surface Fill Method calculates height differences between SRTM and infill data to create a "delta" surface with voids where the SRTM has no values, then interpolates across voids. The void is then replaced by infill DEM adjusted by the interpolated delta surface, resulting in an exact match of heights at the edges of each void. Two changes to the Delta Surface Fill Method were made: interpolation of the delta surface was achieved with natural neighbour interpolation (Sibson, 1981; implemented in ArcGIS 9.3) rather than inverse distance weighted interpolation; and a mean plane inside larger voids was not used.

Water bodies
Water bodies defined from the SRTM Water Body Data as part of the DSM processing were set to the same elevations as in the DSM.

Edit rules for land surrounding water bodies
SRTM edit rules set all land adjacent to water at least 1m above water level to ensure containment of water (Slater et al., 2006). Following vegetation removal, void filling and water flattening, the heights of all grid cells adjacent to water was set to at least 1 cm above the water surface. The smaller offset (1cm rather than 1m) could be used because the cleaned digital surface model is in floating point format rather than integer format of the original SRTM.

Some small islands within water bodies are represented as voids within the SRTM due to edit rules. These voids are filled as part of void filling process, and their elevations set to a minimum of 1 cm above surrounding water surface across the entire void fill.

Overview of quality assessment
The quality of vegetation offset removal was manually assessed on a 1/8 $\times$1/8 degree grid. Issues with the vegetation removal were identified and recorded in ancillary data layers. The assessment was based on visible artefacts rather than comparison with reference data so relies on the detection of artefacts by edges.

The issues identified were:

- vegetation offsets are still visible (not fully removed)
- vegetation offset overestimated
- linear vegetation offset not fully removed
- incomplete removal of built infrastructure and other minor issues

DEM Ancillary data layers
The vegetation removal and assessment process produced two ancillary data layers:

- A shapefile of 1/8 $\times$ 1/8 degree tiles indicating which tiles have been affected by vegetation removal and any issue noted with the vegetation offset removal

- A difference surface showing the vegetation offset that has been removed; this shows the effect of vegetation on heights as observed by the SRTM radar instrument and is related to vegetation height, density and structure.

The water and void fill masks for the 1 second DSM were also applied to the DEM. Further information is provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Positional accuracy:

The horizontal positional error is the same as for the raw SRTM 1 second data, with 90% of tested locations within 7.2m for Australia. See Rodriguez *et al.* (2006) for more information.

Attribute accuracy:

Accuracy was tested on the 1 second DEM using 1198 Permanent Survey Marks distributed across the Australian Continent relative to the Australian Height Datum (AHD71). Results of this comparison show the absolute accuracy of the data as tested relative to AHD71 to be 7.582m at the 95th percentile with a RMS error of 3.868 in open, flat terrain. 99 percent of points are within a height difference of less than 9.602m.

The removal of striping artefacts improves the representation of the landform shape, particularly in low relief areas, but it is not clear whether this also produces an improvement in overall height accuracy. Some striping remains in the data at a much reduced level (mostly less than 0.3m amplitude). Additional artefacts including long-wavelength (~10km) striping have not been corrected.

The removal of vegetation offsets provides a significant improvement in the representation of the landform shape, particularly in low relief areas, and areas of remnant vegetation. Elevation accuracy varies in forested areas. Comparisons with several higher resolution datasets suggest that elevation accuracy varies depending on the height and structure of the existing vegetation, quality of vegetation input masks and local relief. Further details of these comparisons are provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Height accuracy is likely to be poorer in areas where voids have been filled using the 9 second DEM, particularly in high relief areas.

Logical Consistency:

The DEM represents heights of the land surface. Due to random noise, the relative elevation between adjacent grid cells can be in error by several metres.

The removal of vegetation involves estimation of vegetation height at the edges of vegetation patches, and interpolation of those heights across areas of continuous vegetation cover. Variations in vegetation height within large areas of vegetation are not captured by this method. The vegetation removal process guarantees that no elevations have been increased as part of the process.

All void areas have been filled and there are no discontinuities due to tile boundaries.

The SRTM editing rules relating to water bodies have been respected in the processing: lakes are flat, rivers decline continuously in a downstream direction and sea surfaces are at 0m elevation. Flattened water bodies occupy the same areas as in the original SRTM 1 second data. Grid cells adjacent to water bodies are at least 1cm above the water surface. Void areas within water bodies (small islands not represented in the original SRTM data) are at least 1cm above the water surface over their entire area.

Completeness:

The DEM covers all of continental Australia and near coastal islands land areas including all islands defined by the available SRTM 1 second elevation and SRTM Water Body Data datasets.

The following tiles containing fragments of mainland or pieces of islands were not supplied at 1 second resolution and are therefore missing from the DEM:

E112 S26	E124 S15	E142 S10
E113 S29	E125 S14	E143 S10
E118 S20	E132 S11	E146 S17
E120 S35	E133 S11	E150 S22
E121 S35	E134 S35	E152 S24
E123 S16	E141 S10	

Note that the coordinates are of the southwestern corner of the tile.

Contact information

Contact organisation: Geoscience Australia (GA)
Contact position: Director, Sales and Distribution, ISB
Mail address: GPO Box 378
Mail address:
Locality: Canberra
State: ACT
Country: Australia
Postcode: 2601
Telephone: +61 2 6249 9966
Facsimile: +61 2 6249 9960
Electronic mail address: sales@ga.gov.au

Metadata information

Metadata Created date: 2009-12-23
Metadata Updated date: 2010-08-30

Additional metadata

Metadata reference XHTML: *NA*
Metadata reference XML: *NA*

Conversion to floating point format
As a by-product of the de-striping process the integer data was converted to floating point format to allow for the continuously varying nature of the striping. Areas where no de-striping was required will contain unaltered integer values, but represented in floating point format for consistency.

Data layers distributed with the data
Four additional data layers provide information about the alterations made to the raw SRTM data to produce this DEM:

- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- A void mask showing cells that were no-data in the raw SRTM and have been filled using the void filling algorithm
- Vegetation masks at 1/8 × 1/8 degree resolution illustrating where vegetation was removed from the DEM and issues noted with the removal
- Tile indexes for the DEM

References

Gallant, Read, Dowling and Austin (in prep) Vegetation Removal methods used in SRTM 1 Second processing. See http://www.clw.csiro.au/publications/waterforahealthycountry/index.html for progress.

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO Land & Water (2010) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0. Geoscience Australia.

Grohman, G., Kroenung, G., and Strebeck, J. (2006) Filling SRTM voids: The delta surface fill method. Photogrammetric Engineering and Remote Sensing 72 (3), 213-216.

Read, Gallant and Dowling (in prep) Destriping and void filling methods used in SRTM 1 Second processing. See http://www.clw.csiro.au/publications/waterforahealthycountry/index.html for progress.

Rodríguez, E., Morris, C.S., and Belz, J.E. (2006) A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing 72 (3), 249-260.

Sibson, R. (1981) A brief description of natural neighbour interpolation. In V. Barnet, editor, Interpreting Multivariate Data, pages 21-36. John Wiley & Sons, Chichester.

Slater, J.A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J. (2006) The SRTM data "finishing" process and products. Photogrammetric Engineering and Remote Sensing 72 (3), 237-247.

For technical queries please contact:

John Gallant
CSIRO Land and Water
Clunies Ross St
CANBERRA ACT 2600
John.Gallant@csiro.au

Nerida Wilson
Geoscience Australia
GPO Box 378
Canberra ACT 2601
elevation@ga.gov.au

Authors: John Gallant, Trevor Dowling, Arthur Read, Nerida Wilson and Phil Tickle.

Appendix C – 1 second DEM-S Metadata

Note: *This metadata describes the dataset in accordance with the ANZLIC (Australia New Zealand Land Information Council) Core Metadata Guidelines Version 2.*

Dataset citation

ANZLIC unique identifier: *ANZCW0703014016*
Title: 1 Second SRTM Derived Smoothed Digital Elevation Model (DEM-S) version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 1 second Shuttle Radar Topographic Mission (SRTM) derived smoothed Digital Elevation Model (DEM-S) Version 1.0 is a 1 arc second (~30m) gridded smoothed version of the DEM (ANZCW0703013355). The DEM-S represents ground surface topography, excluding vegetation features, and has been smoothed to reduce noise and improve the representation of surface shape. The dataset was derived from the 1 second Digital Elevation Model Version 1.0 (DSM; ANZCW0703013336) by an adaptive smoothing process that applies more smoothing in flatter areas than hilly areas, and more smoothing in noisier areas than in less noisy areas. This DEM-S supports calculation of local terrain shape attributes such as slope, aspect and curvatures that could not be reliably derived from the unsmoothed DEM because of noise. A full description of the methods is in progress (Gallant *et al.,* in prep).

ANZLIC search words:
- LAND Topography Models
- ECOLOGY Landscape

Spatial domain:

Geographic extent name: AUSTRALIA EXCLUDING EXTERNAL TERRITORIES - AUS - Australia - Australia
Geographic bounding box:
- **North bounding latitude:** -10°
- **South bounding latitude:** -44 °
- **East bounding longitude:** 154°
- **West bounding longitude:** 113°

Data currency

Beginning date: 2000-2-11
Ending date: 2000-2-22

Dataset status

Progress:
Version 1.0 of the 1 second smoothed DEM-S is complete as at 30 August 2010.

Maintenance and update frequency:
Updates and revisions are anticipated, primarily to incorporate improvements to the bare-earth DEM and DEM-S over time. A first revision is anticipated in 2011 and further revisions are likely.

Reference system:
Horizontal datum WGS84. Vertical datum EGM96.

Access

Stored data format:

DIGITAL - ArcGIS-grid ArcInfo grid

Available format type:

DIGITAL - ArcGIS-grid ArcInfo grid

Access constraints:

The data are subject to Commonwealth of Australia Copyright. A licence agreement is required and a licence fee is also applicable for packaged data (included in the purchase price).

This data is strictly for Government use only.

Data quality

Lineage:

Source data

1. SRTM 1 second Version 2 data (Slater et al., 2006), supplied by Defence Imagery and Geospatial Organisation (DIGO) as 813 1 x 1 degree tiles. Data was produced by NASA from radar data collected by the Shuttle Radar Topographic Mission in February 2000.
2. GEODATA 9 second DEM Version 3 (Geoscience Australia, 2008) used to fill voids.
3. SRTM Water Body Data (SWBD) shapefile accompanying the SRTM data (Slater et al., 2006). This defines the coastline and larger inland waterbodies for the SRTM DEM and DSM.
4. Vegetation masks and water masks applied to the DEM to remove vegetation.
5. Adaptive smoothing applied to DEM to produce DEM-S.

DSM processing

This DEM was based on the 1 second SRTM-derived Digital Surface Model (DSM) that was itself derived from the 1 second Shuttle Radar Topographic Mission data. The DSM was produced by removing stripes, filling voids and re-flattening water bodies. Further details are provided in the DSM metadata (ANZCW0703013336).

The vegetation removal used the DSM *without* voids filled so that vegetation height estimates would not be affected by interpolated heights and so that voids adjacent to vegetated areas could be filled using bare-earth elevations.

DEM processing (vegetation offset removal)

Vegetation offsets were identified using Landsat-based mapping of woody vegetation. The height offsets were estimated around the edges of vegetation patches then interpolated to a continuous surface of vegetation height offset that was subtracted from the DSM to produce a bare-earth DEM. Further details are provided in the DSM metadata (ANZCW0703013336).

DEM-S Adaptive smoothing

The smoothing process was based on the amount of noise in the DEM. The noise was estimated from the local variation in the difference between elevation and the mean of nearby elevations.

The adaptive smoothing process was designed to smooth flat areas to a greater degree than steep areas, and to respond to the degree of noise so that very noisy flat areas are smoothed more than less noisy flat areas. The process operated over multiple resolutions, allowing smoothing over quite large distances in areas of very low relief. The smoothing was performed on overlapping tiles, with sufficient overlap that cells used in the final product were not impacted by edge effects.

In essence, the smoothing process operated by comparing the variance of elevations in a 3x3 group of cells with the mean noise variance in the group. If the elevation variance was larger than the mean noise it was considered to be due to real topographic variation and the elevations were left unchanged, while if it was smaller it was considered to be due to noise and the elevations were replaced by the mean elevation in the group. This was applied at successively coarser resolutions, producing smoothing over large areas where the topographic variation was small compared to the noise levels. The algorithm actually used statistical tests to make the decisions, and combined the multiple estimates of elevation at different resolutions using variance weighting.

Water bodies
Water bodies defined from the SRTM Water Body Data as part of the DSM processing were set to the same elevations as in the DSM after the smoothing.

The water bodies are also removed from the DEM (set to null) before the smoothing operation to prevent them affecting the land elevations unduly. One cell of water adjacent to land is retained to prevent shoreline elevations from being raised to match the higher elevations further from the shore.

Further information is provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Positional accuracy:

The horizontal positional error is the same as for the raw SRTM 1 second data, with 90% of tested locations within 7.2 m for Australia. See Rodriguez *et al.* (2006) for more information.

Attribute accuracy:

Accuracy of the 1 second DEM (before smoothing to form DEM-S) was tested using 1198 Permanent Survey Marks (PSM) distributed across the Australian Continent relative to the Australian Height Datum (AHD71). Results of this comparison show the absolute accuracy of the data as tested relative to AHD71 to be 7.582m at the 95^{th} percentile with a RMS error of 3.868 in open, flat terrain. 99 percent of points are within a height difference of less than 9.602m.

The smoothing process estimated the typical improvements in the order of 2-3m.This would make the DEM-S accuracy of approximately 5m. Relative elevation accuracy between adjacent cells is improved in DEM-S due to the reduction in noise levels; this has not been quantified but is evident in the comparison of slopes calculated before and after smoothing as shown in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Height accuracy is likely to be poorer in areas where voids have been filled using the 9 second DEM, particularly in high relief areas.

Logical Consistency:

The DEM-S represents ground elevation with greatly improved relative elevations between adjacent grid cells in low relief areas due to the smoothing process. Slopes as small as 0.02% (2 m in 10 km) can be resolved in this DEM-S.

The removal of vegetation involves estimation of vegetation height at the edges of vegetation patches, and interpolation of those heights across areas of continuous vegetation cover. Variations in vegetation height within large areas of vegetation are not captured by this method. The vegetation removal process guarantees that no elevations have been increased as part of the process.

All void areas have been filled and there are no discontinuities due to tile boundaries.

The SRTM editing rules relating to water bodies have been respected in the processing: lakes are flat, rivers decline continuously in a downstream direction and sea surfaces are at 0 m elevation. Flattened water bodies occupy the same areas as in the original SRTM 1 second data. Grid cells adjacent to water bodies are at least 1 cm above the water surface. Void areas within water bodies (small islands not represented in the original SRTM data) are at least 1 cm above the water surface over their entire area.

Completeness:

The DEM covers all of continental Australia and near coastal islands land areas including all islands defined by the available SRTM 1 second elevation and SRTM Water Body Data datasets.

The following tiles containing fragments of mainland or pieces of islands were not supplied at 1 second resolution and are therefore missing from the DEM:

E112 S26 E113 S29 E118 S20 E120 S35 E121 S35 E123 S16	E124 S15 E125 S14 E132 S11 E133 S11 E134 S35 E141 S10	E142 S10 E143 S10 E146 S17 E150 S22 E152 S24

Note that the coordinates are of the southwestern corner of the tile.

Contact information

Contact organisation: Geoscience Australia (GA)
Contact position: Director, Sales and Distribution, ISB
Mail address: GPO Box 378
Mail address:
Locality: Canberra
State: ACT
Country: Australia
Postcode: 2601
Telephone: +61 2 6249 9966
Facsimile: +61 2 6249 9960
Electronic mail address: sales@ga.gov.au

Metadata information

Metadata created date: 2010-08-30

Additional metadata

Metadata reference XHTML: *NA*
Metadata reference XML: *NA*

Conversion to floating point format
The smoothing process alters all data values in the DEM by varying amounts and the result is a floating point data set capturing in some places very small but meaningful differences in elevation between adjacent cells.

Ancillary data layers distributed with the data
Five additional data layers provide information about the alterations made to the raw SRTM data to produce this DEM:
- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- A void mask showing cells that were no-data in the raw SRTM and have been filled using the void filling algorithm
- Vegetation masks at 1/8 × 1/8 degree resolution illustrating where vegetation was removed from the DEM and issues noted with the removal
- Tile indexes for the DEM-S

References:

Gallant, in (in prep) An adaptive smoothing method for improving noisy DEMs.

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO Land & Water (2010) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0. Geoscience Australia.

Rodríguez, E., Morris, C.S., and Belz, J.E. (2006) A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing 72 (3), 249-260.

Slater, J.A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J. (2006) The SRTM data "finishing" process and products. Photogrammetric Engineering and Remote Sensing 72 (3), 237-247.

For technical queries please contact:
John Gallant
CSIRO Land and Water
Clunies Ross St
CANBERRA ACT 2600
e-mail: John.Gallant@csiro.au

Nerida Wilson
Geoscience Australia
GPO Box 378
Canberra ACT 2601
elevation@ga.gov.au

Authors: John Gallant, Trevor Dowling, Arthur Read, Nerida Wilson and Phil Tickle.

Appendix D – 3 second DSM Metadata

Note: *This metadata describes the dataset in accordance with the ANZLIC (Australia New Zealand Land Information Council) Core Metadata Guidelines Version 2.*

Dataset citation

ANZLIC unique identifier: ANZCW0703014216
Title: 1 second SRTM Derived 3 second Digital Surface Model (DSM) version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 3 second (~90m) Shuttle Radar Topographic Mission (SRTM) derived Digital Surface Model (DSM) Version 1.0 was derived from resampling the 1 arc second (~30m) gridded DSM (ANZCW0703013336) that represents ground surface topography as well as features above the ground such as vegetation and man-made structures. The 1 second DSM was derived from the SRTM data acquired in February 2000, supported by the GEODATA 9 second DEM in void areas and the SRTM Water Body Data. Stripes and voids have been removed from the 1 second SRTM data to provide an enhanced and complete DSM for Australia and near-shore islands. A full description of the methods is in progress (Read *et al.,* in prep). The 3 second DEM was produced for use by government and the public under Creative Commons attribution. Further information can be found in the User Guide.

The 1 second DSM forms the source for the 1 second DEM with vegetation offsets removed (ANZCW0703013355) and the smoothed version (ANZCW0703014016). All 1 second products resampled to 3 seconds are available (DSM; ANZCW0703014216, DEM; ANZCW0703014182, DEM-S; ANZCW0703014217).

ANZLIC search words:

LAND Topography Models
ECOLOGY Landscape

Spatial domain:

Geographic extent name: AUSTRALIA EXCLUDING EXTERNAL TERRITORIES - AUS - Australia - Australia
Geographic bounding box:

North bounding latitude: -10°
South bounding latitude: -44 °
East bounding longitude: 154°
West bounding longitude: 113°

Data currency

Beginning date: 2000-2-11
Ending date: 2000-2-22

Dataset status

Progress:
Version 1.0 of the 3 second bare-earth DSM is complete as at 30 August 2010.

Maintenance and update frequency:
Updates and revisions are anticipated, primarily to incorporate improvements to the bare-earth DEM over time. Further revisions are likely once the 1 second products have been released.

Reference system:
Horizontal datum WGS84. Vertical datum EGM96.

Access

Stored data format:
DIGITAL - ArcGIS-grid ArcInfo grid
Available format type:
DIGITAL - ArcGIS-grid ArcInfo grid
Access constraints:

Data quality

Lineage:

Source data
1. SRTM 1 second Version 2 data (Slater et al., 2006), supplied by Defence Imagery and Geospatial Organisation (DIGO) as 813 1 x 1 degree tiles. Data was produced by NASA from radar data collected by the Shuttle Radar Topographic Mission in February 2000.
2. GEODATA 9 second DEM Version 3 (Geoscience Australia, 2008) used to fill voids.
3. SRTM Water Body Data (SWBD) shapefile accompanying the SRTM data (Slater et al., 2006). This defines the coastline and larger inland waterbodies for the SRTM DSM.
4. 1 second DSM resampled to 3 second DSM.

In order to understand the 3 second DSM the processing of the parent dataset, the 1 second DSM is described below.

1 second DSM processing
The 1 second SRTM-derived Digital Surface Model (DSM) was derived from the 1 second Shuttle Radar Topographic Mission data by removing stripes, filling voids and re-flattening water bodies. Further details are provided in the 1 second DSM metadata (ANZCW0703013336) and the User Guide (Geoscience Australia & CSIRO, 2010).

De-striping
SRTM data contains striping artefacts oriented approximately NE-SW and NW-SE that vary in amplitude from about 0.2m to nearly 4m. The wavelength of the striping is approximately 800m. Stripes were detected in the elevation data using a 2-dimensional Fast Fourier Transform. Peaks in the spectra were visually identified and manually delineated using a tool designed specifically for this purpose. Striping occurred everywhere except where relief was high enough to obscure striping. Spectral analysis was performed on sub-tiles to account for spatial variation in the intensity and direction of striping. Fourier transform was applied to overlapping sub-tiles covering 1536 x 1536 cells (0.43 x 0.43 degrees). Central 1024 x 1024 cells were retained, each comprising one sixteenth of a 1 x 1 degree tile (900 x 900 cells) with a 62-cell overlap on each edge to provide smooth transitions between sub-tiles.

Void filling
Voids (areas without data) occur in the data due to low radar reflectance (typically open water or dry sandy soils) or topographic shadowing in high relief areas. Delta Surface Fill Method (Grohman et al., 2006) was adapted for this task, using GEODATA 9 second DEM as infill data source. The 9 second data was refined to 1 second resolution using ANUDEM 5.2 without drainage enforcement. Delta Surface Fill Method calculates height differences between SRTM and infill data to create a "delta" surface with voids where the SRTM has no values, then interpolates across voids. The void is then replaced by infill DEM adjusted by the interpolated delta surface, resulting in an exact match of heights at the edges of each void. Two changes to the Delta Surface Fill Method were made: interpolation of the delta surface was achieved with natural neighbour

interpolation (Sibson, 1981; implemented in ArcGIS 9.3) rather than inverse distance weighted interpolation; and a mean plane inside larger voids was not used.

Water bodies
Flat water bodies in the original 1 second data were modified as part of the de-striping process and were re-flattened afterwards. SRTM Water Body Data was converted to a 1 second resolution grid then adjusted to match the extent of equal-height pixels in original SRTM 1 second data. Grid cells within that water mask were set to the original SRTM height.

Edit rules for land surrounding water bodies
SRTM edit rules set all land adjacent to water at least 1m above water level to ensure containment of water (Slater et al., 2006). Following de-striping, void filling and water flattening, the heights of all grid cells adjacent to water was set to at least 1cm above the water surface. The smaller offset (1cm rather than 1m) could be used because the cleaned digital surface model is in floating point format rather than integer format of the original SRTM.

Some small islands within water bodies are represented as voids within the SRTM due to edit rules. These voids are filled as part of void filling process, and their elevations set to a minimum of 1cm above surrounding water surface across the entire void fill.

DSM Ancillary data layers
Four additional data layers were used to make alterations to the raw SRTM data to produce the 1 second DSM:

- A destripe mask indicating which ¼ × ¼ degree tiles have been affected by destriping and which have not been destriped
- A striping magnitude layer showing the amplitude of the striping at 0.01 degree (~ 1km) resolution
- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- A void mask showing cells that were no-data in the raw SRTM and have been filled using the void filling algorithm

Resampling to 3 seconds
The 1 second SRTM derived Digital Surface Model (DSM) mosaic was resampled to 3 seconds of arc (90m) in ArcGIS software using aggregation tool. This tool determines a new cell value based on multiplying the cell resolution by a factor of the input (in this case three) and determines the mean value of input cells with the new extent of the cell (i.e. Mean value of the 3x3 input cells). The 3 second DSM mosaic was converted to integer format to make the file size more manageable. It does not affect the accuracy of the data at this resolution.

Further information on the processing is provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Positional accuracy:

The horizontal positional error is estimated to be three times that of the 1 second products. The 1 second products are the same as the raw SRTM 1 second data, with 90% of tested locations within 7.2 m for Australia. See Rodriguez *et al.* (2006) for more information on SRTM accuracy.

Attribute accuracy:

Elevation accuracy is essentially three times the raw SRTM 1 second data accuracy, with 90% of tested heights within 9.8m for Australia, which makes the 3 second DSM accuracy about 29m.Errors in height are still mostly due to random variation (noise) that is spatially uncorrelated beyond distances of about 100m (1 second DSM), but there are some broader scale errors. The noise component is typically about +/- 2m (in the 1 second DSM) but in some areas is much larger. See Rodriguez *et al.* (2006) for more information.

The removal of striping artefacts improves the representation of the landform shape, particularly in low relief areas, but it is not clear whether this also produces an improvement in overall height accuracy. Some striping remains in the data at a much reduced level (mostly less than 0.3m amplitude in the 1 second DSM). Additional artefacts including long-wavelength (~10km) striping have not been corrected (in the 1 second DSM).

Height accuracy is likely to be poorer in areas where voids have been filled using the 9 second DEM, particularly in high relief areas.

Logical Consistency:

The DSM represents elevation. Due to random noise, the relative elevation between adjacent grid cells can be in error by several metres.

All void areas have been filled and there are no discontinuities due to tile boundaries.

The SRTM editing rules relating to water bodies have been respected in the processing: lakes are flat, rivers decline continuously in a downstream direction and sea surfaces are at 0m elevation. Flattened water bodies occupy the same areas as in the original SRTM 1 second data. Grid cells adjacent to water bodies are at least 1cm above the water surface. Void areas within water bodies (small islands not represented in the original SRTM data) are at least 1cm above the water surface over their entire area.

Completeness:

The DSM covers all of continental Australia and near coastal islands land areas including all islands defined by the available SRTM 1 second elevation and SRTM Water Body Data datasets. Some fragments of mainland or pieces of islands may be missing.

Contact information

Contact organisation: Geoscience Australia (GA)
Contact position: Director, Sales and Distribution, ISB
Mail address: GPO Box 378
Mail address:
Locality: Canberra
State: ACT
Country: Australia
Postcode: 2601
Telephone: +61 2 6249 9966
Facsimile: +61 2 6249 9960
Electronic mail address: sales@ga.gov.au

Metadata information

Metadata date: 2010-08-30

Additional metadata

Metadata reference XHTML: *NA*
Metadata reference XML: *NA*

Conversion to floating point format
As a by-product of the de-striping process the integer data was converted to floating point format to allow for the continuously varying nature of the striping. Areas where no de-striping was required will contain unaltered integer values, but represented in floating point format for consistency. The three second data was produced as an integer values as the decimal values are well below any affect on the accuracy.

Ancillary data layers distributed with the data

- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- JPEG Image of the 3 second DSM

References

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3.

Geoscience Australia and CSIRO Land & Water (2010) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0. Geoscience Australia.

Grohman, G., Kroenung, G., and Strebeck, J. (2006) Filling SRTM voids: The delta surface fill method. Photogrammetric Engineering and Remote Sensing 72 (3), 213-216.

Read, Gallant and Dowling (in prep) Destriping and void filling methods used in SRTM 1 Second processing. See http://www.clw.csiro.au/publications/waterforahealthycountry/index.html for progress.

Rodríguez, E., Morris, C.S., and Belz, J.E. (2006) A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing 72 (3), 249-260.

Sibson, R. (1981) A brief description of natural neighbour interpolation. In V. Barnet, editor, Interpreting Multivariate Data, pages 21-36. John Wiley & Sons, Chichester.

Slater, J.A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J. (2006) The SRTM data "finishing" process and products. Photogrammetric Engineering and Remote Sensing 72 (3), 237-247.

For technical queries please contact:
c/o Geoscience Australia
elevation@ga.gov.au
or GA Sales on 02 6249 9966

Authors: John Gallant (CSIRO), Trevor Dowling (CSIRO), Arthur Read (CSIRO), Nerida Wilson (Geoscience Australia) and Phil Tickle (Geoscience Australia).

Appendix E – 3 second DEM Metadata

Note: *This metadata describes the dataset in accordance with the ANZLIC (Australia New Zealand Land Information Council) Core Metadata Guidelines Version 2.*

Dataset citation

ANZLIC unique identifier: ANZCW0703014182
Title: 1 second SRTM Derived 3 second Digital Elevation Model (DEM) version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 3 second (~90m) Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) version 1.0 was derived from resampling the 1 arc second (~30m) gridded DEM (ANZCW0703013355). The DEM represents ground surface topography, and excludes vegetation features. The dataset was derived from the 1 second Digital Surface Model (DSM; ANZCW0703013336) by automatically removing vegetation offsets identified using several vegetation maps and directly from the DSM. The 1 second product provides substantial improvements in the quality and consistency of the data relative to the original SRTM data, but is not free from artefacts. Man-made structures such as urban areas and power line towers have not been treated. The removal of vegetation effects has produced satisfactory results over most of the continent and areas with defects are identified in the quality assessment layers distributed with the data and described in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010). A full description of the methods is in progress (Read *et al.,* in prep; Gallant *et al.,* in prep). The 3 second DEM was produced for use by government and the public under Creative Commons attribution.

The 3 second DSM and smoothed DEM are also available (DSM; ANZCW0703014216, DEM-S; ANZCW0703014217).

ANZLIC search words:
- LAND Topography Models
- ECOLOGY Landscape

Spatial domain:

Geographic extent name: AUSTRALIA EXCLUDING EXTERNAL TERRITORIES - AUS - Australia - Australia
Geographic bounding box:
- **North bounding latitude:** -10°
- **South bounding latitude:** -44 °
- **East bounding longitude:** 154°
- **West bounding longitude:** 113°

Data currency

Beginning date: 2000-2-11
Ending date: 2000-2-22

Dataset status

Progress:
Version 1.0 of the 1 second bare-earth DEM is complete as at 23 December 2009.

Maintenance and update frequency:
Updates and revisions are anticipated, primarily to incorporate improvements to the bare-earth DEM over time. Further revisions are likely once the 1 second products have been released.

Reference system:
Horizontal datum WGS84. Vertical datum EGM96.

Access

Stored data format:
DIGITAL - ArcGIS-grid ArcInfo grid
Available format type:
DIGITAL - ArcGIS-grid ArcInfo grid
Access constraints:

Data quality

Lineage:

Source data
1. SRTM 1 second Version 2 data (Slater et al., 2006), supplied by Defence Imagery and Geospatial Organisation (DIGO) as 813 1 x 1 degree tiles. Data was produced by NASA from radar data collected by the Shuttle Radar Topographic Mission in February 2000.
2. GEODATA 9 second DEM Version 3 (Geoscience Australia, 2008) used to fill voids.
3. SRTM Water Body Data (SWBD) shapefile accompanying the SRTM data (Slater et al., 2006). This defines the coastline and larger inland waterbodies for the DEM and DSM.
4. Vegetation masks and water masks applied to the DEM to remove vegetation.
5. 1 second DEM resampled to 3 second DEM.

1 second DSM processing
The 1 second SRTM-derived Digital Surface Model (DSM) was derived from the 1 second Shuttle Radar Topographic Mission data by removing stripes, filling voids and re-flattening water bodies. Further details are provided in the DSM metadata (ANZCW0703013336).

1 second DEM processing (vegetation offset removal)
Vegetation offsets were identified using Landsat-based mapping of woody vegetation. The height offsets were estimated around the edges of vegetation patches then interpolated to a continuous surface of vegetation height offset that was subtracted from the DSM to produce a bare-earth DEM. Further details are provided in the 1 second DSM metadata (ANZCW0703013355).

Void filling
Voids (areas without data) occur in the data due to low radar reflectance (typically open water or dry sandy soils) or topographic shadowing in high relief areas. Delta Surface Fill Method (Grohman et al., 2006) was adapted for this task, using GEODATA 9 second DEM as infill data source. The 9 second data was refined to 1 second resolution using ANUDEM 5.2 without drainage enforcement. Delta Surface Fill Method calculates height differences between SRTM and infill data to create a "delta" surface with voids where the SRTM has no values, then interpolates across voids. The void is then replaced by infill DEM adjusted by the interpolated delta surface, resulting in an exact match of heights at the edges of each void. Two changes to the Delta Surface Fill Method were made: interpolation of the delta surface was achieved with natural neighbour interpolation (Sibson, 1981; implemented in ArcGIS 9.3) rather than inverse distance weighted interpolation; and a mean plane inside larger voids was not used.

Water bodies
Water bodies defined from the SRTM Water Body Data as part of the DSM processing were set to the same elevations as in the DSM.

Edit rules for land surrounding water bodies
SRTM edit rules set all land adjacent to water at least 1m above water level to ensure containment of water (Slater et al., 2006). Following vegetation removal, void filling and water flattening, the heights of all grid cells adjacent to water was set to at least 1 cm above the water surface. The smaller offset (1cm rather than 1m) could be used because the cleaned digital surface model is in floating point format rather than integer format of the original SRTM.

Some small islands within water bodies are represented as voids within the SRTM due to edit rules. These voids are filled as part of void filling process, and their elevations set to a minimum of 1 cm above surrounding water surface across the entire void fill.

Overview of quality assessment
The quality of vegetation offset removal was manually assessed on a 1/8 ×1/8 degree grid. Issues with the vegetation removal were identified and recorded in ancillary data layers. The assessment was based on visible artefacts rather than comparison with reference data so relies on the detection of artefacts by edges.

The issues identified were:

- vegetation offsets are still visible (not fully removed)
- vegetation offset overestimated
- linear vegetation offset not fully removed
- incomplete removal of built infrastructure and other minor issues

DEM Ancillary data layers
The vegetation removal and assessment process produced two ancillary data layers:

- A shapefile of 1/8 × 1/8 degree tiles indicating which tiles have been affected by vegetation removal and any issue noted with the vegetation offset removal
- A difference surface showing the vegetation offset that has been removed; this shows the effect of vegetation on heights as observed by the SRTM radar instrument and is related to vegetation height, density and structure.

The water and void fill masks for the 1 second DSM were also applied to the DEM. Further information is provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Resampling to 3 seconds
The 1 second SRTM derived Digital Elevation Model (DEM) was resampled to 3 seconds of arc (90m) in ArcGIS software using aggregation tool. This tool determines a new cell value based on multiplying the cell resolution by a factor of the input (in this case three) and determines the mean value of input cells with the new extent of the cell (i.e. Mean value of the 3x3 input cells). The 3 second SRTM was converted to integer format for the national mosaic to make the file size more manageable. It does not affect the accuracy of the data at this resolution.

Further information on the processing is provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Positional accuracy:

The horizontal positional error is estimated to be three times that of the 1 second products. The 1 second products are the same as the raw SRTM 1 second data, with 90% of tested locations within 7.2 m for Australia. See Rodriguez *et al.* (2006) for more information on SRTM accuracy.

Attribute accuracy:

The accuracy of the 3 second DEM is determined to be three times that of the accuracy of the 1 second DEM. This is approximately 22m.

Accuracy was tested on the 1 second DEM using 1198 Permanent Survey Marks distributed across the Australian Continent relative to the Australian Height Datum (AHD71). Results of this comparison show the absolute accuracy of the data as tested relative to AHD71 to be 7.582m at the 95^{th} percentile with a RMS error of 3.868 in open, flat terrain. 99 percent of points are within a height difference of less than 9.602m.

The removal of striping artefacts from the 1 second DEM improves the representation of the landform shape, particularly in low relief areas, but it is not clear whether this also produces an improvement in overall height accuracy. Some striping remains in the data at a much reduced level (mostly less than 0.3m amplitude). Additional artefacts including long-wavelength (~10km) striping have not been corrected.

The removal of vegetation offsets in the 1 second DEM provides a significant improvement in the representation of the landform shape, particularly in low relief areas, and areas of remnant vegetation. Elevation accuracy varies in forested areas. Comparisons with several higher resolution datasets suggest that elevation accuracy varies depending on the height and structure of the existing vegetation, quality of vegetation input masks and local relief. Further details of these comparisons are provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Height accuracy is likely to be poorer in areas where voids have been filled using the 9 second DEM, particularly in high relief areas.

Logical Consistency:

The DEM represents elevation. Due to random noise, the relative elevation between adjacent grid cells can be in error by several metres.

The removal of vegetation involves estimation of vegetation height at the edges of vegetation patches, and interpolation of those heights across areas of continuous vegetation cover. Variations in vegetation height within large areas of vegetation are not captured by this method. The vegetation removal process guarantees that no elevations have been increased as part of the process.

All void areas have been filled and there are no discontinuities due to tile boundaries.

The SRTM editing rules relating to water bodies have been respected in the processing: lakes are flat, rivers decline continuously in a downstream direction and sea surfaces are at 0m elevation. Flattened water bodies occupy the same areas as in the original SRTM 1 second data. Grid cells adjacent to water bodies are at least 1cm above the water surface. Void areas within water bodies (small islands not represented in the original SRTM data) are at least 1cm above the water surface over their entire area.

Completeness:

The DEM covers all of continental Australia and near coastal islands land areas including all islands defined by the available SRTM 1 second elevation and SRTM Water Body Data datasets.

The following tiles containing fragments of mainland or pieces of islands were not supplied at 1 second resolution and are therefore missing from the DEM:

E112 S26	E124 S15	E142 S10
E113 S29	E125 S14	E143 S10
E118 S20	E132 S11	E146 S17
E120 S35	E133 S11	E150 S22
E121 S35	E134 S35	E152 S24
E123 S16	E141 S10	

Note that the coordinates are of the southwestern corner of the tile.

Contact information

Contact organisation: Geoscience Australia (GA)
Contact position: Director, Sales and Distribution, ISB
Mail address: GPO Box 378
Mail address:
Locality: Canberra
State: ACT
Country: Australia
Postcode: 2601
Telephone: +61 2 6249 9966
Facsimile: +61 2 6249 9960
Electronic mail address: sales@ga.gov.au

Metadata information

Metadata date: 2010-08-30

Additional metadata

Metadata reference XHTML: *NA*
Metadata reference XML: *NA*

Conversion to floating point format
As a by-product of the de-striping process the integer data was converted to floating point format to allow for the continuously varying nature of the striping. Areas where no de-striping was required will contain unaltered integer values, but represented in floating point format for consistency. The 3 second data was produced as an integer values as the decimal values are well below any affect on the accuracy.

Ancillary data layers distributed with the data
- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- JPEG Image of the 3 second DEM.

References

Gallant, Read, Dowling and Austin (in prep) Vegetation Removal methods used in SRTM 1 Second processing. See http://www.clw.csiro.au/publications/waterforahealthycountry/index.html for progress.

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO Land & Water (2010) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0. Geoscience Australia.

Grohman, G., Kroenung, G., and Strebeck, J. (2006) Filling SRTM voids: The delta surface fill method. Photogrammetric Engineering and Remote Sensing 72 (3), 213-216.

Read, Gallant and Dowling (in prep) Destriping and void filling methods used in SRTM 1 Second processing. See http://www.clw.csiro.au/publications/waterforahealthycountry/index.html for progress.

Rodríguez, E., Morris, C.S., and Belz, J.E. (2006) A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing 72 (3), 249-260.

Sibson, R. (1981) A brief description of natural neighbour interpolation. In V. Barnet, editor, Interpreting Multivariate Data, pages 21-36. John Wiley & Sons, Chichester.

Slater, J.A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J. (2006) The SRTM data "finishing" process and products. Photogrammetric Engineering and Remote Sensing 72 (3), 237-247.

For technical queries please contact:
c/o Geoscience Australia
elevation@ga.gov.au
or GA Sales on 02 6249 9966

Authors: John Gallant (CSIRO), Trevor Dowling (CSIRO), Arthur Read (CSIRO), Nerida Wilson (Geoscience Australia) and Phil Tickle (Geoscience Australia).

Appendix F – 3 second DEM-S Metadata

Note: *This metadata describes the dataset in accordance with the ANZLIC (Australia New Zealand Land Information Council) Core Metadata Guidelines Version 2.*

Dataset citation

ANZLIC unique identifier: *ANZCW0703014217*
Title: 1 Second SRTM Derived 3 second Smoothed Digital Elevation Model (DEM-S) version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 3 second (~90m) Smoothed Digital Elevation Model (DEM-S) Version 1.0 was derived from resampling the 1 second SRTM derived DEM-S (gridded smoothed digital elevation model; ANZCW0703014016). The DEM represents ground surface topography, excluding vegetation features, and has been smoothed to reduce noise and improve the representation of surface shape. The DEM-S was derived from the 1 second Digital Surface Model (DSM; ANZCW0703013336) and the Digital Elevation Model Version 1.0 (DEM; ANZCW0703013355) by an adaptive smoothing process that applies more smoothing in flatter areas than hilly areas, and more smoothing in noisier areas than in less noisy areas. This DEM-S supports calculation of local terrain shape attributes such as slope, aspect and curvatures that could not be reliably derived from the unsmoothed 1 second DEM because of noise. A full description of the methods is in progress (Gallant *et al.,* in prep) and in the 1 second User Guide. The 3 second DEM was produced for use by government and the public under Creative Commons attribution.

The 1 second DSM and DEM that forms the basis of the product are also available as 3 second products (DSM; ANZCW0703014216, DEM; ANZCW0703014182, DEM-S; ANZCW0703014217).

ANZLIC search words:

LAND Topography Models
ECOLOGY Landscape

Spatial domain:

Geographic extent name: AUSTRALIA EXCLUDING EXTERNAL TERRITORIES - AUS - Australia - Australia
Geographic bounding box:

North bounding latitude: -10°
South bounding latitude: -44 °
East bounding longitude: 154°
West bounding longitude: 113°

Data currency

Beginning date: 2000-2-11
Ending date: 2000-2-22

Dataset status

Progress:
Version 1.0 of the 3 second DEM-S is complete as at 30 August 2010.

Maintenance and update frequency:

Updates and revisions are anticipated, primarily to incorporate improvements to the bare-earth DEM over time. Further revisions are likely once the 1 second products have been released.

Reference system:
Horizontal datum WGS84. Vertical datum EGM96.

Access

Stored data format:
DIGITAL - ArcGIS-grid ArcInfo grid
Available format type:
DIGITAL - ArcGIS-grid ArcInfo grid
Access constraints:

Data quality

Lineage:

Source data
1. SRTM 1 second Level 2 data (Slater et al., 2006), supplied by Defence Imagery and Geospatial Organisation (DIGO) as 813 1 x 1 degree tiles. Data was produced by NASA from radar data collected by the Shuttle Radar Topographic Mission in February 2000.
2. GEODATA 9 second DEM Version 3 (Geoscience Australia, 2008) used to fill voids.
3. SRTM Water Body Data (SWBD) shapefile accompanying the SRTM data (Slater et al., 2006). This defines the coastline and larger inland waterbodies for the SRTM DEM and DSM.
4. Vegetation masks and water masks applied to the DEM to remove vegetation.
5. Adaptive smoothing applied to DEM to produce 1 second DEM-S.
6. 1 second DEM-S resampled to 3 second DEM-S

In order to understand the 3 second DEM the processing of the parent dataset, the 1 second DEM-S is described below.

1 second DSM processing
The 1 second SRTM-derived Digital Surface Model (DSM) was derived from the 1 second Shuttle Radar Topographic Mission data by removing stripes, filling voids and re-flattening water bodies. Further details are provided in the DSM metadata (ANZCW0703013336).

1 second DEM processing (vegetation offset removal)
Vegetation offsets were identified using Landsat-based mapping of woody vegetation. The height offsets were estimated around the edges of vegetation patches then interpolated to a continuous surface of vegetation height offset that was subtracted from the DSM to produce a bare-earth DEM. Further details are provided in the DSM metadata (ANZCW0703013355).

Adaptive smoothing
The adaptive smoothing process was designed to smooth flat areas to a greater degree than steep areas, and to respond to the degree of noise so that very noisy flat areas are smoothed more than less noisy flat areas. The process operated over multiple resolutions, allowing smoothing over quite large distances in areas of very low relief. The smoothing was performed on overlapping tiles, with sufficient overlap that cells used in the final product were not impacted by edge effects.

The smoothing process was based on the amount of noise in the 1 second DEM. The noise was estimated from the local variation in the difference between elevation and the mean of nearby elevations.

In essence, the smoothing process operated by comparing the variance of elevations in a 3x3 group of cells with the mean noise variance in the group. If the elevation variance was larger than the mean noise it was considered to be due to real topographic variation and the elevations were left unchanged, while if it was smaller it was considered to be due to noise and the elevations were replaced by the mean elevation in the group. This was applied at successively coarser resolutions, producing smoothing over large areas where the topographic variation was small compared to the noise levels. The algorithm actually used statistical tests to make the decisions, and combined the multiple estimates of elevation at different resolutions using variance weighting.

Water bodies
Water bodies defined from the SRTM Water Body Data as part of the DSM processing were set to the same elevations as in the DSM after the smoothing.

The water bodies are also removed from the DEM (set to null) before the smoothing operation to prevent them affecting the land elevations unduly. One cell of water adjacent to land is retained to prevent shoreline elevations from being raised to match the higher elevations further from the shore.

Resampling to 3 seconds
The 1 second SRTM derived smoothed Digital Elevation Model (DEM-S) was resampled to 3 seconds of arc (90m) in ArcGIS software using aggregation tool.This tool determines a new cell value based on multiplying the cell resolution by a factor of the input (in this case three) and determines the mean value of input cells with the new extent of the cell (i.e. Mean value of the 3x3 input cells). The 3 second SRTM was left in floating point format which does make this dataset slower to open/run.

Further information on the processing is provided in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010).

Positional accuracy:

The horizontal positional error is estimated to be three times that of the 1 second products. The 1 second products are the same as the raw SRTM 1 second data, with 90% of tested locations within 7.2 m for Australia. See Rodriguez *et al.* (2006) for more information on SRTM accuracy.

Attribute accuracy:

Accuracy of the 3 second DEM-S was tested using the same 1198 PSM as the 1 second DEM accuracy assessment. Results of the comparison showed the absolute accuracy of the data as tested relative to AHD71 to be 14.54m at the 95th percentile with an RMS error of 7.029m in open, flat terrain. 99 percent of points are within a height difference of less than 29.97m.

Relative elevation accuracy between adjacent cells is improved in the DEM-S due to the reduction in noise levels; this has not been quantified but is evident in the comparison of slopes calculated before and after smoothing as shown in the User Guide (Geoscience Australia and CSIRO Land & Water, 2010). The smoothing process estimated the typical improvements in the order of 2-3m in the 1 second DEM-S.

Height accuracy is likely to be poorer in areas where voids have been filled using the 9 second DEM, particularly in high relief areas.

Logical Consistency:

The 1 second DEM-S represents ground elevation with greatly improved relative elevations between adjacent grid cells in low relief areas due to the smoothing process. Slopes as small as 0.02% (2 m in 10 km) can be resolved in the DEM-S.

The removal of vegetation involves estimation of vegetation height at the edges of vegetation patches, and interpolation of those heights across areas of continuous vegetation cover. Variations in vegetation height within large areas of vegetation are not captured by this method. The vegetation removal process guarantees that no elevations have been increased as part of the process.

All void areas have been filled and there are no discontinuities due to original tile boundaries.

The SRTM editing rules relating to water bodies have been respected in the processing: lakes are flat, rivers decline continuously in a downstream direction and sea surfaces are at 0m elevation. Flattened water bodies occupy the same areas as in the original SRTM 1 second data. Grid cells adjacent to water bodies are at least 1cm above the water surface. Void areas within water bodies (small islands not represented in the original SRTM data) are at least 1cm above the water surface over their entire area.

Completeness:

The DEM-S covers all of continental Australia and near coastal islands land areas including all islands defined by the available SRTM 1 second elevation and SRTM Water Body Data datasets. Some fragments of mainland or pieces of islands may be missing.

Contact information

Contact organisation: Geoscience Australia (GA)
Contact position: Director, Sales and Distribution, ISB
Mail address: GPO Box 378
Mail address:
Locality: Canberra
State: ACT
Country: Australia
Postcode: 2601
Telephone: +61 2 6249 9966
Facsimile: +61 2 6249 9960
Electronic mail address: sales@ga.gov.au

Metadata information

Metadata date: 2009-08-30

Additional metadata

Metadata reference XHTML: *NA*
Metadata reference XML: *NA*

Conversion to floating point format
The smoothing process alters all data values in the 1 second DEM by varying amounts and the result is a floating point data set capturing in some places very small but meaningful differences in elevation between adjacent cells.

Ancillary data layers
- A water mask at 1 second resolution showing the cells that are part of the flattened water bodies
- JPEG Image of the 3 second DEM-S

References

Gallant, in (in prep) An adaptive smoothing method for improving noisy DEMs.

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO Land & Water (2010) 1 Second SRTM-Derived Digital Elevation Model (DSM, DEM, DEM-S and DEM-H) User Guide. Version 1.0. Geoscience Australia.

Rodríguez, E., Morris, C.S., and Belz, J.E. (2006) A global assessment of the SRTM performance. Photogrammetric Engineering and Remote Sensing 72 (3), 249-260.

Slater, J.A., Garvey, G., Johnston, C., Haase, J., Heady, B., Kroenung, G., and Little, J. (2006) The SRTM data "finishing" process and products. Photogrammetric Engineering and Remote Sensing 72 (3), 237-247.

For technical queries please contact:
c/o Geoscience Australia
elevation@ga.gov.au
or GA Sales on 02 6249 9966

Authors: John Gallant (CSIRO), Trevor Dowling (CSIRO), Arthur Read (CSIRO), Nerida Wilson (Geoscience Australia) and Phil Tickle (Geoscience Australia).

Appendix G – Loading the data

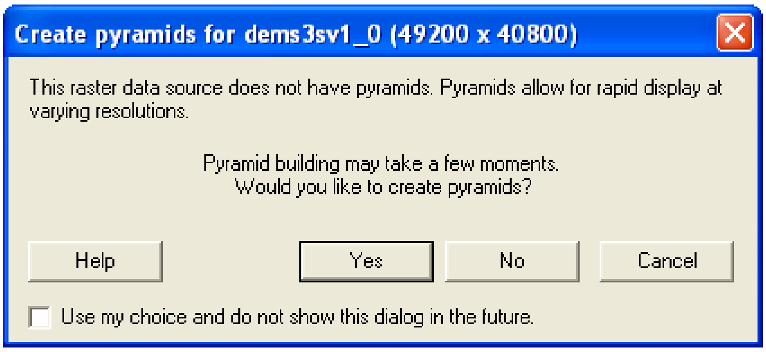
To assist you in loading and viewing the data into your preferred software, some basic instructions are described as a guide if you are unfamiliar with raster data. This is a guide only and there may be other ways to import the data. Geoscience Australia is able to provide further information on the product and data format itself but is not able to provide specific software advice. For this please consult your software company for technical support. As data processing capacity is improved, other software packages will be detailed.

Into ESRI ArcGIS

Open ArcMap. Either using the button in ArcCatalog  or through Windows Start Program menu. Either open a new mxd or a blank mxd when prompted.

To add the SRTM either press the **Add Data** icon  or go to File > Add Data. Navigate to the directory where you have stored the SRTM data. The raster grid should appear with an icon like this  next to the file name.

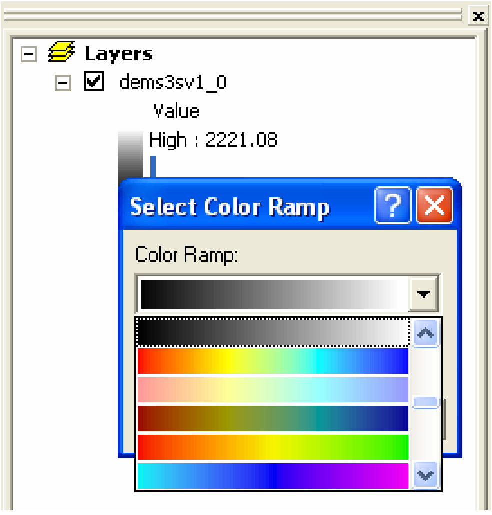
When asked if you would like to **Create Pyramids** it is advised that you click yes. This will take some time now but will save time when viewing the files later. Please note that Building Pyramids almost doubles the file size but at a later stage you can delete the pyramids if needed.

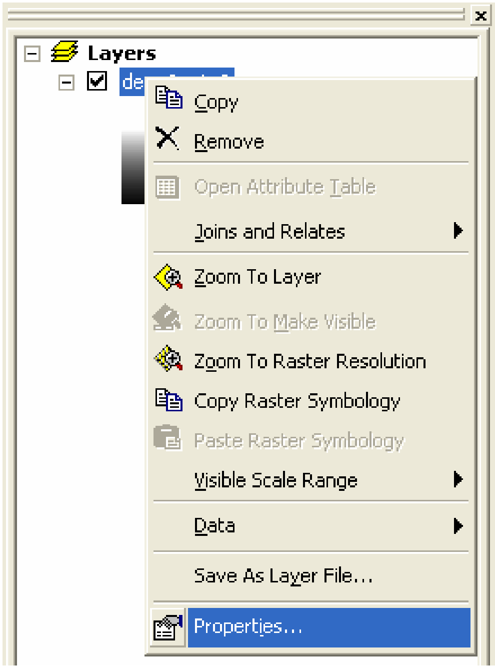


Once the file opens you the **Navigation Tools** to *Zoom in*, *Zoom Out*, *Zoom to Full Extent*, *Zoom to Previous* etc. 

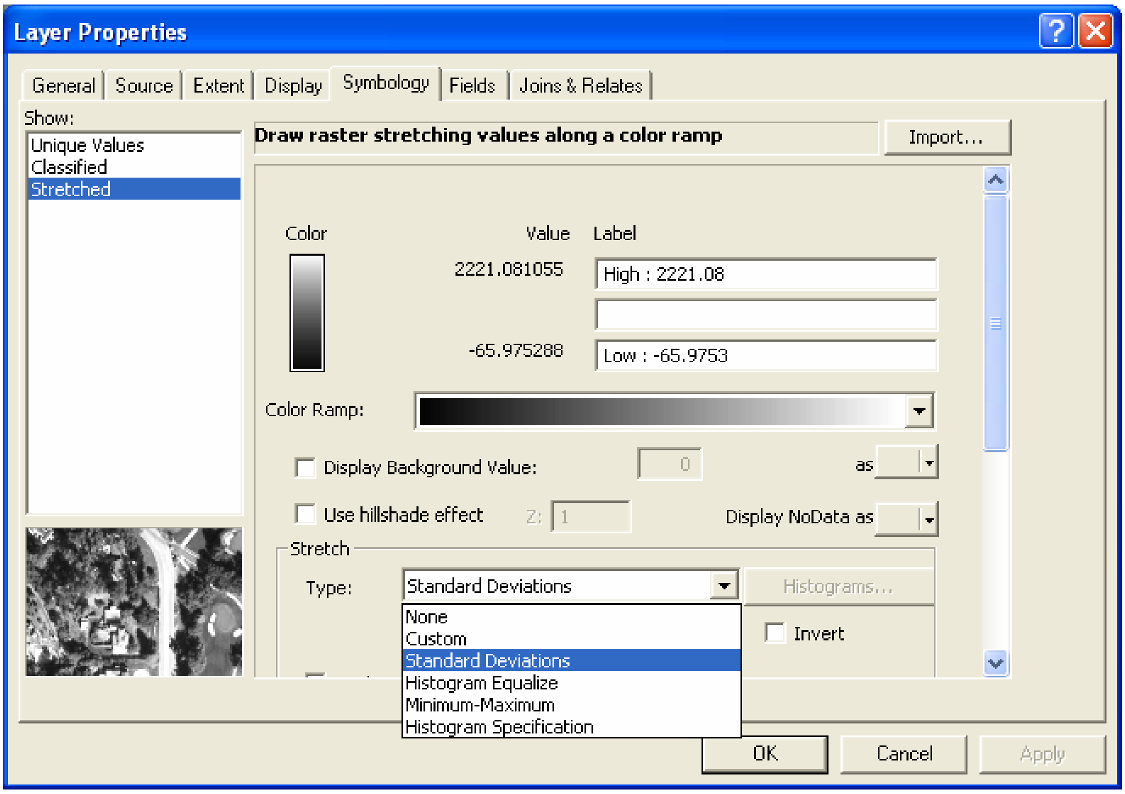
To load this toolbar, right-click in black area at the top of ArcMap and scroll down til you get to *Tools* and tick to turn it on – then position it in the window to suit.

To change the elevation colour ramp, go to Layers Contents box and click on the coloured strip or right click on the layer go to **Properties** (or double click layers name), then under *Symbology* tab for further options.





Once in the Properties the min/max values or other values can be altered as desired, apply a stretch, apply a hillshade effect or change to a classified colour ramp (defined colour for each range of elevation values selected).



If it asks for you to *Compute Histogram* say yes. Same for *Calculate Statistics*.

It is recommended that the *Display NoData* and *Display Background Value* as *No Colour*.

Now you are ready to query or view the data.

You can also view the data in ArcCatalog by clicking the Preview tab after navigating to the location of the data. If you haven't connected to a drive click the

Connect to Folder button  to view a drive. You will be asked to Build Pyramids if you haven't already done this (see above).

Into Pitney Bowes MapInfo

Open MapInfo Professional.

Go to File > Open. Select ESRI grid and then navigate to location of SRTM data. Select the hdr.adf file (Header File) and press open.

This should load the ESRI data once it has created a .TAB file in the folder.