Australian Government
Geoscience Australia

1 second SRTM Derived Products User Guide

1 arc second DSM, DEM, DEM-S & DEM-H

3 arc second DSM, DEM & DEM-S

Version 1.0.4

October 2011

1 second DSM product Restricted for Government Use Only

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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
1/10/2011	Inclusion of 1 second DEM-H. Modification of 1 second products for public release.	NW	1.0.4

1 second SRTM Derived Digital Elevation Models
User Guide – Version 1.0.4

Product Description

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Acknowledgements

Authors include John Gallant, Trevor Dowling, Arthur Read from CSIRO and from Geoscience Australia; Nerida Wilson, Phil Tickle, Chris Inskeep.

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Licensing

Creative Commons – 1 second & 3 second Products (excluding 1 second DSM)

In June 2011, the Level-2 (~1 second or 30 m) SRTM 'bare-earth' models (DEM, DEM-S and DEM-H) were approved by Australia's Defence Imagery and Geospatial Organisation (DIGO) and the United States Department of Defence for public release. These products are now available under Creative Commons. It does not include the Digital Surface Model (DSM) (and associated vegetation layers) which are still supplied under a government restricted licence.

The 3 second SRTM Digital Elevation Models (DSM, DEM and DEM-S) were released in August 2010 under Creative Commons Attribution 3.0 Australia licence.

Creative Commons means the data can be shared (copied, distributed and transmitted) or adapted providing you acknowledge Geoscience Australia as the author or licensor.

Licence - 1 second DSM (Government Use Only)

The only product in the 1 second range that is not for public release is the Digital Surface Model (DSM) which is strictly for **Government use only**. It is provided on request 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 DSM product. 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 DSM is not available to universities or students unless they are working on a government project. The licence agreement will cover all versions of DSM product derived from the SRTM data once signed. Under the agreement with DIGO, Geoscience Australia is required to keep a record of all government agencies that have received the DSM data. The data is subject to Commonwealth of Australia Copyright. The 1 second DSM data is provided upon request to eligible parties by contacting elevation@ga.gov.au

Data Schema

Data Format

Data is stored as continuous 32 bit Floating Point ESRI Grids (tiles and mosaic) and ESRI shapefiles for some reference data. One second (~30 m) Grid tiles are named per the latitude and longitude of the south west corner. A suffix of 'dem1_0', 'dems1_0' or 'demh1_0' has been applied to the tile names to differentiate between the elevation models and the version number (in this case version 1.0).

The 3 second DEM and DSM are available in integer format and the 3 second DEM-S is in 32 bit Floating Point in a national mosaic.

If ordering the data through the Geoscience Australia Sales Centre, the data will be supplied as a national mosaic product in ESRI Grid format. Geoscience Australia does not provide customised extents or file formats.

A subset of the data can be downloaded from the National Elevation Data Framework (NEDF) web portal at http://nedf.ga.gov.au in many formats in national coverage or tile format (initially ESRI Grid). Orders over a certain size will incur a data transfer cost (same as purchasing through Sales).

Further information on loading data into various software packages is explained in Appendix H. Otherwise please consult your software vendor.

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 products with a hill shade applied and 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); the Digital Elevation Model (DEM), the Smoothed Digital Elevation Model (DEM–S) and the hydrologically enforced (DEM–H) products. 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.

These products have 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 will be minimised over time as more accurate national DEM products evolve. Details of known errors in the data are explained in this *User Guide*. We 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 30 m) products are available to government agencies and their collaborators and contractors. Reduced resolution versions of the products at 3 second (~ 90 m) were released in 2010. Another product for public use is the GEODATA3 9 second (~250 m) DEM which has hydrological enforcement applied, unlike the 3 second DEM, and is available through Geoscience Australia Sales Centre.

Overview

The 1 second DSM, DEM, DEM-S and DEM-H are national elevation data products derived from the Shuttle Radar Topography Mission (SRTM) data. The SRTM data is not suitable for routine application due to various artefacts and noise.

The data has been treated with several processes to produce more usable products:

- A cleaned digital surface model (DSM)
  - regular grid representing ground surface topography 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 areas.
- A hydrologically enforced digital elevation model (DEM–H)
  - A hydrologically enforced DEM is based on DEM-S that has had drainage lines imposed and been further smoothed using the ANUDEM interpolation 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 25 m resolution DEMs produced by State and Territory agencies from digitised topographic maps.

For any analysis where surface shape is important, one of the smoothed DEMs (DEM-S or DEM-H) should be used. DEM-S is preferred for shape and vertical accuracy and DEM-H for hydrological connectivity. The DSM is suitable if you want to see the vegetation as well as the land surface height. There are few cases where DEM is the best data source, unless access to a less processed product is necessary.

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 almost 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 and version 1.0 of the hydrologically enforced DEM–H was released in October 2011. 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 3 second products were derived from the 1 second data and version 1.0 was released in August 2010. Future releases of these products will occur when the 1 second products have been improved. At this stage there is no 3 second DEM-H product, which requires re-interpolation with drainage enforcement at that resolution.

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, excludes 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

During eleven days in February 2000, Space Shuttle Endeavour collected global elevation data on the SRTM. Acquired by the National Geospatial-Intelligence Agency (NGA) and National Aeronautics and Space Administration (NASA), the data is publicly available globally at three arc second (~90 metre) resolution and one arc second (~30 metre) resolution over the United States.

Australia's Defence Imagery and Geospatial Organisation (DIGO) were provided access to the 1 second SRTM data over Australia. Following the establishment of the National Elevation Data Framework (NEDF) and passing of the Water Act in 2007, Geoscience Australia (GA), the Bureau of Meteorology (BoM), the

Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian National University (ANU) formalised a collaboration to derive a series of 1 second SRTM-DEMs that would underpin the new NEDF and the BoMs Australian Hydrological Geospatial Fabric, or Geofabric.

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 60 m 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 6 m of the reference heights. In much of the clear flat areas of Australia the height errors are less than 3 m, 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 is reflected by 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-S 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).

The main processing of the SRTM products has included:

- Removal of stripes
- Void filling
- Tree offset removal using automated methods
- Adaptive smoothing of DEM v1.0
- Water masking (to re-flatten water bodies affected by processing)
- Drainage enforcement and flow direction checking.

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 800 m apart and their amplitude is typically around 1 m, but up to 4 m 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).

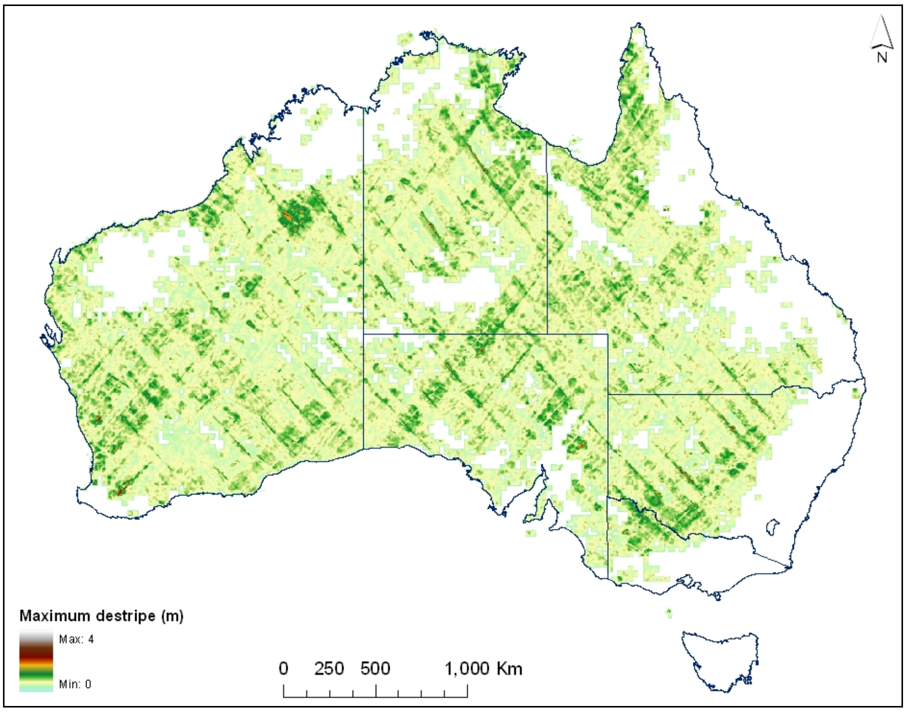


Figure 1. Magnitude and distribution of stripe cleaning.

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).

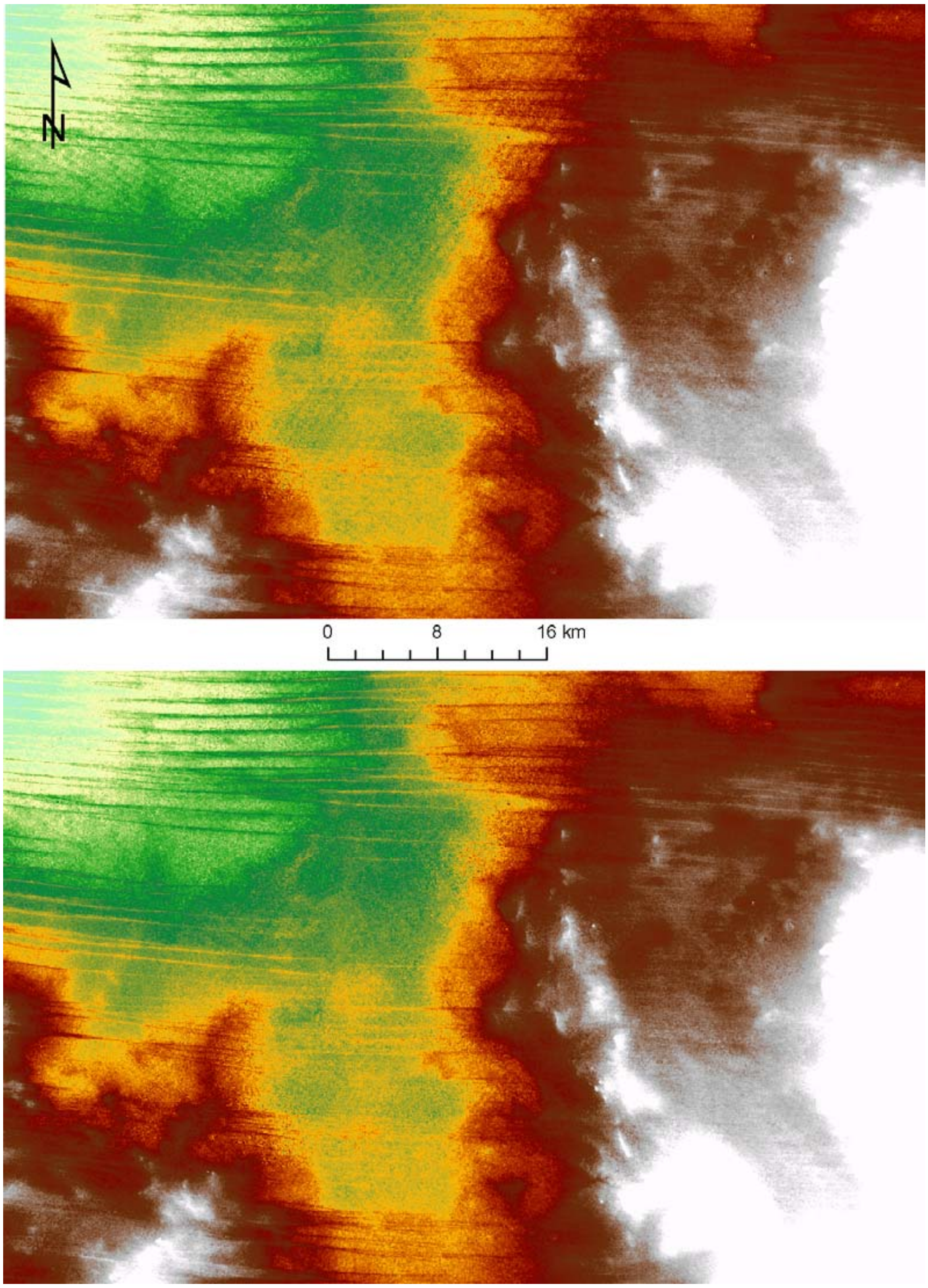


Figure 2. Example of good stripe removal. Southesk Tablelands in Great Sandy Desert, WA, 126.3E 20.2S. Elevation range 220 – 320 m.

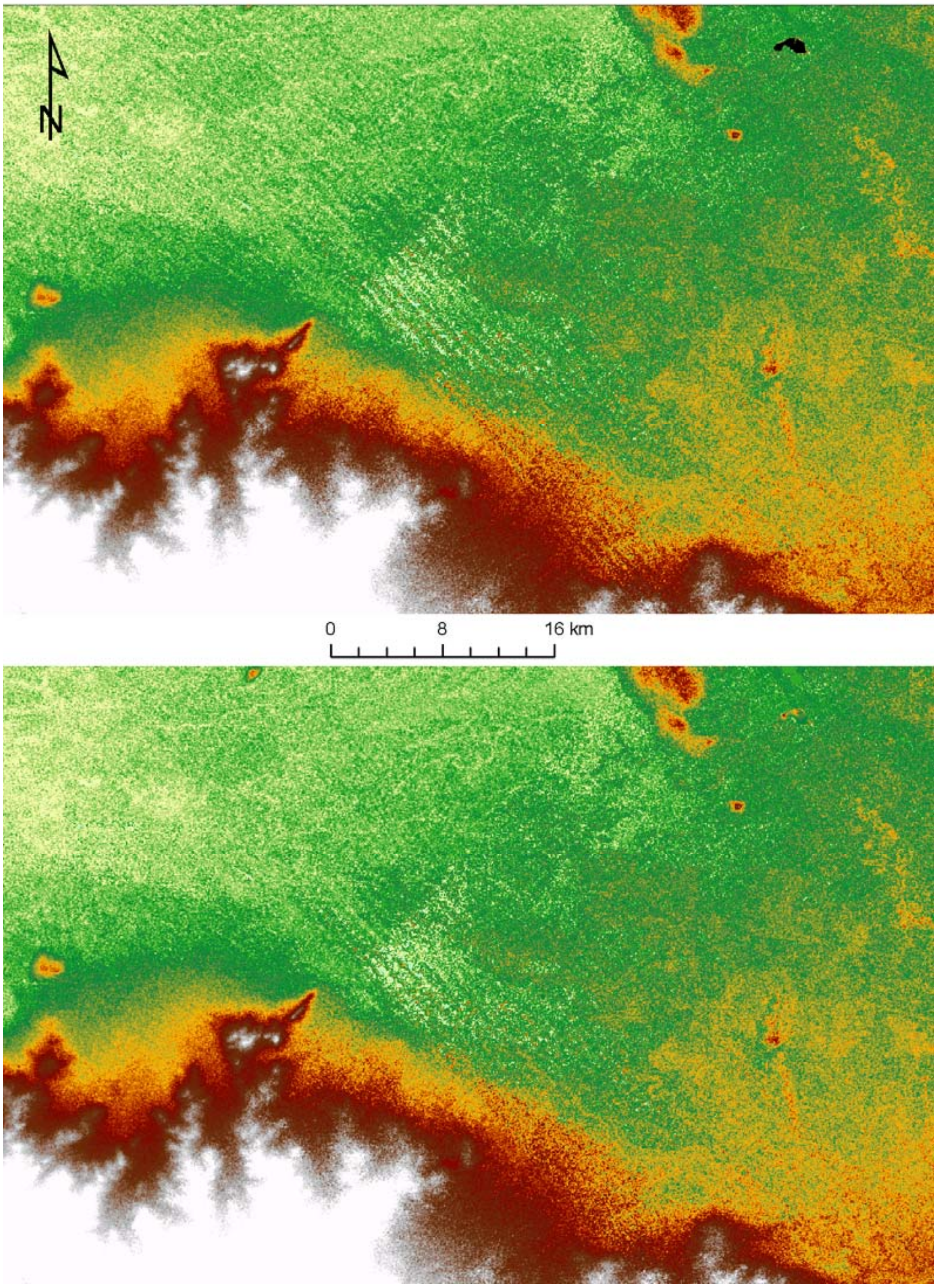


Figure 3. Example of poor stripe removal; there are also some voids among the stripes. Bogan River near Brewarrina, NSW, 146.7E 30.2S. Elevation range 105 – 160 m.

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 in 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 was considered as an alternate source of filling voids in the steep areas but rejected due to inconsistent quality.

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).

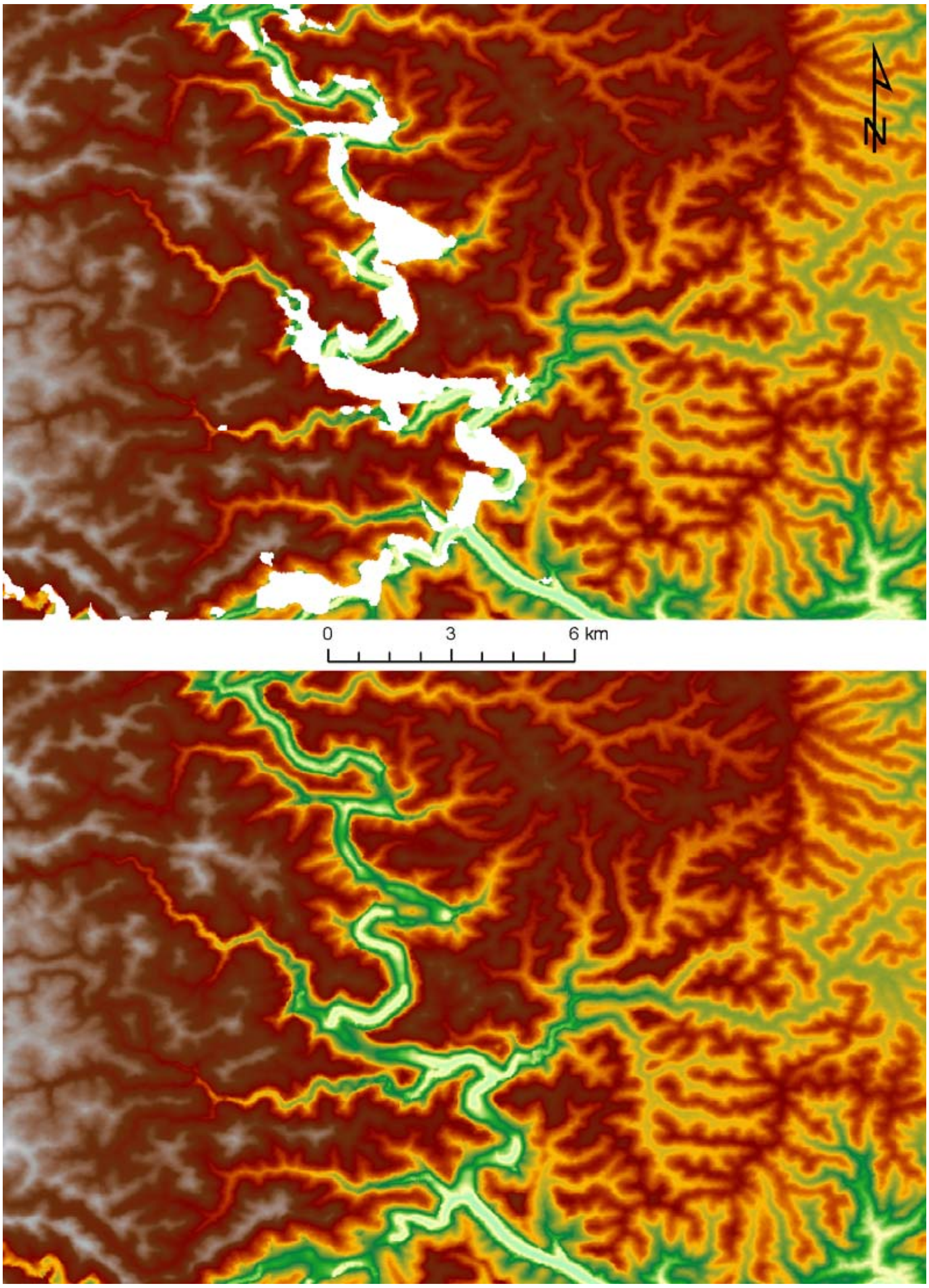


Figure 4. Void filling in canyon area, a fairly good result although canyon bottom has not quite been captured properly. Colo River, Wollemi National Park, NSW, 150.6E 33.3S. Elevation range 0 – 800 m.

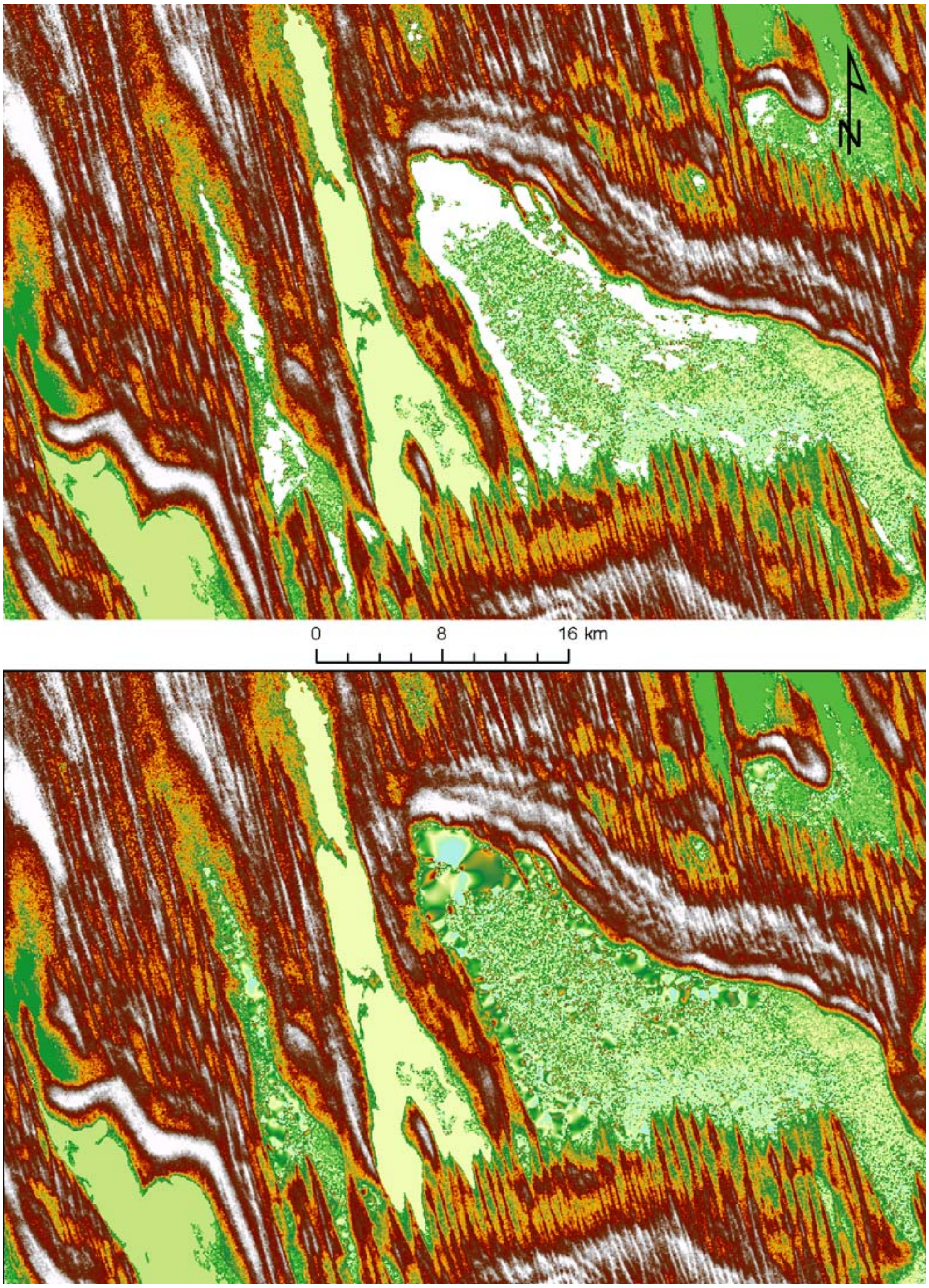


Figure 5. Voids filled in a lake bed; the elevations replacing the void are variable due to the noisy data around the edge of the void. Poolowanna Lake, Simpson Desert, SA, 137.6E 26.7S. Elevation range 20 - 70 m.

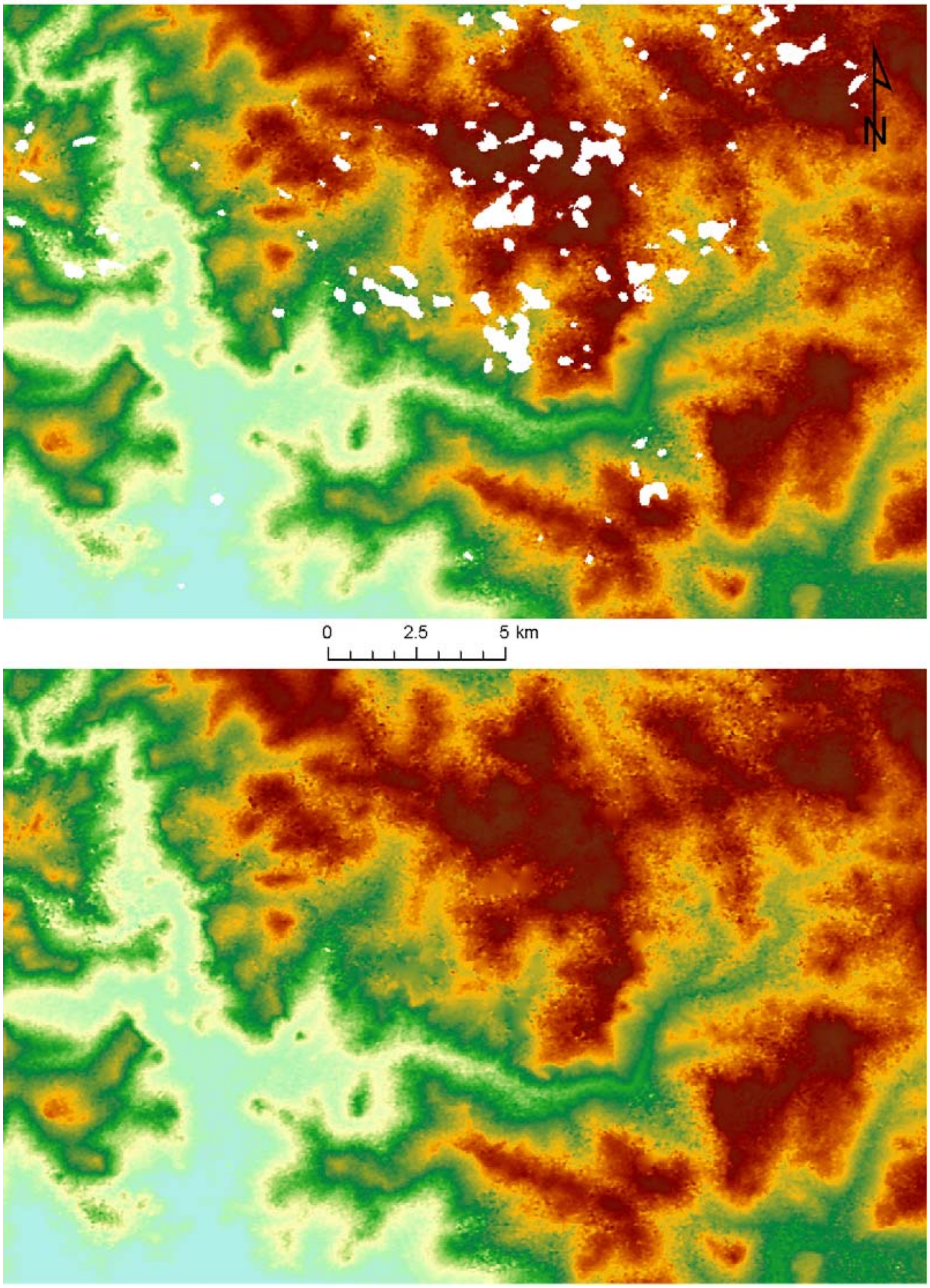


Figure 6. Voids that are probably due to low reflectivity in dry sandy soils. Coomallo Hill, WA, 115.4E 30.2S. Elevation range 100 – 400 m.

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 significant 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.

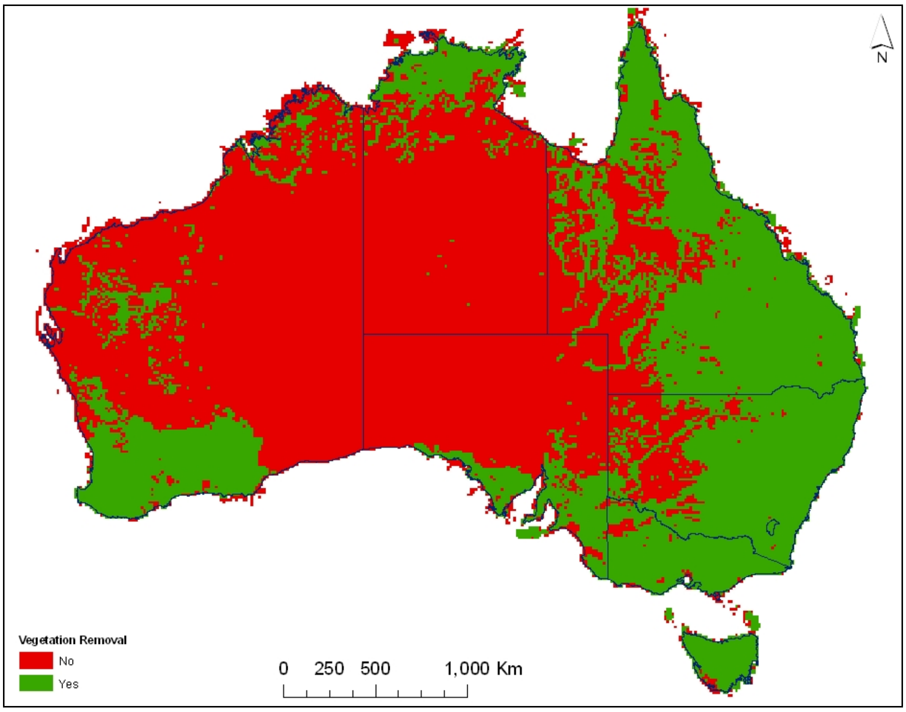


Figure 7. Distribution of vegetation removal in the SRTM.

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.

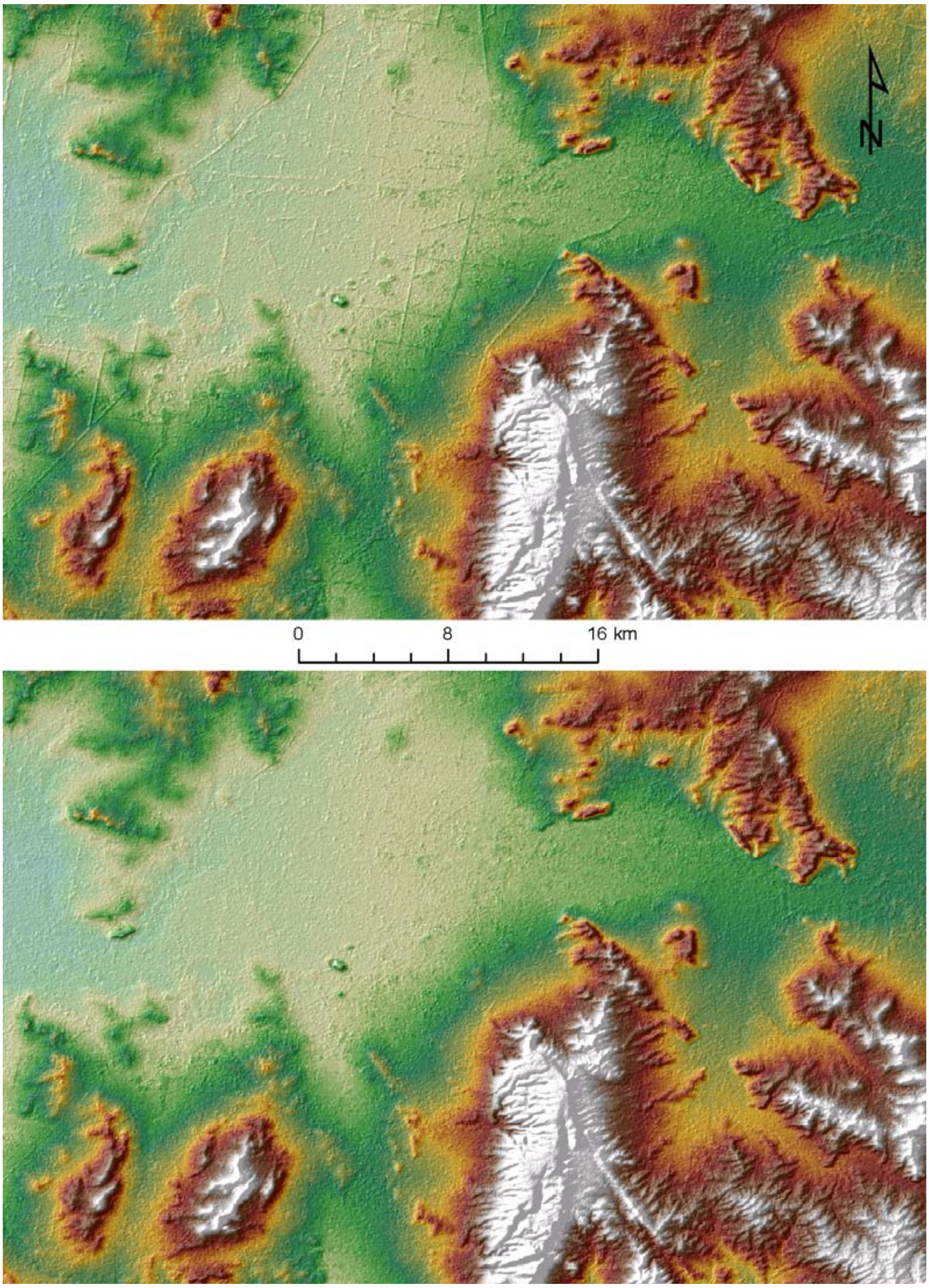


Figure 8. An example of effective removal of vegetation offset. Culcairn, NSW, 147.0E 35.7S. Elevation range 150 – 600 m.

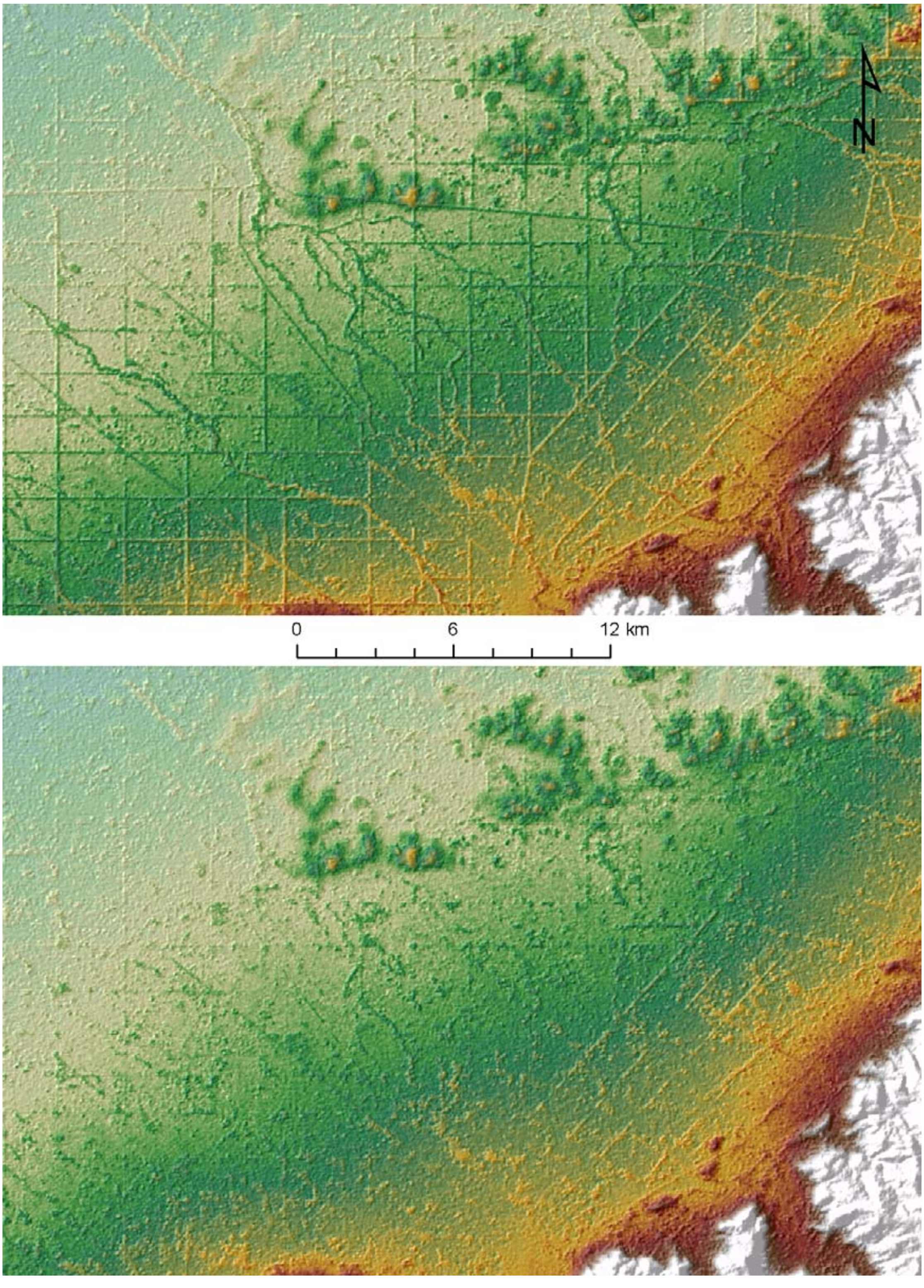


Figure 9. Poor vegetation removal - much improved but many vegetation features remain. Euroa, VIC, 145.5E 36.7S. Elevation range 120 – 240 m.

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 2-3 m but in some cases by as much as 10 m. In high relief areas where elevations change by many m 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, however 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 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 ±110 m, although the maximum change is less than ±50 m 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 0.2 m 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 m.

Figure 11 shows the profound impact of smoothing on a derived slope. This area of Western Australia has subtle relief and relatively high noise levels: the noise amplitude is 3-4 m in the noisier area and about 1 m 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.

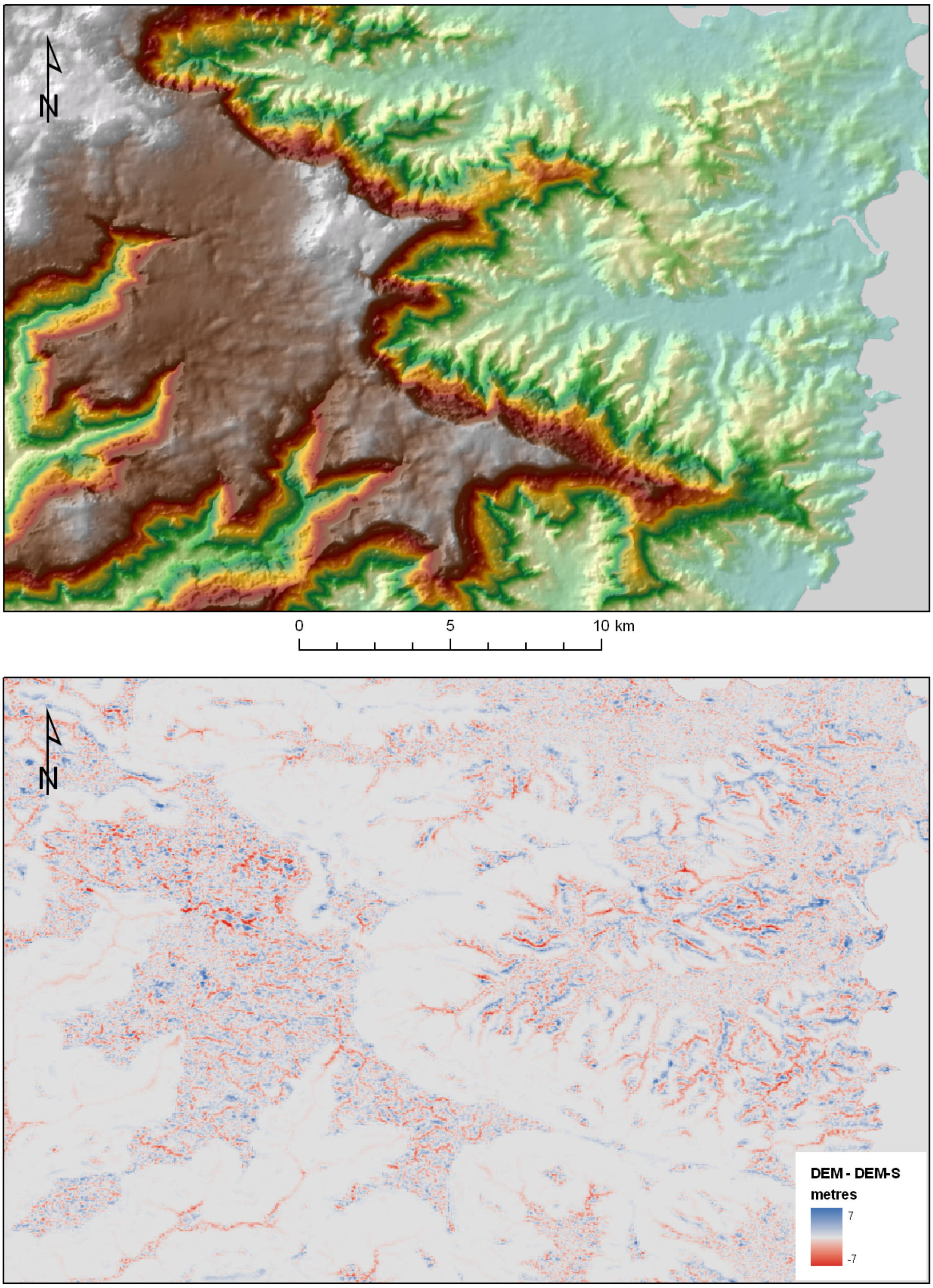


Figure 10. Smoothed DEM-S (top). The bottom image shows the difference between the DEM and smoothed DEM-S, with red showing areas that have been raised due to smoothing and blue those that have been lowered. The differences in the low-relief uplands and lowlands show random patterns of noise that have 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 0 – 750 m.

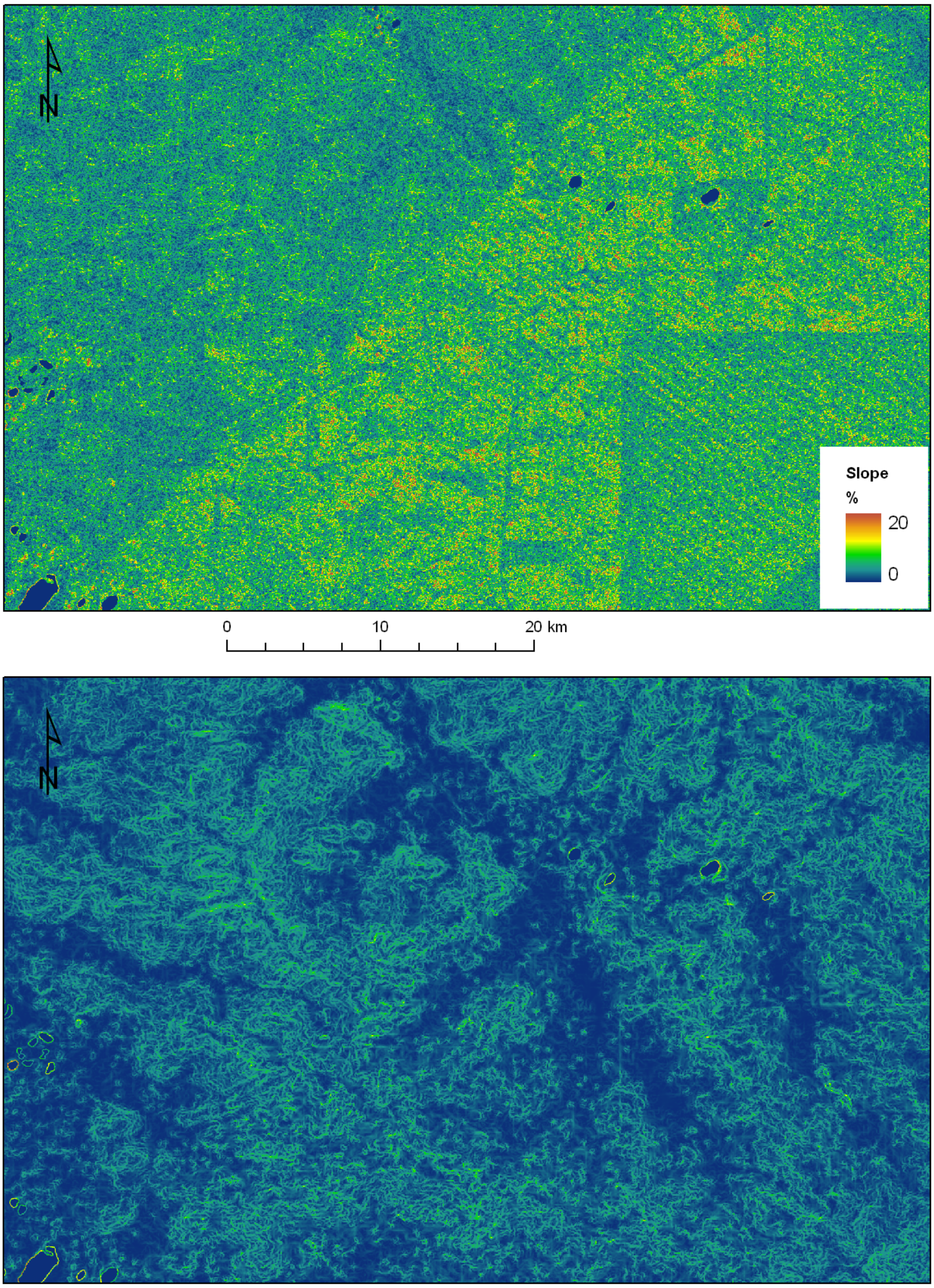


Figure 11. Slope before (top) and after smoothing (bottom); the slope colour scale is the same in both cases. The broad diagonal stripe of higher slopes is due to particularly high noise levels in that area, almost completely obscuring the topographic structure in the slope map. After smoothing, the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

Drainage Enforcement

The SRTM DEM does not represent channels except where they are quite large. This is partly due to the SRTM radar's inherent resolution of around 50 m (Farr *et al*, 2007) and partly due to the prevalence of trees on drainage lines in much of Australia that obscure, and effectively raise, the channel. Drainage enforcement using independently mapped stream lines is therefore required to produce a DEM that properly represents flow paths through the landscape.

The ANUDEM software (Hutchinson, 1988, 1989, 2009), version 5.2.5, dated 1 December 2010 was the result of significant revisions to the code during the project in order to work effectively on the SRTM data, as summarised in Hutchinson *et al* (2009). ANUDEM uses a discretised spline interpolation method that smooths the surface, while enforcing continuous descent along supplied drainage lines and removing spurious sinks where that is consistent with the accuracy of the source elevation data (DEM-S).

The 1:250,000 scale stream line data used to produce the GEODATA 9 second DEM Version 3 was chosen as the source of drainage line data as this data set was the only available source of mostly cleaned and correctly oriented drainage lines covering the entire continent. This 1:250,000 scale data, with a spatial accuracy of about 200 m, was significantly coarser than the 1 second DEM-S which is accurate to 50 m or better.

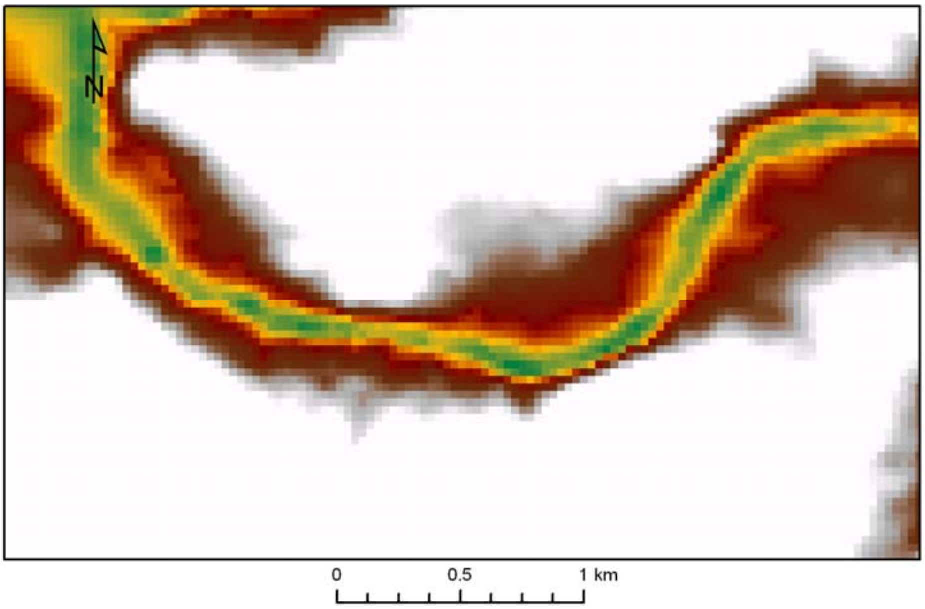
In low relief landscapes the spatial error of the 1:250,000 stream lines is not a significant problem, but in steeper areas the spatial offsets result in drainage lines being incised into hillslopes rather than valley floors. Apart from distorting the terrain surface, this results in errors in the stream network since the valley floor already present in the DEM-S remains and the enforced drainage line forms a parallel flow path. To prevent this, the mapped stream lines were used only where slope in DEM-S was less than 10 degrees. The excised segments were replaced with infilling stream lines derived from DEM-S using a version of the A^T search algorithm (Ehlschlaeger, 1989; known primarily as its implementation in GRASS as r.watershed) that constructs flow lines through depressions without first filling the depressions to the outlet level. Figure 12(a-e) illustrates this process.

The ANUDEM software cannot process the entire continent, or entire drainage basins, at the 1 second resolution in a single pass. Drainage enforcement was therefore performed separately for each 1x1 degree tile using ½ degree overlaps on each side. The resulting 2x2 degree tiles were trimmed to a 100 cell overlap, mosaicked with adjacent trimmed tiles then clipped to the 1x1 degree tile. The mosaicking with 100 cell overlaps was done to help ensure there are no elevation discontinuities at tile boundaries. However there are differences in smoothing on different tiles due to the automatic adjustment of smoothing parameters in ANUDEM.

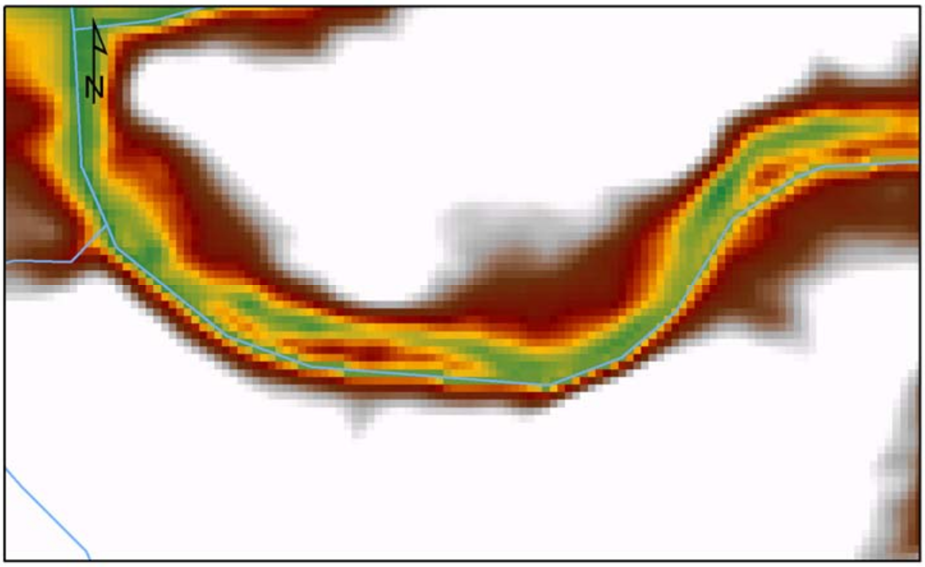
The mosaicking process does not guarantee the preservation of continuous descent along drainage lines so a final descent enforcement step was applied using the 'CheckStreamDescent' program written for that purpose. 'CheckStreamDescent' processes all tiles as a single data set so continuous descent of all stream lines to their termination points was ensured.

As a final step, the ocean areas were set to 'nodata'. Other water bodies have not been altered after drainage enforcement and most water bodies include a drainage line through them reflecting the connectors in the AusHydro data. Note that this is in contrast to the finishing of the DSM, DEM and DEM-S which all contain flattened water bodies and used the SRTM edit rules to ensure that land adjacent to water bodies is at a higher elevation than the water.

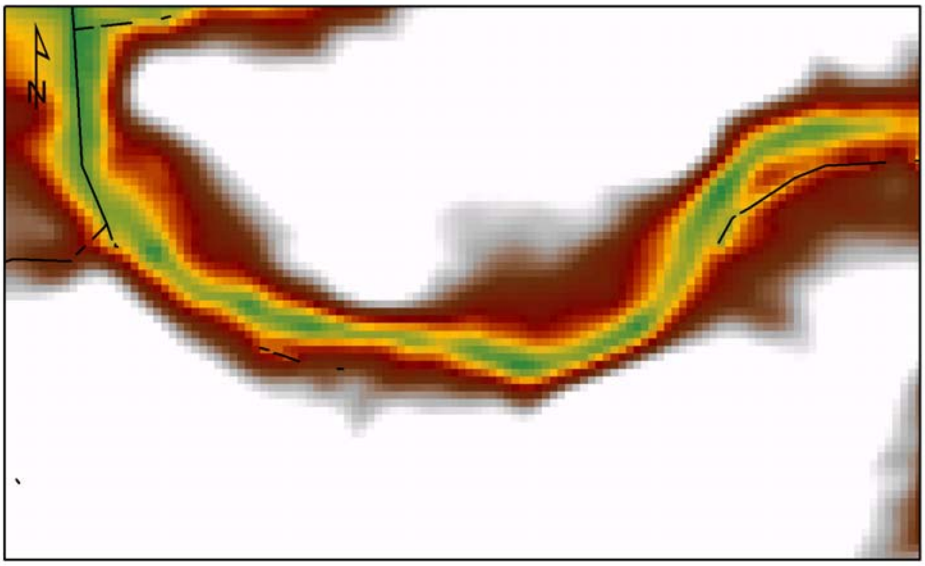
Examples of drainage enforcement in different environments are shown in Figures 12 – 15.



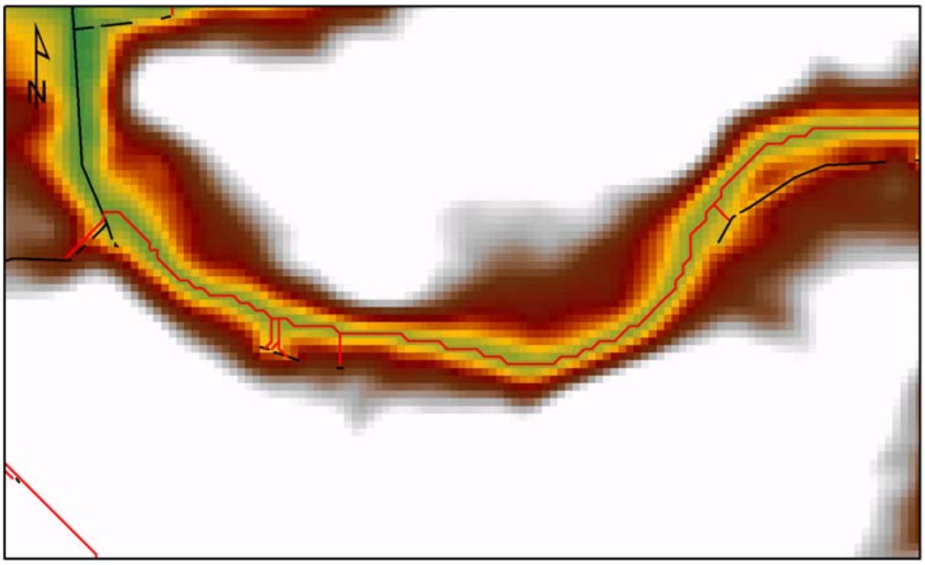
(a)



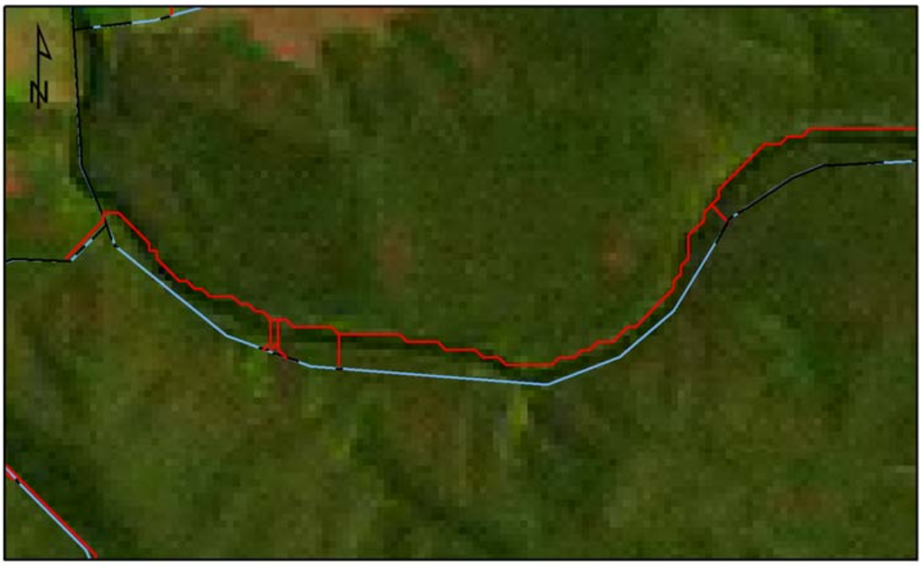
(b)



(c)



(d)



(e)

Figure 12. Illustration of the improvement from combining clipped AusHydro stream lines and infill lines for drainage enforcement in the Kiewa River below Dartmouth Dam, Victoria, 147.42E, 36.52S. Elevation range 250 – 350 m. (a) DEM-S with no drainage enforcement; the valley is clearly visible but consists of a series of depressions with lower (green) areas separated by higher (yellow) elevations. (b) Drainage enforcement using unmodified AusHydro stream lines (blue); note the duplication of drainage structure caused by spatial offsets of the mapped stream lines. (c) Drainage enforcement using AusHydro lines clipped to areas where slope is less than 10 degrees (black); note the incomplete drainage enforcement along the river. (d) DEM-H drainage enforced using both clipped AusHydro lines (black) and infill lines (red) derived from DEM-S; drainage enforcement is continuous along the river line. The clipped segments of AusHydro produce erroneous drainage enforcement in some areas but they do not create significant hydrological network problems because they are isolated. (e) The several versions of drainage lines superimposed on Landsat imagery showing the good agreement between the infill lines (red) derived from DEM-S and the true river channel.

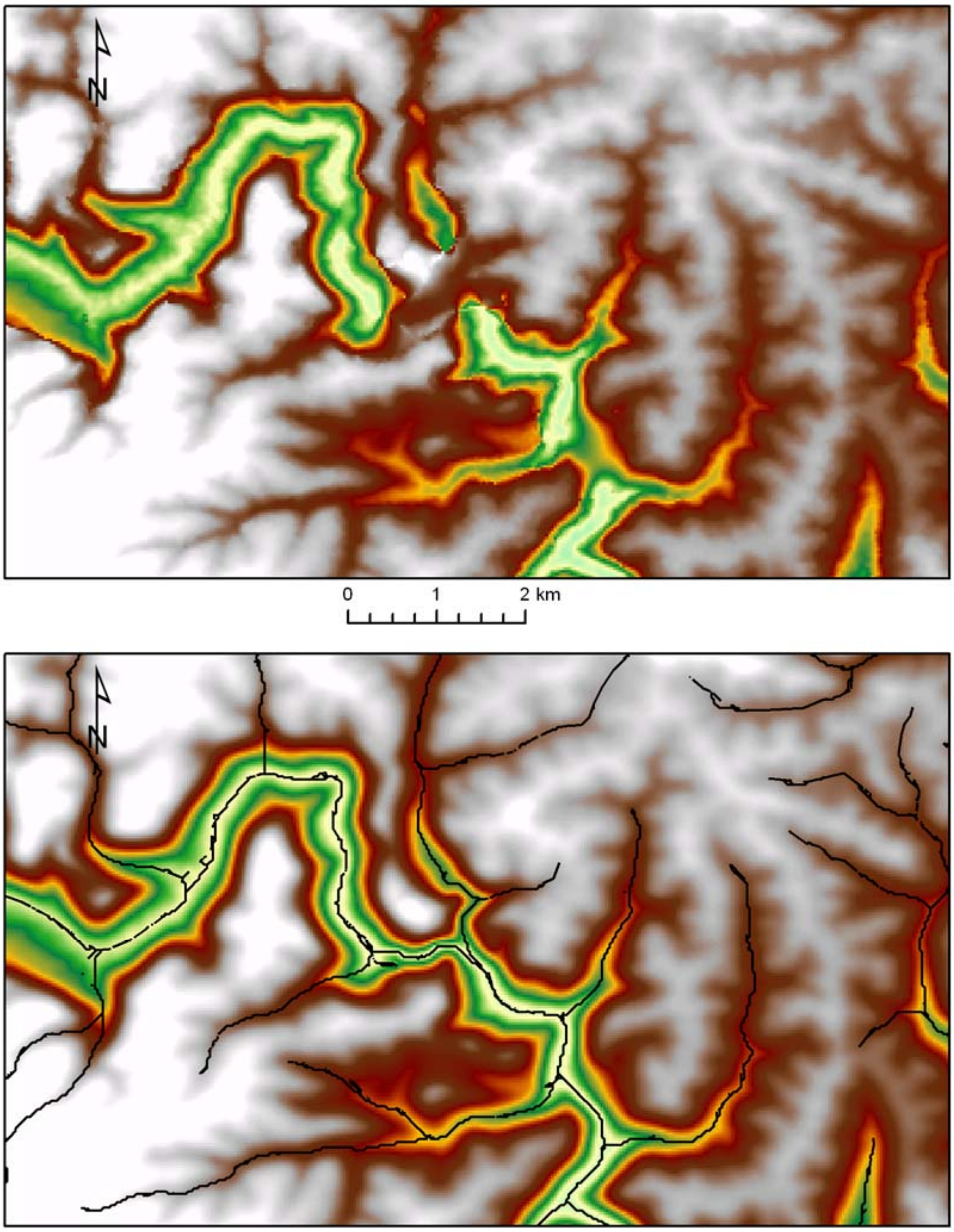


Figure 13. Drainage enforcement in a canyon area, Capertee River in Wollemi National Park, NSW, 150.43E, -33.16S. Elevation range 150 – 650 m. DEM-S (top) and DEM-H (bottom) with the stream lines used for the enforcement comprised of segments of AusHydro stream lines and infill lines derived from DEM-S.

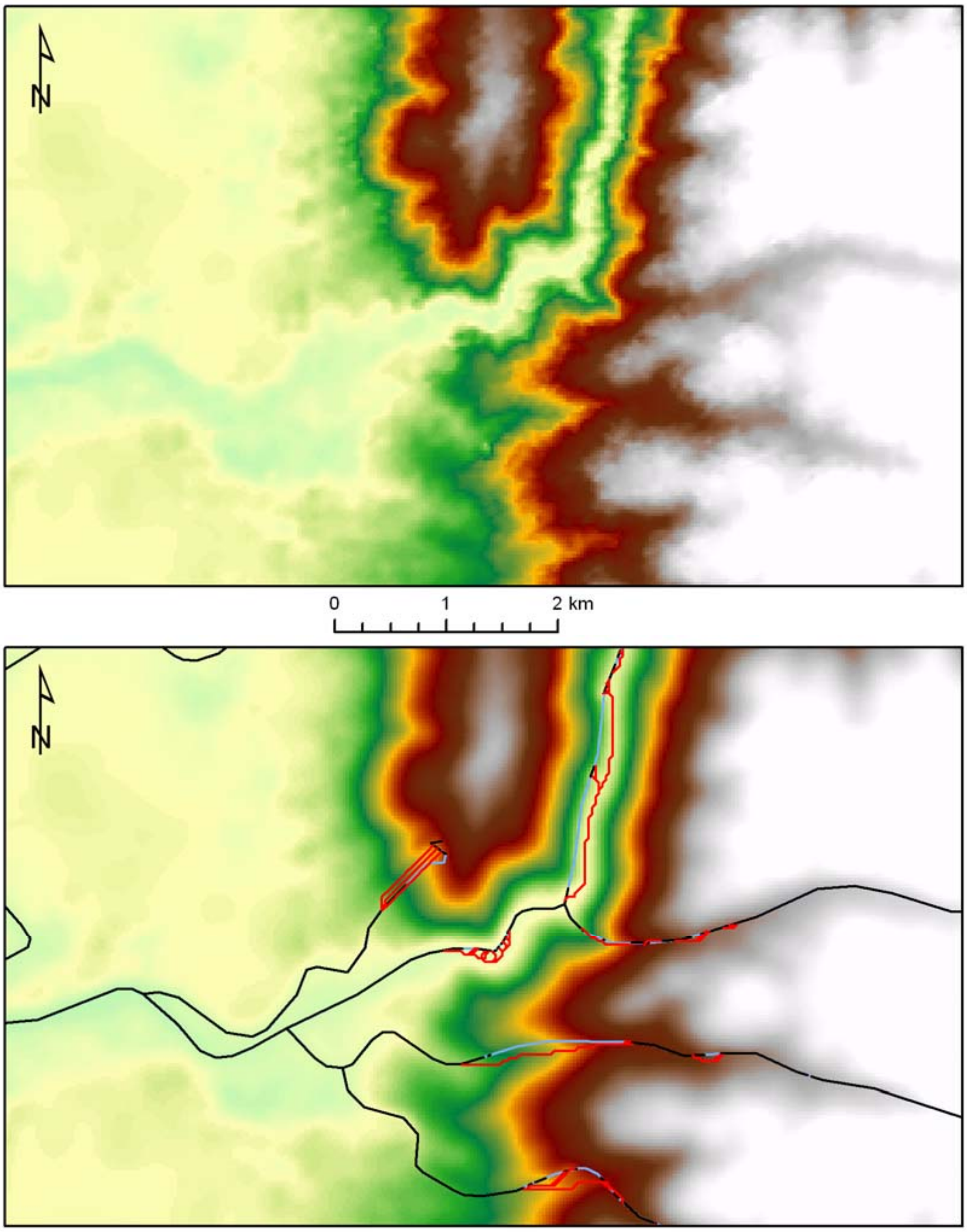


Figure 14. Drainage enforcement in high and low relief areas, Avon River at Mt Mambup on the north-eastern edge of Perth, WA, 116.05E, 31.77S. Elevation range 0 – 250 m. DEM-S (top) and DEM-H (bottom) with AusHydro stream lines (blue), clipped AusHydro lines (black) and infill lines (red) derived from DEM-S. Note that in the low relief areas the AusHydro lines are used unmodified while in higher relief areas they are replaced by the infill lines derived from DEM-S. While the AusHydro lines in low relief areas are still commonly misplaced by up to 200 m the spatial error does not cause significant hydrological anomalies.

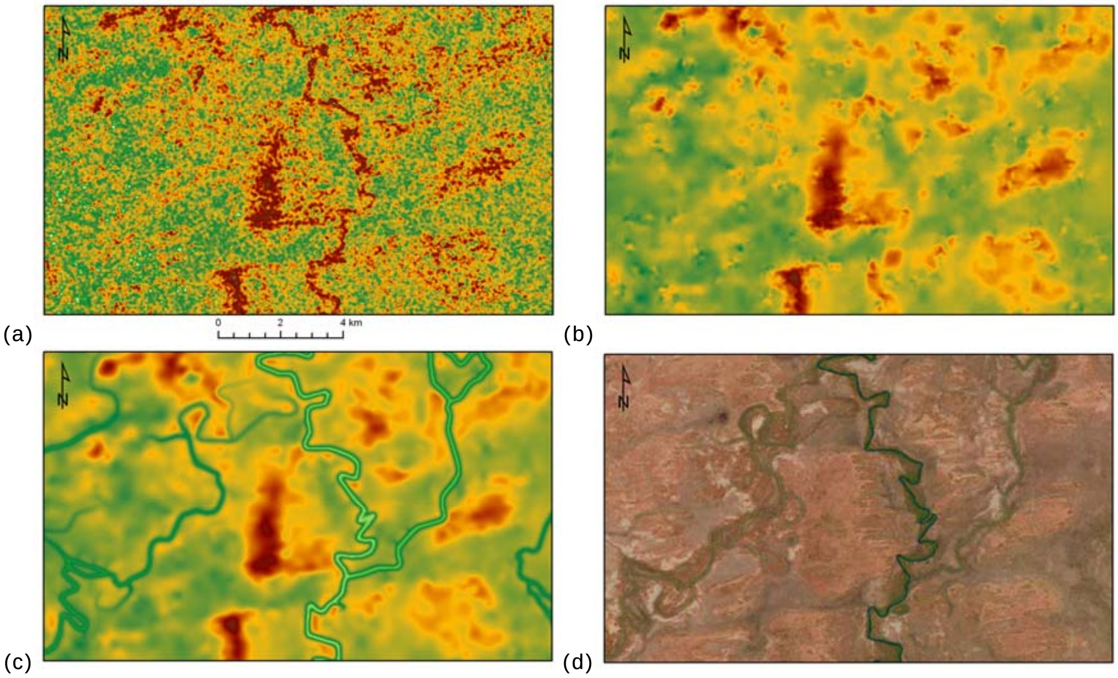


Figure 15. Drainage enforcement in a low relief floodplain, Darling River at Bono near Menindee, NSW, 142.38E, 32.57S. Elevation range 50 – 80 m. (a) Digital surface model (DSM) showing substantial noise and offsets due to trees along the river. (b) Smoothed DEM-S, which includes some elevation offsets along the river. (c) DEM-H showing enforcement of river channels through the floodplain and preservation of numerous shallow depressions (darker green areas) in the floodplain. (d) Landsat image.

Elevations near coasts and the water and ocean masks

The original SRTM elevation data was prepared using 'edit rules', which specified (amongst other things) that land areas adjacent to water bodies are at least 1 m above the water level; note that the original SRTM data was in integer form so the 1 m increment was the smallest possible. Any land elevations that were equal to or lower than the adjacent water elevations were raised to 1 m above the water elevation. Land cells immediately adjacent to the coast were therefore at least 1 m in elevation, although cells further inland can have lower elevations.

The modifications to the SRTM elevations to remove stripes, remove offsets due to trees, reduce noise and enforce drainage have induced changes to elevations that may result in lower elevations, raising the possibility of logically inconsistent land elevations lower than the adjacent water elevations. The DSM and DEM have had a modified version of the edit rules applied to ensure that land areas adjacent to coast are at least 0.01 m. Note again that the edit rules only apply to cells *immediately* adjacent to the coast, so cells further inland can have negative elevations. In some cases this is due to over-estimation of vegetation heights, in other cases it is due to the original SRTM data.

The edit rules were not applied after the adaptive smoothing to produce DEM-S so there are some areas where land elevations adjacent to water bodies (including the ocean) are lower than the adjacent water elevations.

In DEM-H, ocean areas have been set to 'NODATA', water bodies have not been re-flattened and the edit rules have not been applied to avoid corrupting the hydrological enforcement. As a result, there are some areas immediately adjacent to the coast with elevations below zero.

The ocean and water masks should be used to determine whether any cell belongs to the land or a water body, rather than relying on elevation values above or below zero. The ocean mask is 1 for ocean cells and NODATA for all other cells. The water mask is 1 for all water bodies (including the ocean) and NODATA for land cells. These masks have been derived from the SRTM Water Body Data (SWBD), which identifies water bodies as ocean, lake or river with relatively arbitrary boundaries between river and ocean in estuaries. The ocean mask includes all water features in the SWBD that are connected to the ocean and have zero elevation.

Also note that there are some areas, particularly on the southern margin of the Gulf of Carpentaria, where there are water bodies with zero elevation (in the original SRTM data, and in DSM) near the coast but separated from the coast by a narrow strip of land, often covered by mangroves. These are typically areas subject to tidal inundation and should not be considered part of the ocean, and are not included in the ocean mask.

Figure 16 illustrates many of these effects.

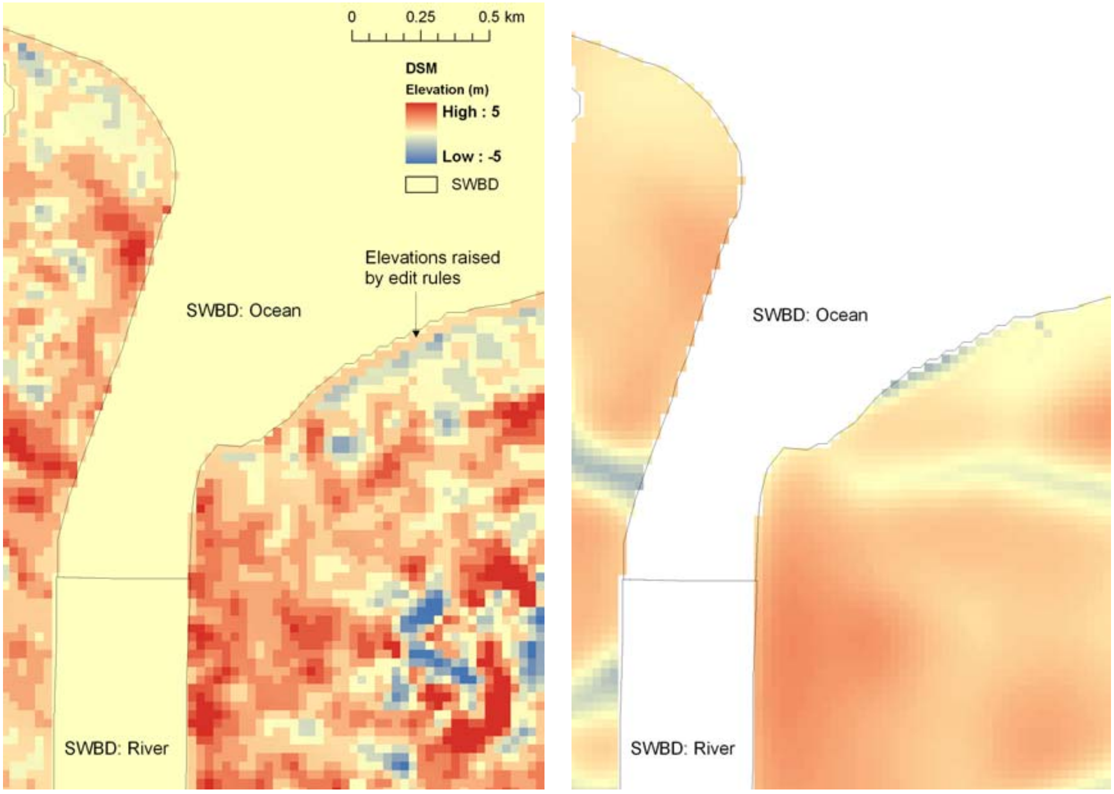


Figure 16. An estuary flowing into the Gulf of Carpentaria showing DSM on the left and DEM-H on the right. The effect of SRTM edit rules on original elevations adjacent to the coast is apparent in the DSM. The SRTM Water Body Data (SWBD) distinguishes between ocean and river in the absence of elevation changes but the ocean mask includes all water cells adjacent to the ocean with 0 m elevation (yellow), and these cells are set to NODATA (white) in DEM-H. Also note the elevations below zero (blue) in DEM-H adjacent to the ocean; the edit rules are not applied to DEM-H.

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 17 to 23). 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 GEODATA 9 second DEM.

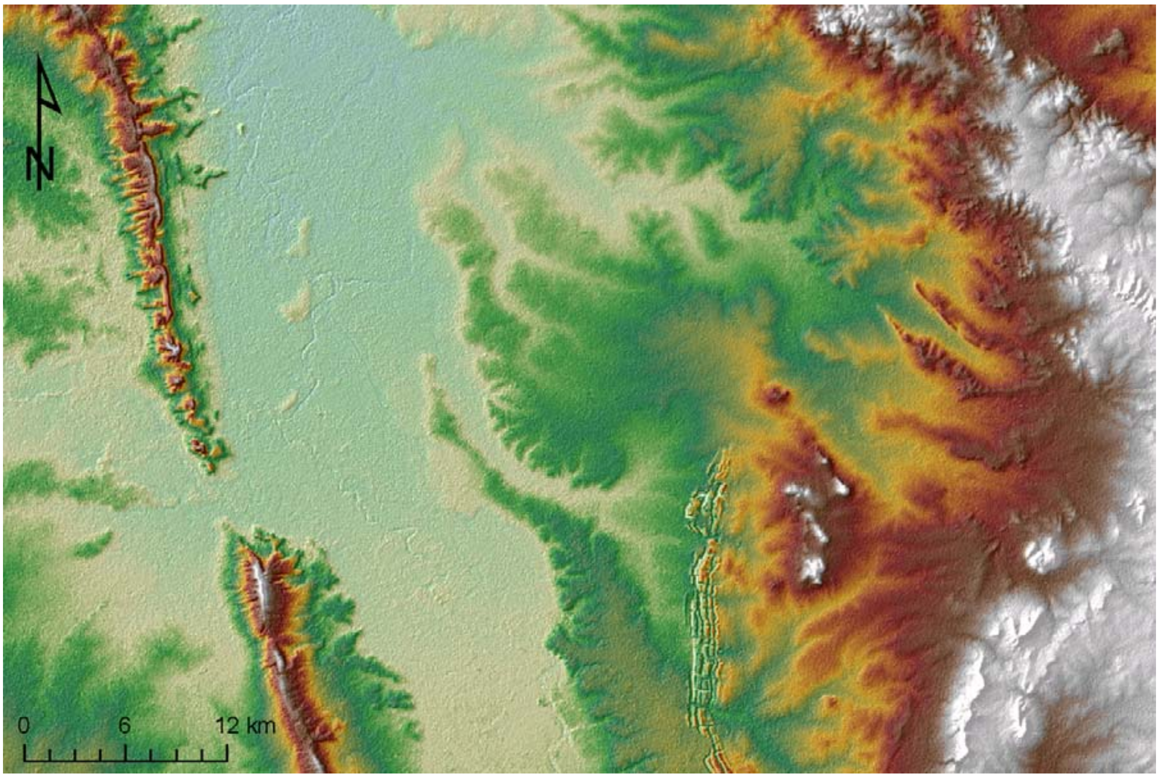


Figure 17. The linear features in the bottom centre are open cut coal mines. Moura, QLD 150.0E 24.5S. Elevation range 220 – 320 m.

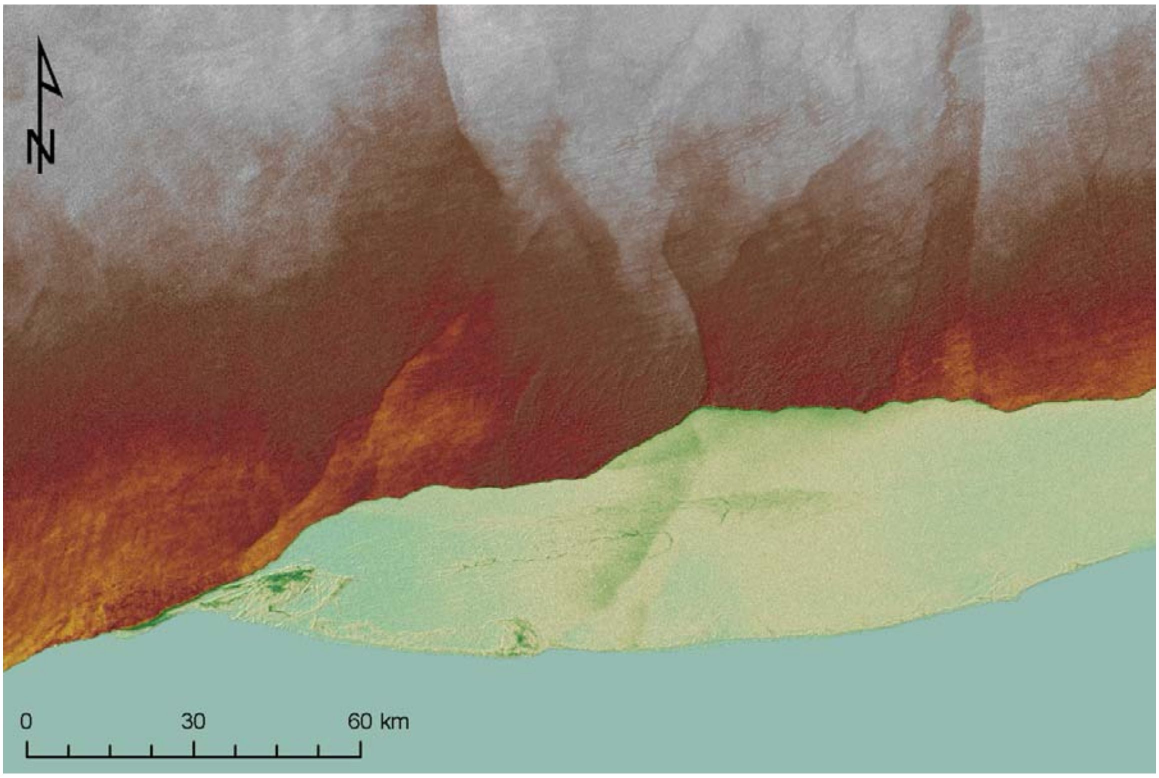


Figure 18. Escarpment at the southern edge of the Nullarbor Plain. Madura, WA 126.8E 31.9S. Elevation range 0 – 170 m.

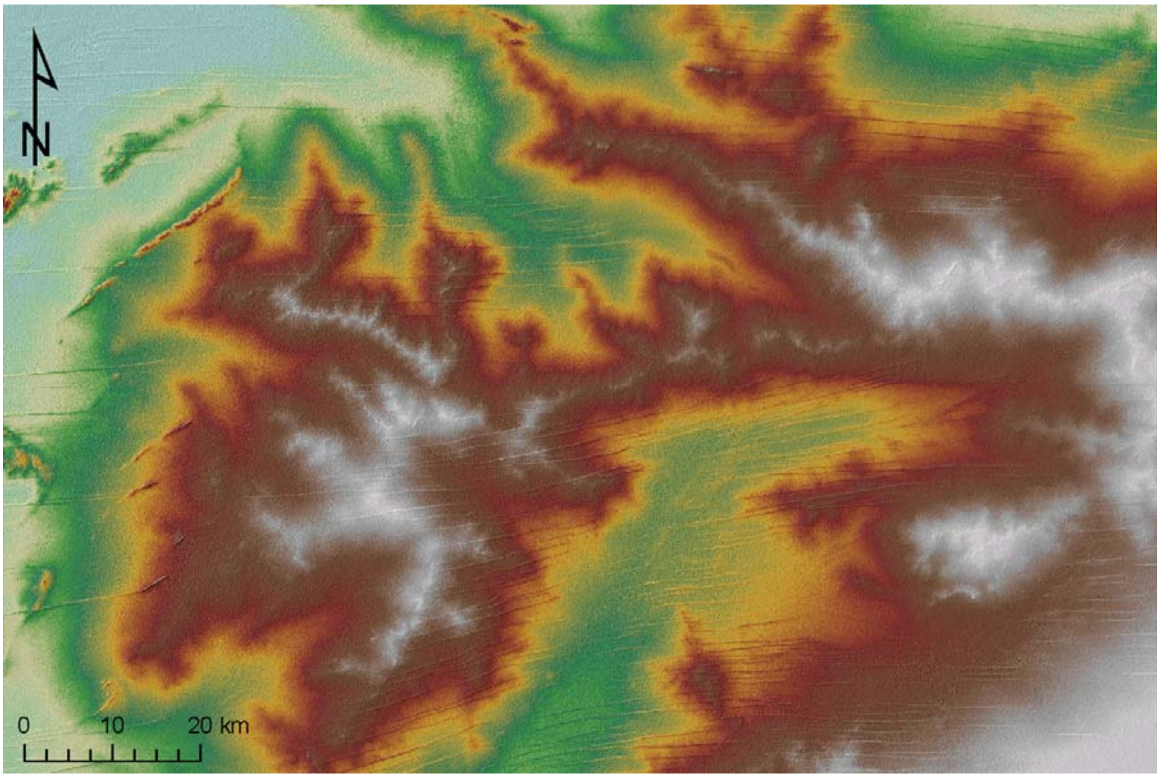


Figure 19. Wilbrunga Range, Tanami Desert, NT 129.5E 21.5S. Elevation range 350 – 480 m.

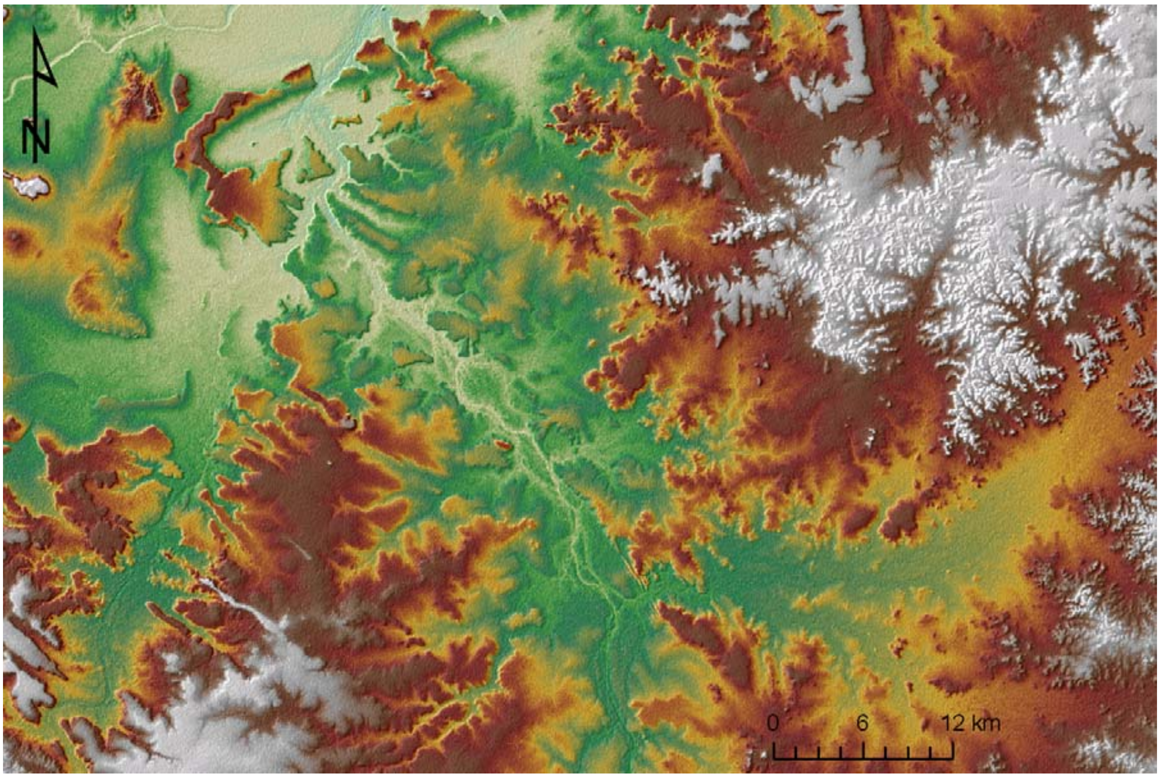


Figure 20. Victoria River, WA, 131.2E 16.6S. Elevation range 70 – 200 m.

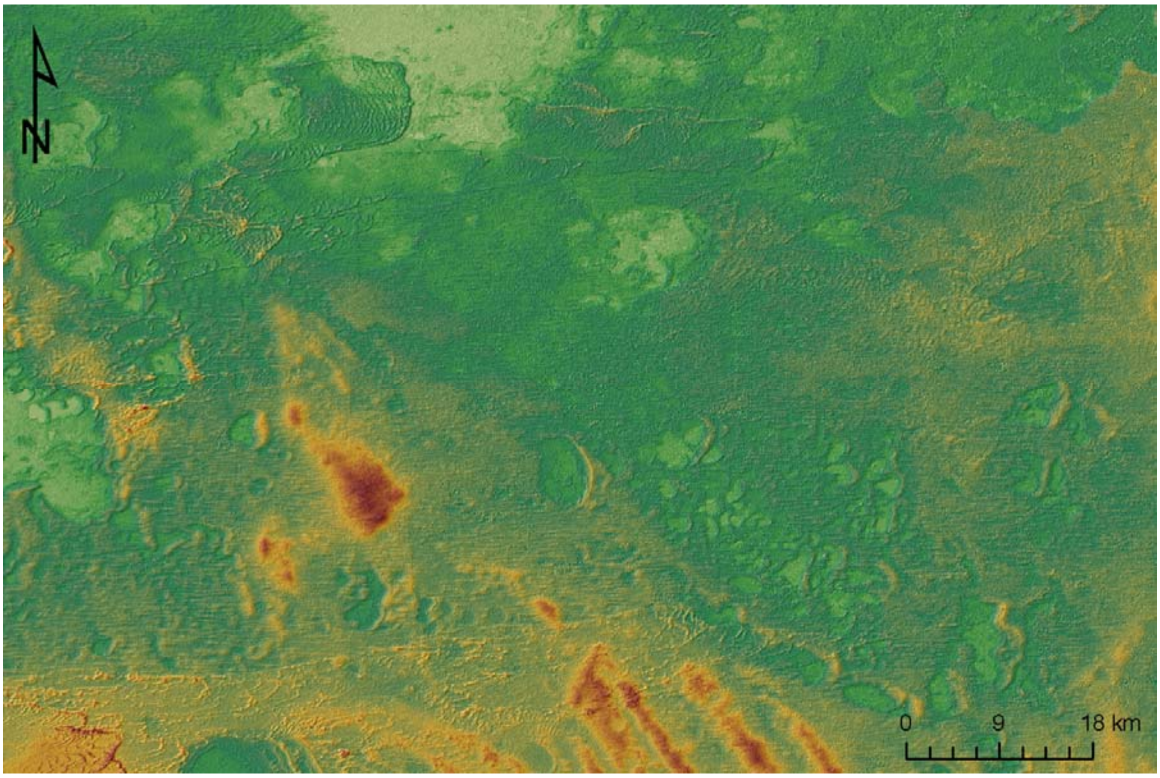


Figure 21. Ouyen, VIC, 142.2E 35.1S. Elevation range 30 – 120 m.

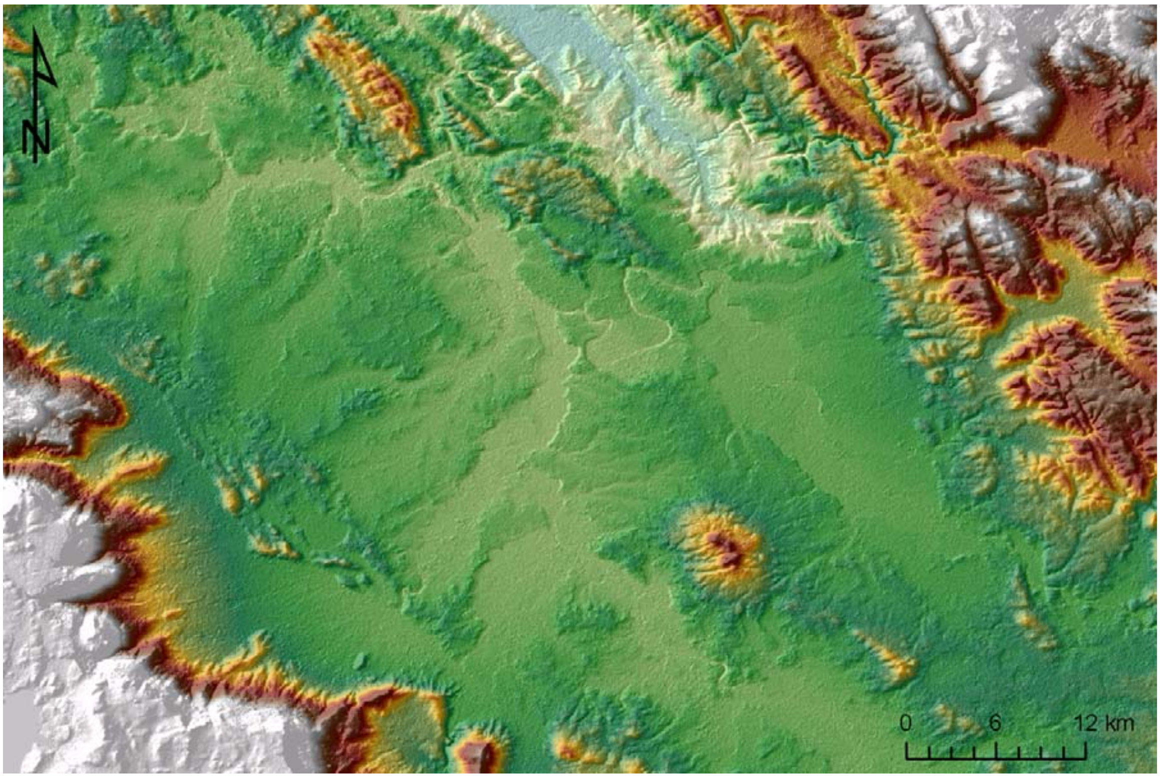


Figure 22. Longford, TAS, 147.2E 41.6S. Elevation range 0 – 700 m.

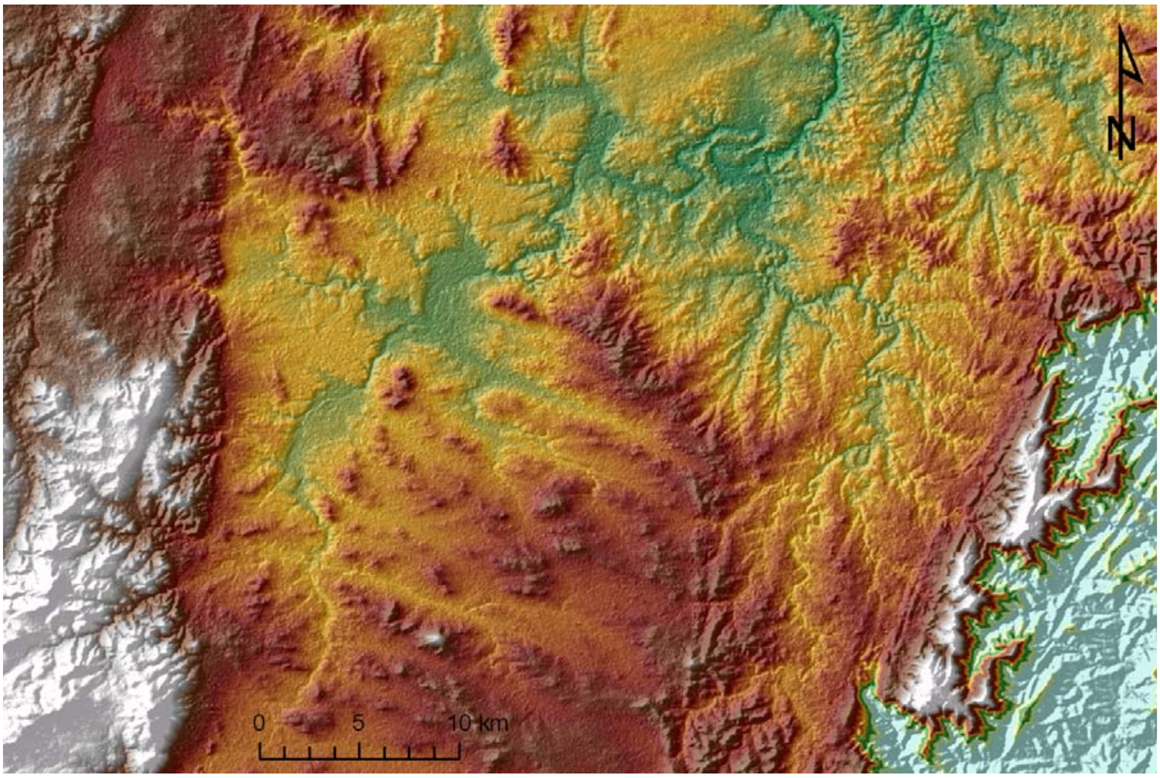


Figure 23. Braidwood, NSW, 149.8E 35.3S. Elevation range 400 – 900 m.

Known Issues

All DEMs are imperfect representations of the earth's 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 de-striping tool. An example is shown 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 24), there are gentle undulations similar to the stripes but with much longer wavelength - about 10 km, rather than the 800 m of the widespread stripes - and amplitude of up to 4 m. These have not yet been treated. Due to the very low gradient of the terrain in the Hay Plain, as low as 1 m per 10 kms, these stripes will impact surface shape and flow patterns at the 10 km scale.

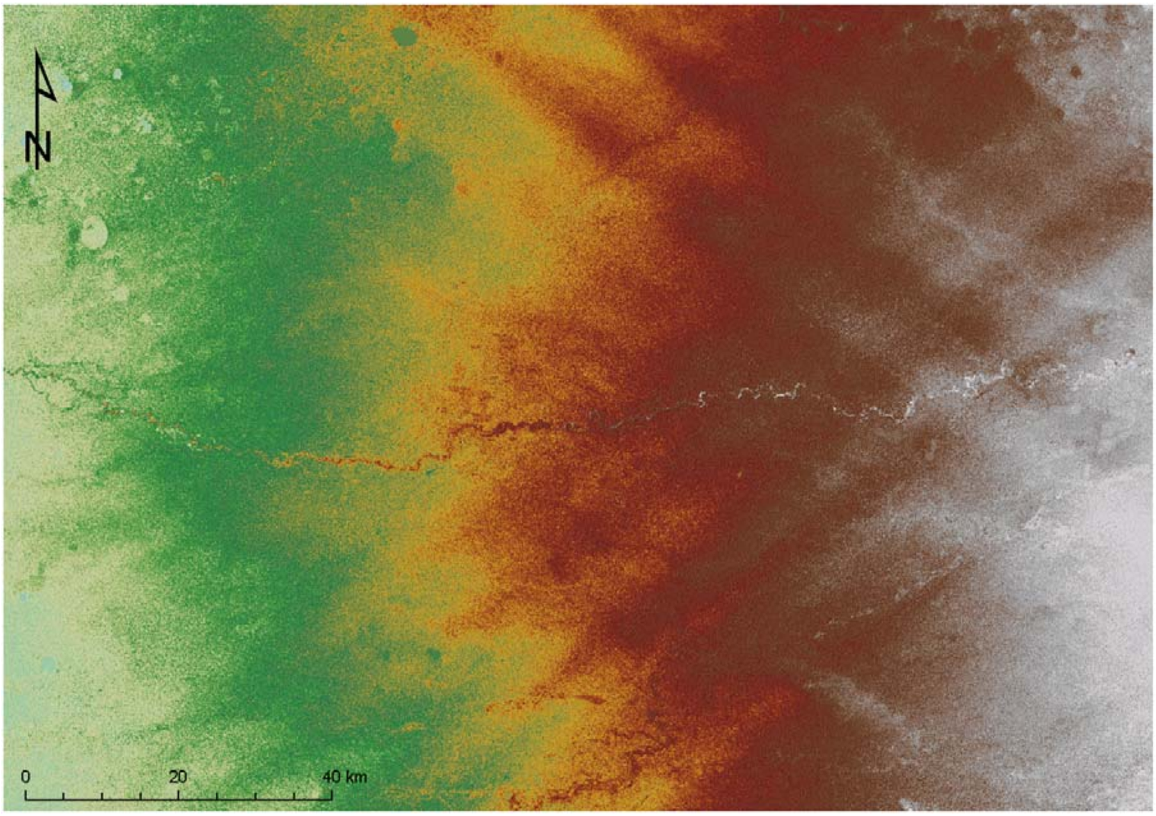


Figure 24. Broad striping in Hay Plain, NSW 144.8E 34.5S. Elevation range 70 – 110 m.

Steps

There are several places where there are steps in elevation along straight lines extending many kms. 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 7 m extends along a 30 km line (Figure 25). 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 1 km. 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.

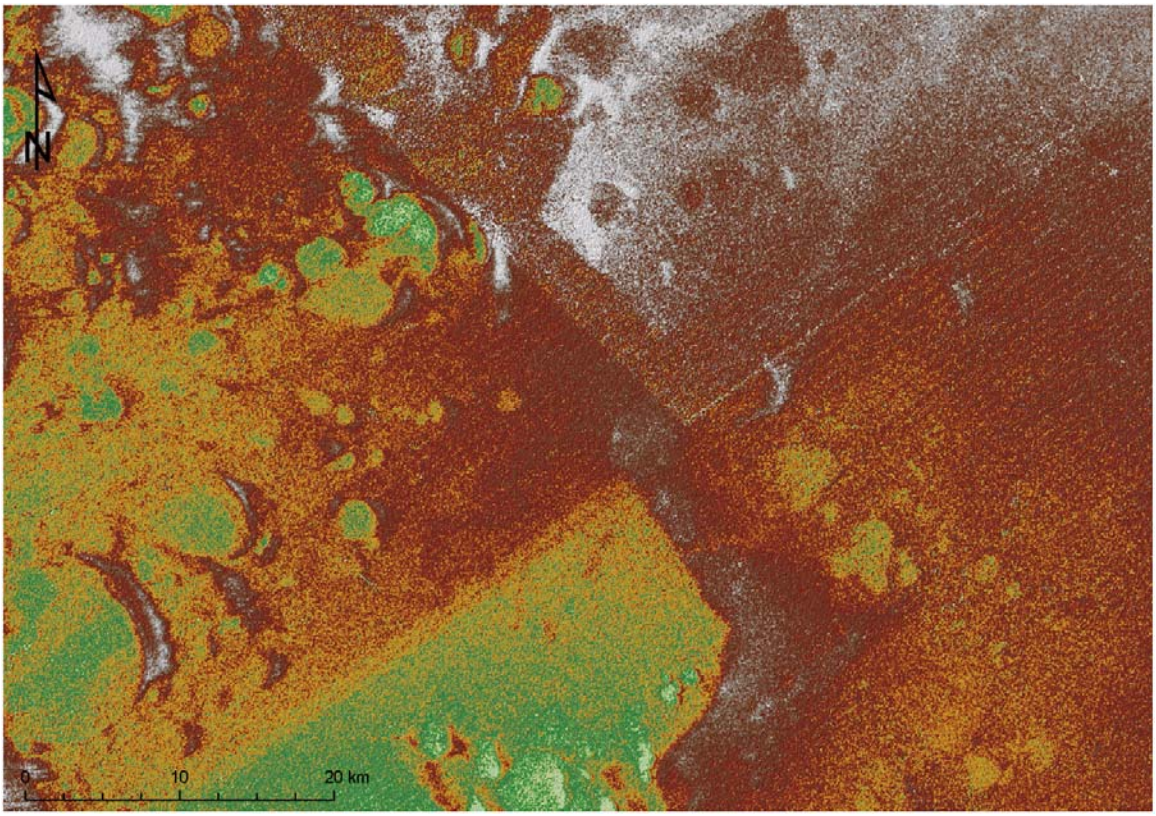


Figure 25. Step north of Balranald, NSW, 144.0E 33.8S. Elevation range 60 – 90 m.

Large offsets

One example of large offsets in elevation has been discovered, affecting the Grose Valley in the Blue Mountains of NSW (Figure 26). 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 they are about 200 m too high. No other errors approaching this magnitude have been detected.

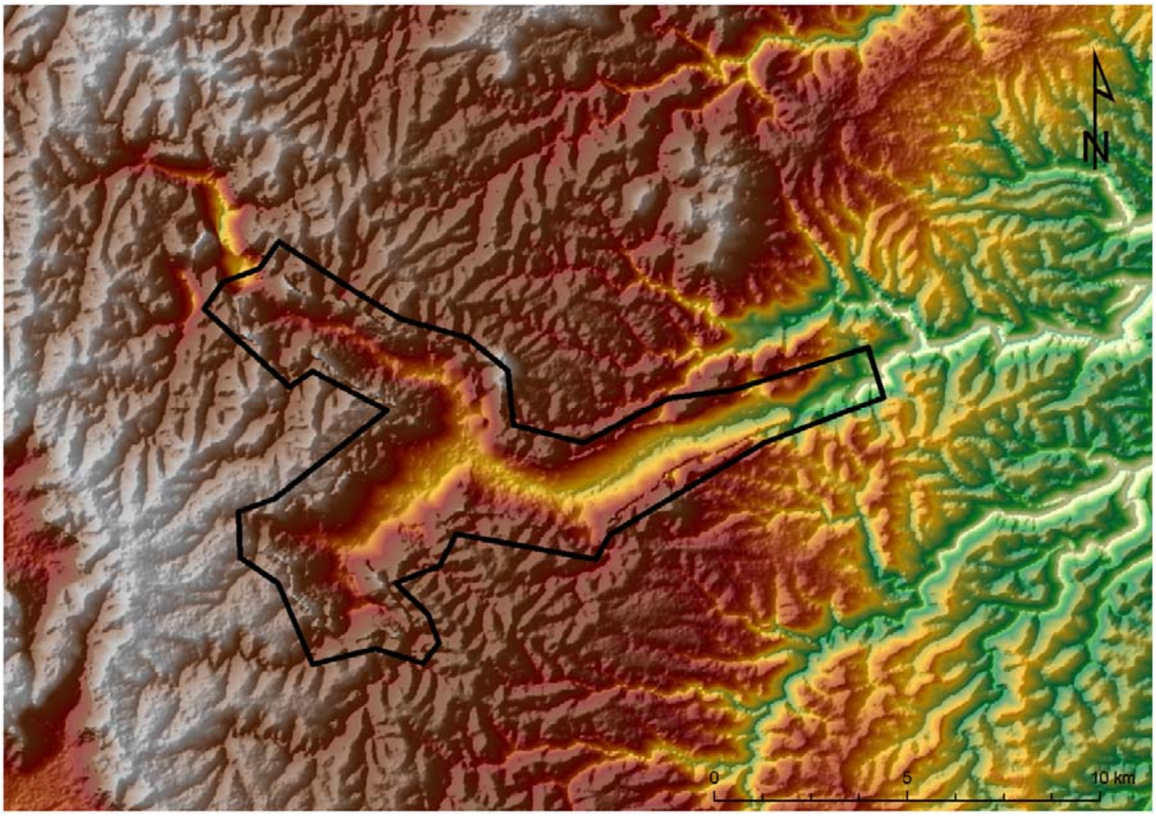


Figure 26. The black polygon encloses the affected area. Grose Valley, NSW, 150.345E 33.602S. Elevation range 100 – 1200 m.

Noise

The SRTM DSM is affected by intrinsic noise due to the nature of the radar acquisition and processing (Figure 27, also visible in many other images). The noise has no directional character, and has a short-range correlation over a distance of about 100 m, appearing as humps and hollows in flat areas. This noise typically has an amplitude of 2-3 m but can be much larger, up to about 10 m.

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 (DEM-S) has most of this noise removed.

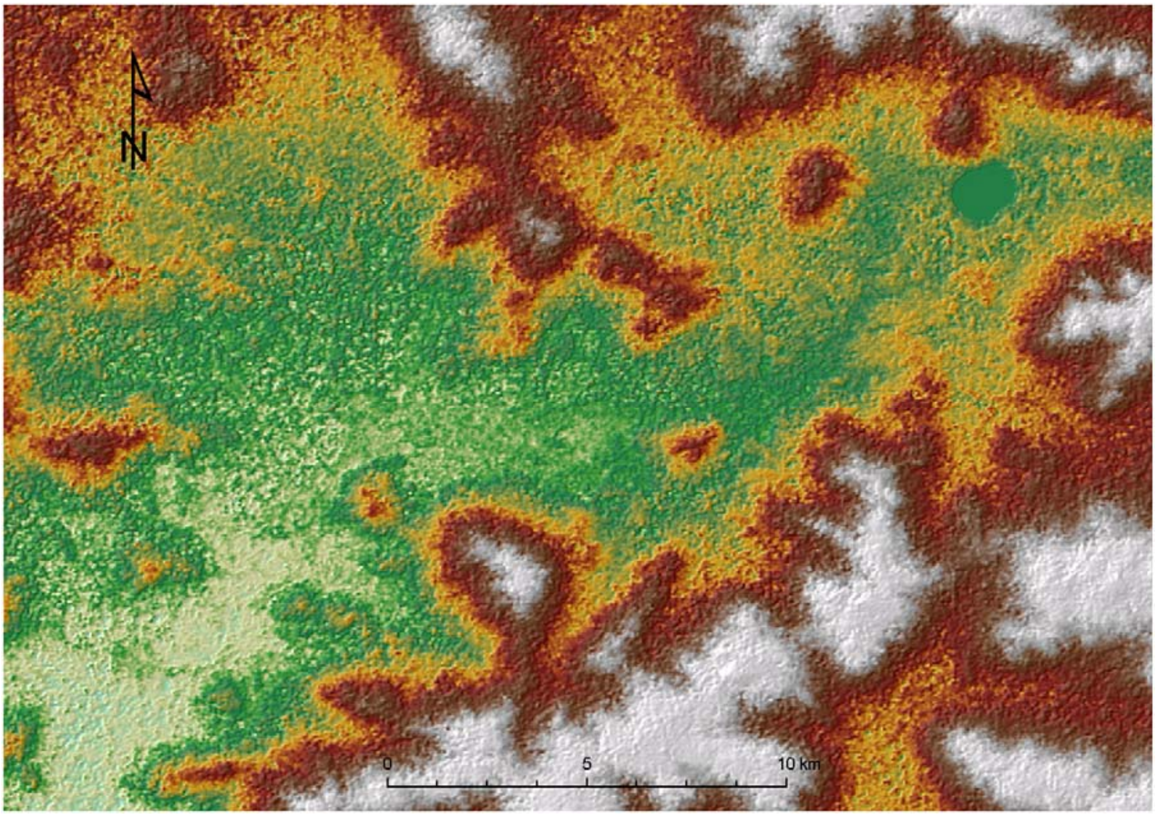


Figure 27. Typical noise in 1 second SRTM DEM - Arthur River near Narrogin, WA, 117.38E 33.05S. Elevation range 270 – 350 m.

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 28 shows a pine forest area in south-west 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.

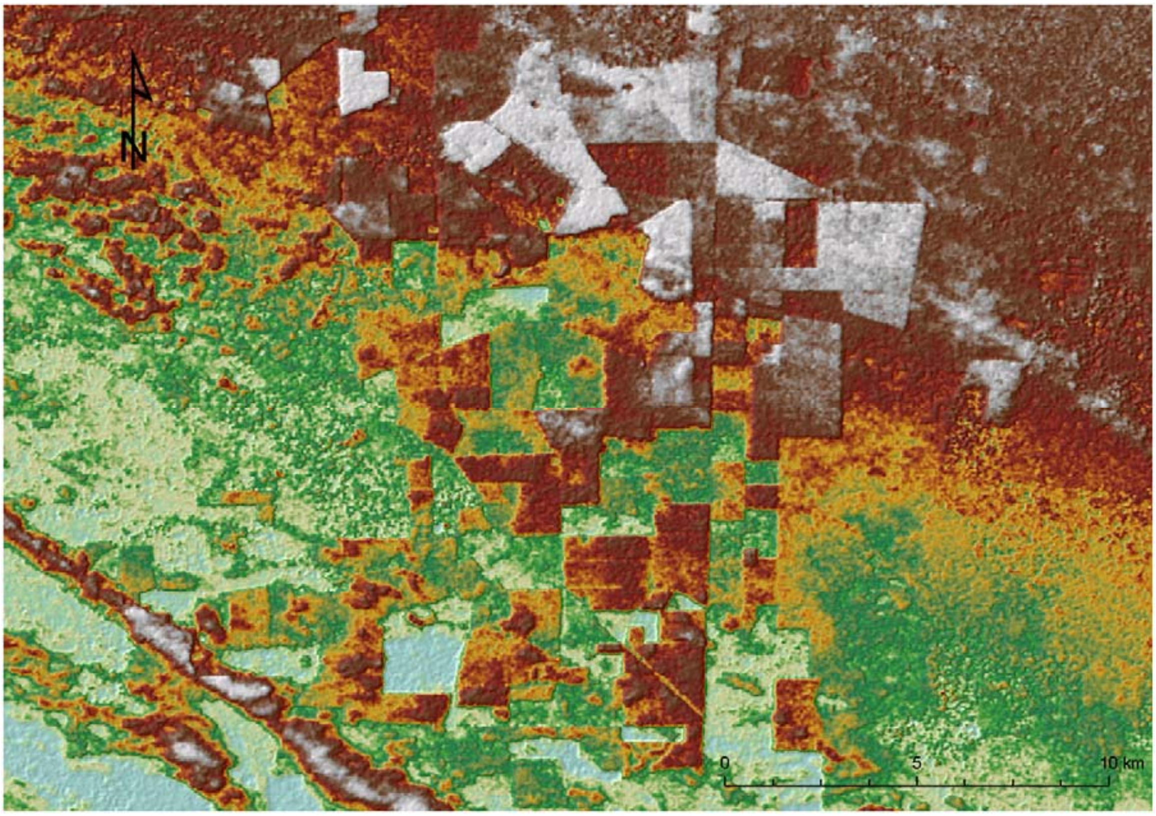


Figure 28. Pine forests in Victoria not completely removed, 140.959E 37.866S.
Elevation range 30 – 80 m.

Vegetation height over-estimated

In a small number of areas the offsets due to trees have been over-estimated. Figure 29 shows the lower end of the Glenelg River in south-western Victoria 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 non-vegetated 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 it 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.

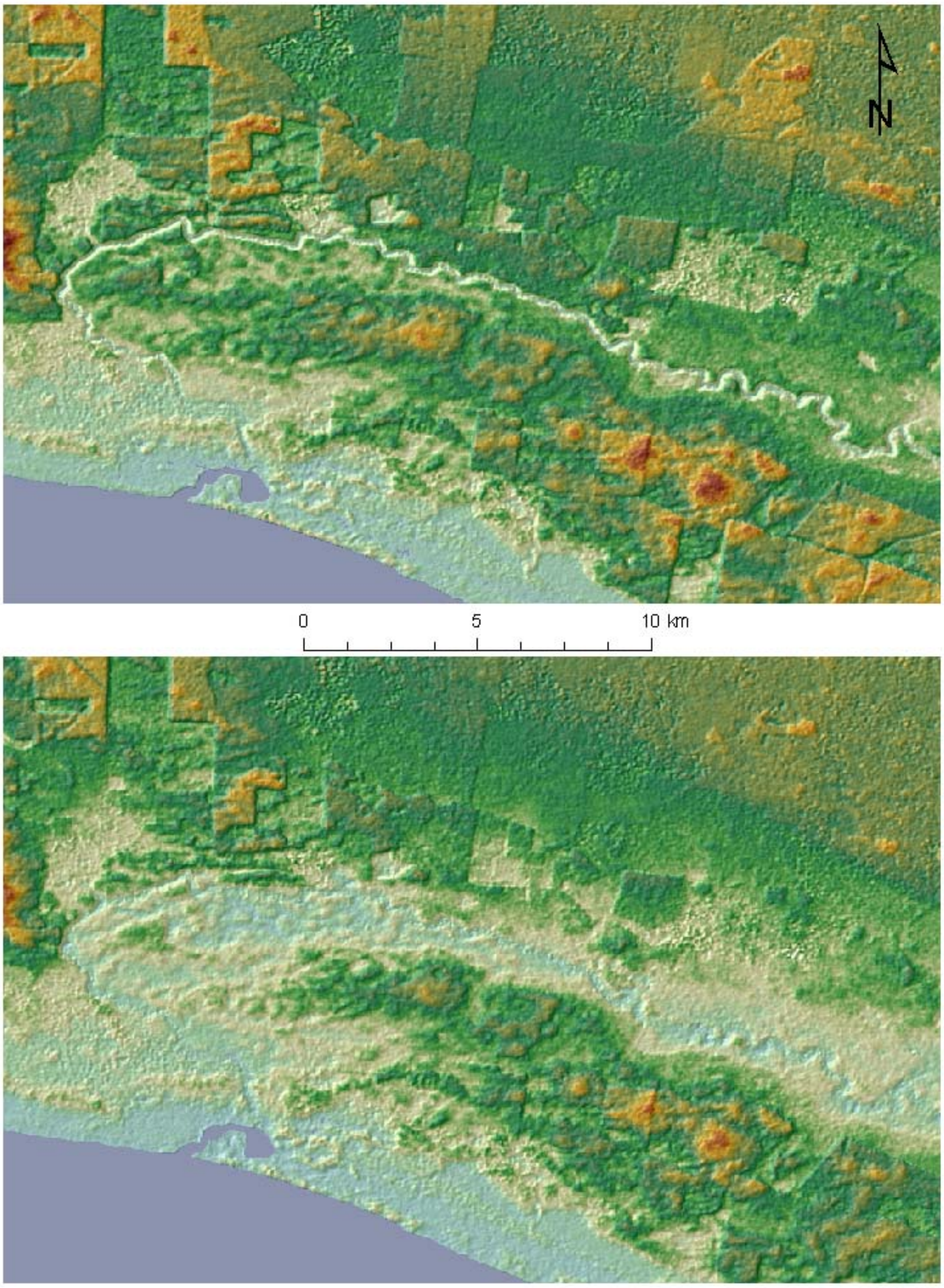


Figure 29. The outlet of the Glenelg River, Victoria, around 141.00E 38.00S (adjacent to the area of Figure 28). The gorge has almost disappeared because the cliffs have been mistakenly identified as vegetation offsets. Elevation range 0 – 150 m.

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, although the adaptive smoothing used to produce DEM-S has removed these features in some cases. The most visible examples are major city centres and power line towers; less dense urban areas are mostly free of such offsets (Figures 30 to 32).

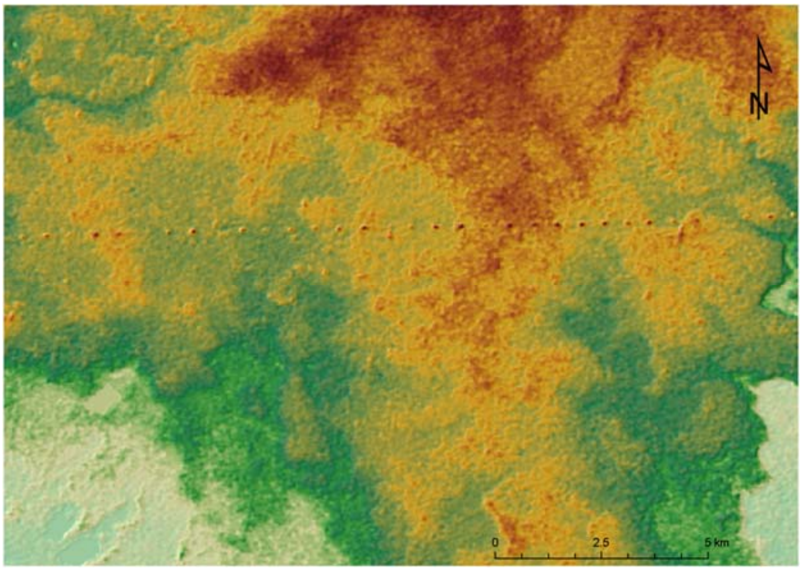


Figure 30. Power line transmission towers near Mortlake, western Victoria, appearing as bumps up to 20 m high. 142.92E 38.05S. Elevation range 120 – 200 m.

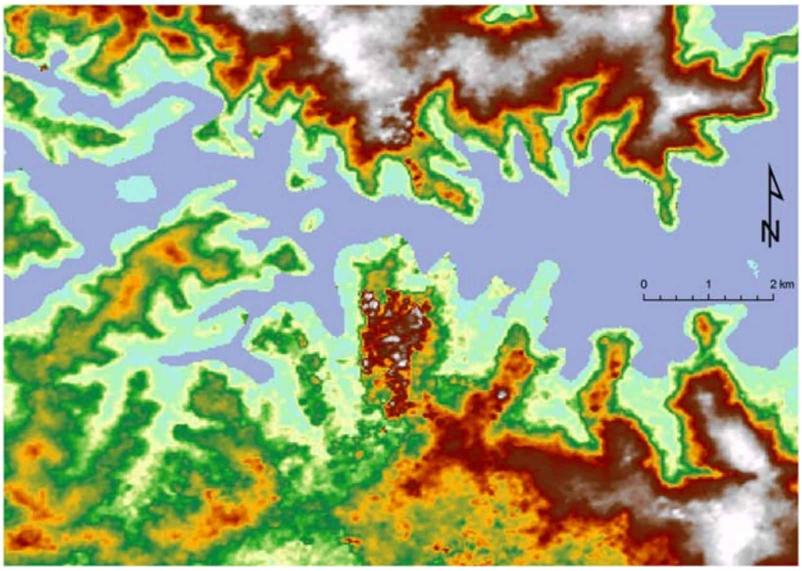


Figure 31. Central Sydney showing significant visible offsets of up to 30 m in the CBD area and isolated features elsewhere. 141.21E 33.87S. Elevation range 0 – 100 m.

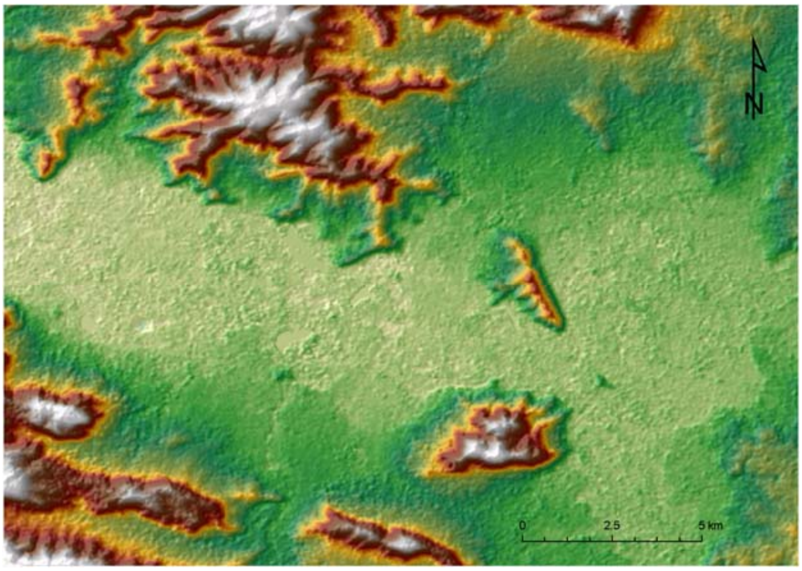


Figure 32. Albury-Wodonga area showing very few artefacts due to urban structures. 146.9E 36.1S. Elevation range 100 – 400 m.

Drainage Related Issues

A number of known defects have been introduced through the drainage enforcement process.

- Extraneous lines created by the stream line infill process (Figure 33)
- Errors in the AusHydro 1:250,000 stream lines (Figure 34)
- Excessive incision on steep slopes due to closely spaced infill streams (Figure 35)
- Substantial reductions (and in some cases increases) in surface elevations due to smoothing by ANUDEM in steep areas in otherwise low relief landscapes (Figure 36)
- Excessive incision downstream of open-cut mines (Figure 37)

Apart from the first two causes, the large and undesirable changes in elevation do not affect the hydrological connectivity of the landscape.

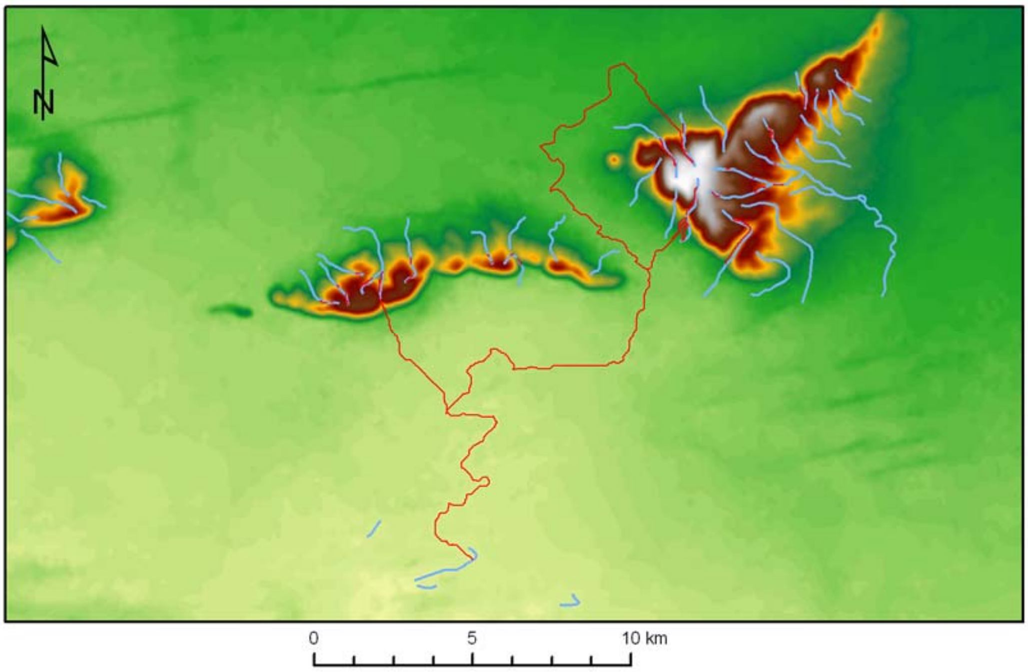


Figure 33. An extraneous infill stream line (red) created due to a defect in the line creation algorithm. The line results in the creation of a drainage feature in DEM-H that does not exist in the landscape except as a series of gradually descending depressions; note the absence of mapped AusHydro lines (blue) in the flat areas. The effect of this issue is small, since the drainage line is incised to a depth of only 1 – 2 m and follows the natural drainage direction of the landscape, but suggests the existence of a channel where none actually exists. Near Newhaven Station, NT, 131.25E 22.75S.
Elevation range 500 - 800 m

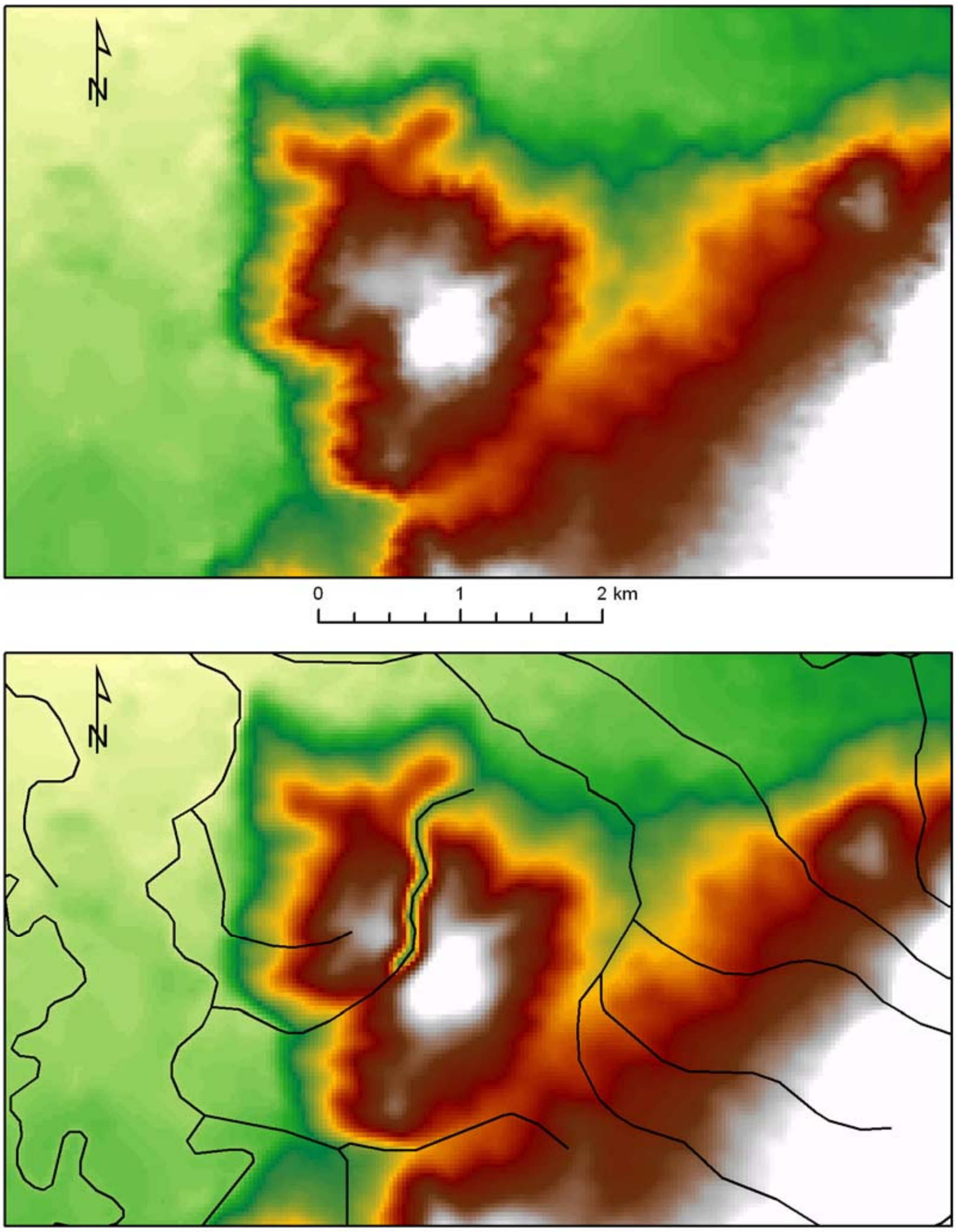


Figure 34. Error in AusHydro 1:250,000 stream line. DEM-S (top) and DEM-H (bottom) with unmodified AusHydro stream lines. The incorrect stream line has been cut by the 10 degree slope threshold near the top of the hill, preventing it from gouging all the way through the hill.
Near Tumut, NSW, 148.29E, 35.34S. Elevation range 250 – 400 m.

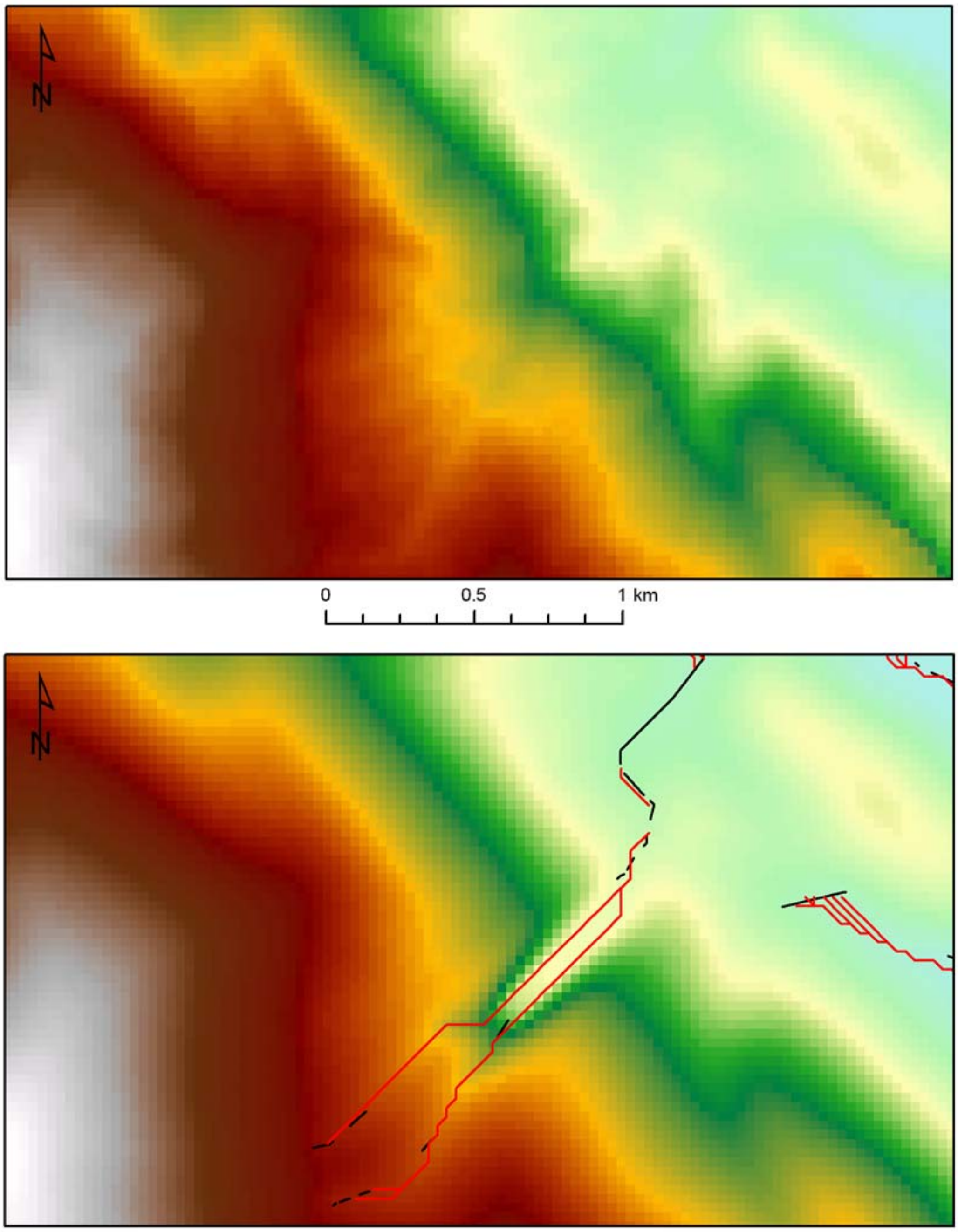


Figure 35. Excessive incision due to closely spaced infill streams, Mt Elliot near Townsville, Qld, 146.99E, 19.48S. Elevation range 100 – 1100 m. Black lines are clipped AusHydro stream lines and red lines are infill stream lines derived from DEM-S.

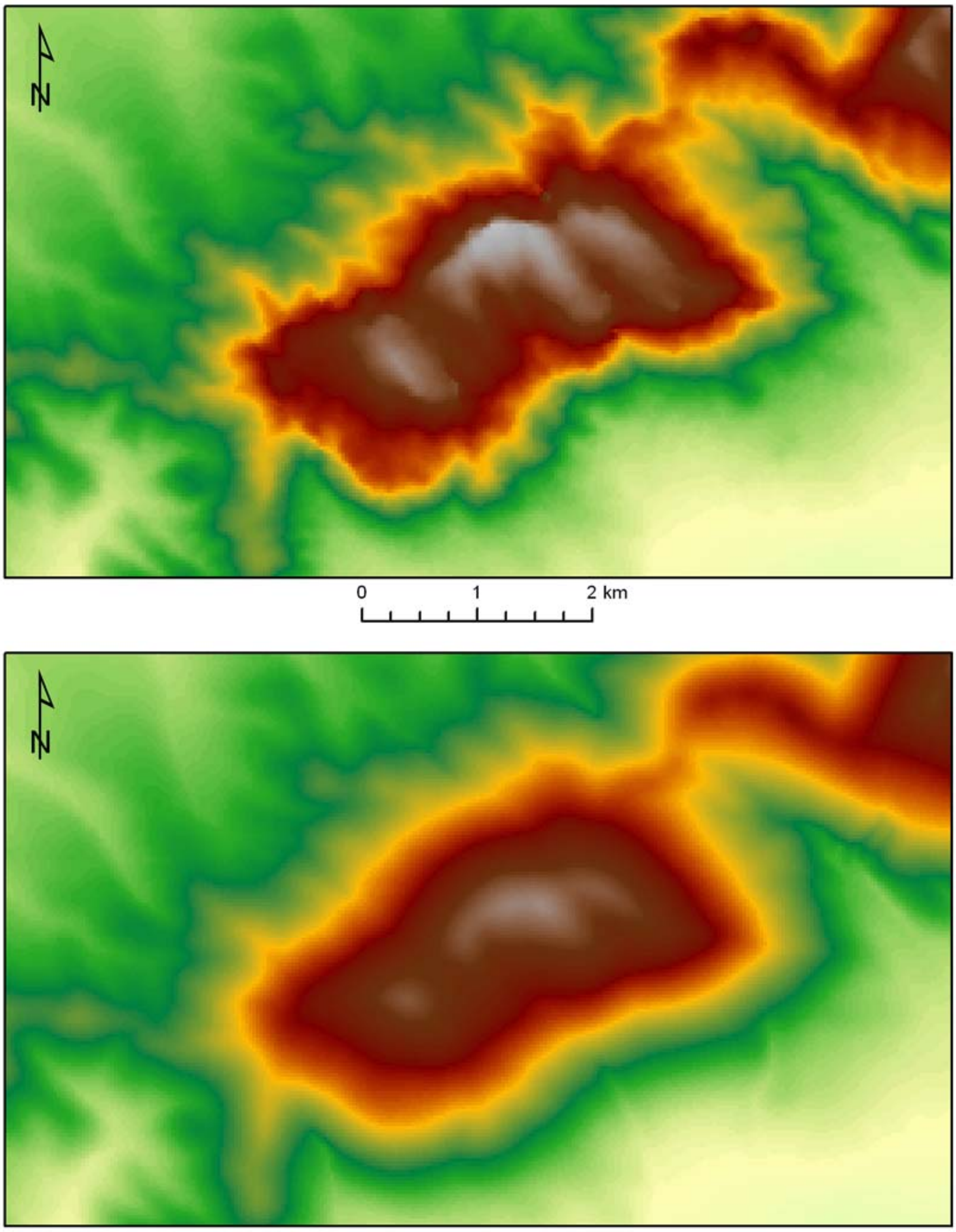


Figure 36. Substantial reduction in height of mountain peak from DEM-S to DEM-H due to smoothing by ANUDEM. Generally flat tiles with a few hills are the most affected. The largest height reductions are nearly 200 m. The smoothing has also raised part of the south-eastern flank of the mountain by over 100 m. Bluff Knoll and Coyanarup Peak, Stirling Range, WA, 118.26E, 34.38S. Elevation range 100 – 1200 m.

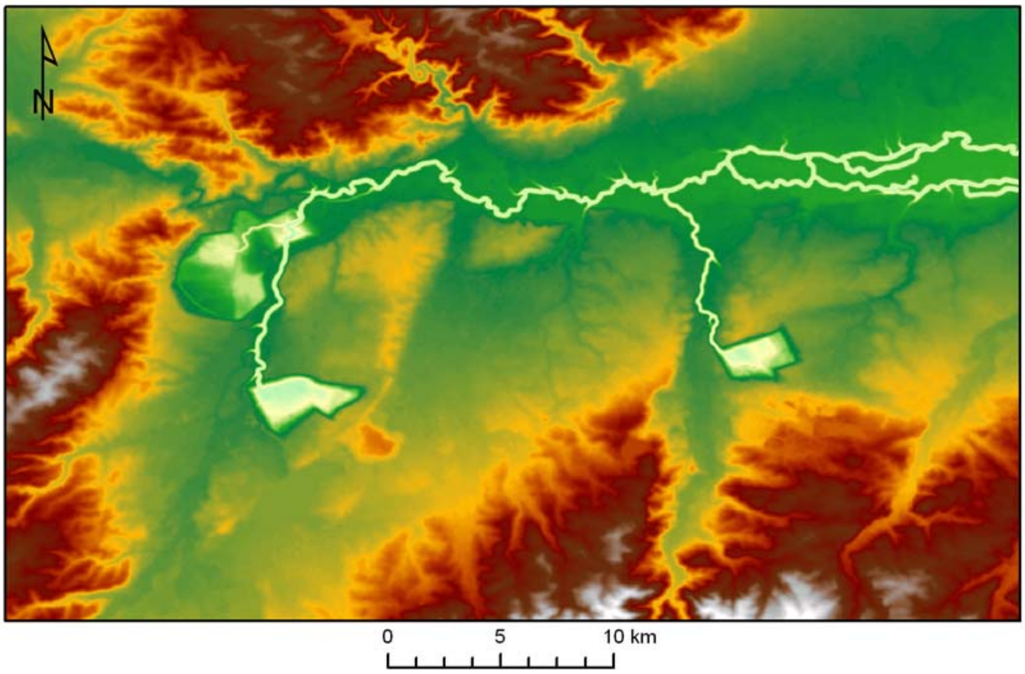


Figure 37. Excessive incision downstream of open-cut mines, Latrobe Valley, Vic, 146.5E, 38.2S. Elevation range 100 – 400 m. The incised drainage line at about 60 m elevation continues to the Gippsland Lakes 100 km downstream.

Incomplete Stream Enforcements

A small number of tiles have been identified in which the AusHydro 1:250,000 steam lines have not been properly enforced into the DEM-H. The tiles identified are listed below with a rating of the degree of error based on an assessment by CSIRO and GA. Larger errors seem to occur in the braided stream networks and often expand across neighbouring tiles. These errors, and any additional errors identified by users and emailed to elevation@ga.gov.au, will be looked at in future revisions and removed where possible.

Longitude	Latitude	Location	Error rating
123	18	WA – Fitzroy River	Large
123	19	WA – Fitzroy River	Large
125	18	WA – Adcock River (north Fitzroy Crossing)	Medium
135	17	NT – McArthur River	Large
136	17	NT – McArthur River	Large
141	17	QLD - Staaten River (from Gulf Carpentaria)	Medium
141	27	QLD – Cooper Creek (east SA/QLD border)	Large
142	17	QLD - Staaten River (from Gulf Carpentaria)	Medium
142	27	QLD – Cooper Creek (east SA/QLD border)	Large
143	28	QLD – Bulloo River	Large
144	28	QLD – Bulloo River	Large
147	43	TAS – River Derwent (north-west Hobart)	Small
148	34	NSW – Lachlan River (south-east Cowra)	Small
149	34	NSW – Lachlan River (south-east Cowra)	Small
149	36	NSW – Lake George	Small
150	36	NSW – various rivers from the coast inland (includes Moruya River, Clyde River at Batemans Bay, Conjola Creek)	Small

An example of a small error is shown below (Figure 38) in the Derwent River near Hobart, Tasmania. Lines that have been missed in the drainage enforcement process are visible as red lines (AusHydro stream lines) with no corresponding black lines (drainage enforcements).

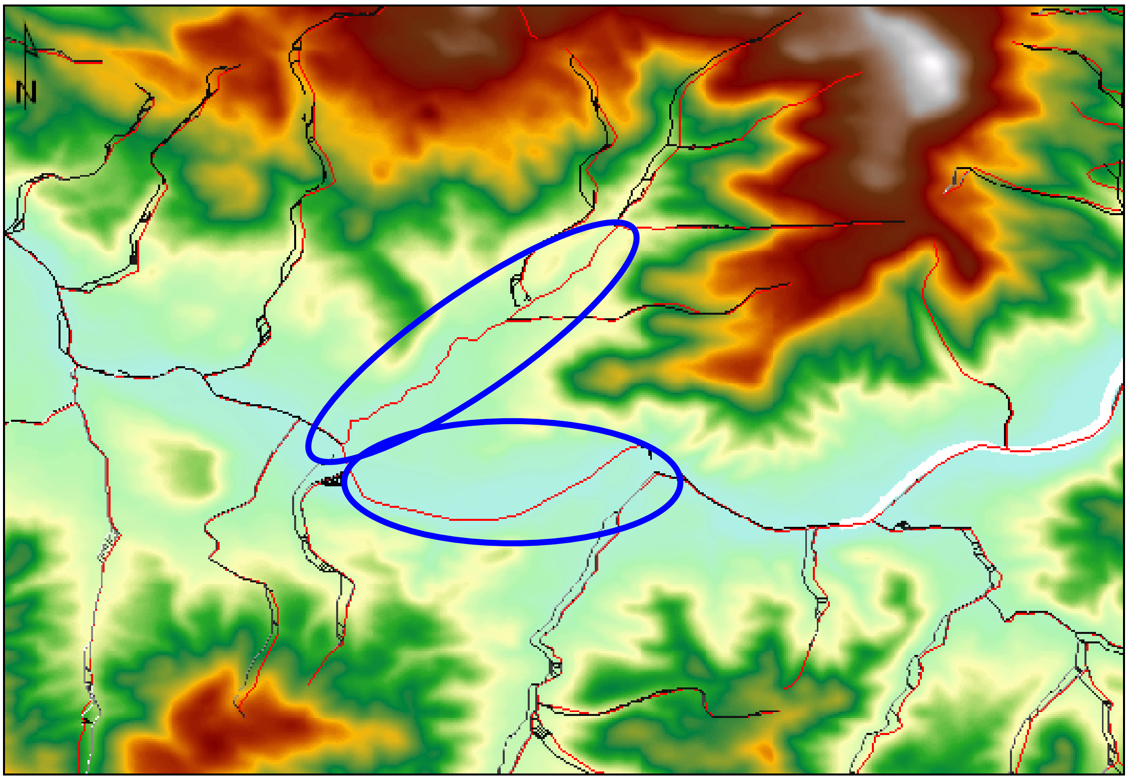


Figure 38. Small errors where parts of the AusHydro stream network have not been enforced into the DEM-H. Derwent River, north-west Hobart, Tas, 147.075E, 42.765S. Elevation range -4 – 964 m. Black shows where stream enforcement has occurred, and red lines are AusHydro stream lines.

Medium errors are those that have a portion of the AusHydro braided stream network omitted from the network enforced into the DEM-H as shown in Figure 39.

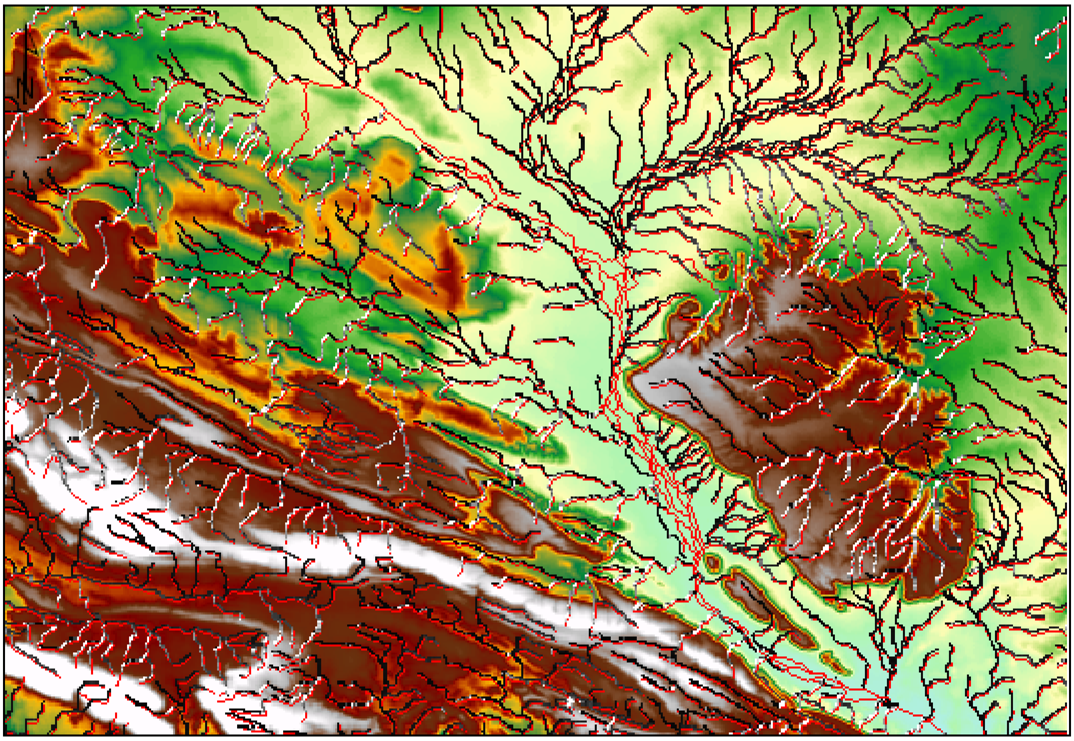


Figure 39. Medium error where part of the AusHydro stream network has not been enforced into the DEM-H. Adcock River, north of Fitzroy Crossing, WA, 125.867E, 17.32S. Elevation range 196 - 934m. Black lines are infill stream lines derived from DEM-S and red lines are AusHydro stream lines.

Large errors are present in Cooper Creek NSW where a significant portion of a braided stream network has not been enforced into the DEM-H (Figure 40).

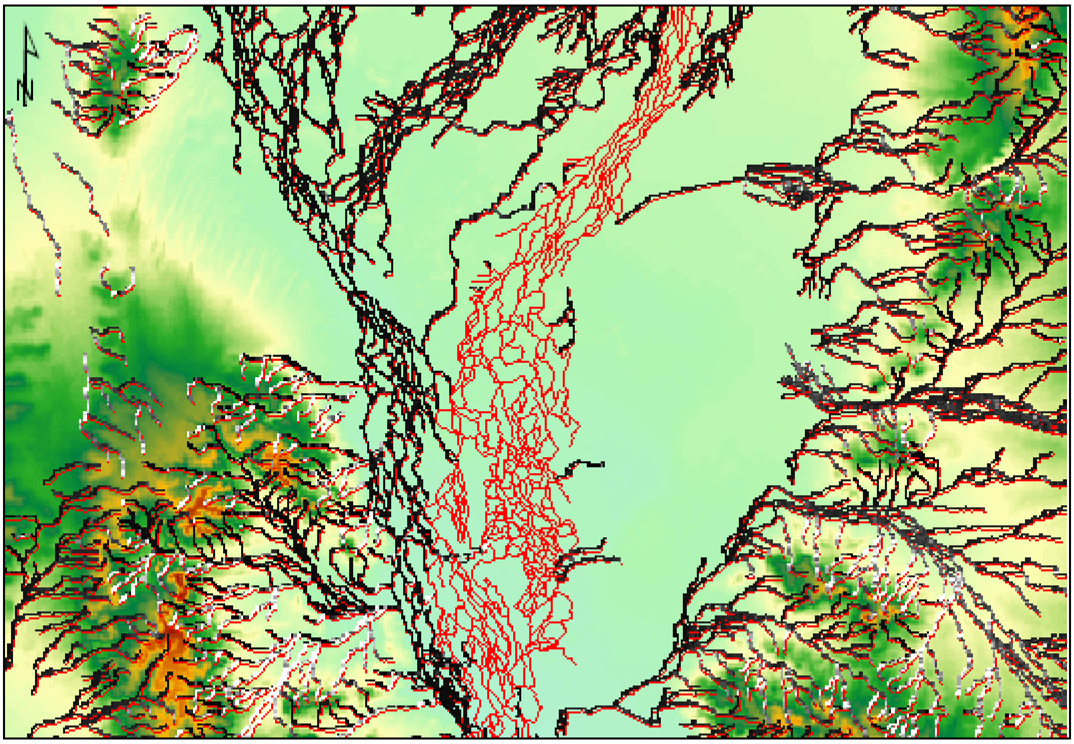


Figure 40. Large error where a large fraction of a major braided network from AusHydro stream network has not been enforced into the DEM-H. Cooper Creek, north-west Bourke, NSW, 141.934E, 26.675S. Elevation range 74-332m. Black lines are infill stream lines derived from DEM-S and red lines are AusHydro stream lines.

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 -0.8 m and 1.2 m 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, it was 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, Queensland, a LiDAR-derived DEM for Lower Darling and the Victorian DEM State-wide product (VicMap Elevation DTM 20 m). Each of these analyses is described below.

The accuracy assessment was completed on the base product, the 1 second DEM. Analysis showed little difference in the vertical accuracy of the DSM, DEM and DEM-S. Relative elevation accuracy between adjacent cells is improved in DEM-S and DEM-H 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).

The elevation error for DEM-H is difficult to characterise. In general it will be similar to the raw SRTM 1 second data, with 90% of tested heights within 9.8 m for Australia, but significant changes to elevation have occurred due to the smoothing and drainage enforcement processes.

Differences in height between DEM-S and DEM-H were examined to identify areas where defects were created by the drainage enforcement process. Some large elevation differences, up to 290 m, were due to valid drainage enforcements in canyons. Other significant differences are related to various problems including:

- Excessive height reductions on steep slopes due to multiple parallel infill stream lines e.g. 152.295°E, 30.943°S.
- Excessive smoothing (lowering of hilltops and raising of lower slopes) in some areas (e.g. the eastern peaks of the Stirling Range, WA, around 118.28°E 34.36°S, with hilltops lowered by around 200 m).
- Drainage enforcements to the level of open-cut mines traversed by mapped stream lines resulting in deep incisions extending long distances downstream of the mines, with the worst instance being from the coal mines in Latrobe Valley, Victoria, to the outlet of the Gippsland Lakes, to an elevation of about -60 m for about 180 km.
- A few extraneous infill stream lines in inland areas creating long stream lines where none were mapped (e.g. in tile e129s25).
- Errors in the 1:250,000 stream lines (e.g. 148.29°E, 35.35°S).

Note that only the last two issues (extraneous infill lines and stream line errors) affect the hydrological quality of DEM-H; the other problems create incorrect elevations but the hydrological connectivity is correctly represented.

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 41 shows the spatial distribution of points and the height differences relative to AHD71 for the 1 second DEM. Figure 42 shows the histogram of differences.

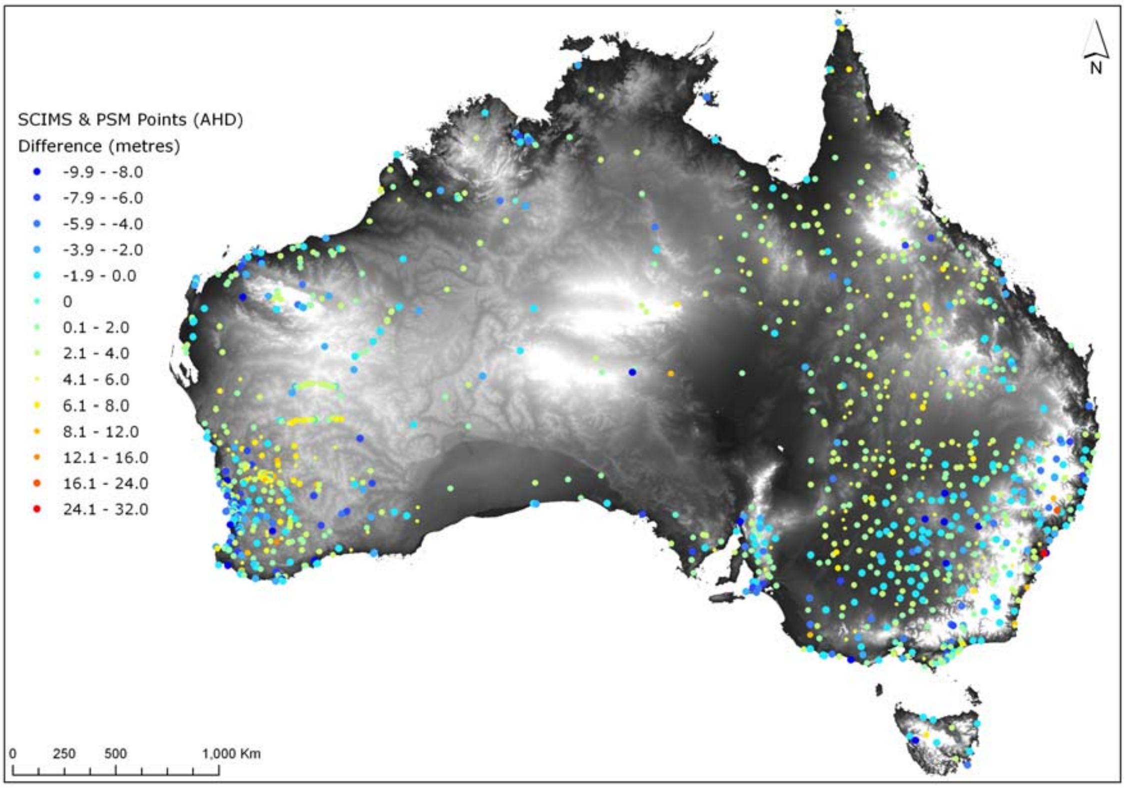


Figure 41. Height difference relative to the AHD71 vertical datum between the DEM and the PSM points.

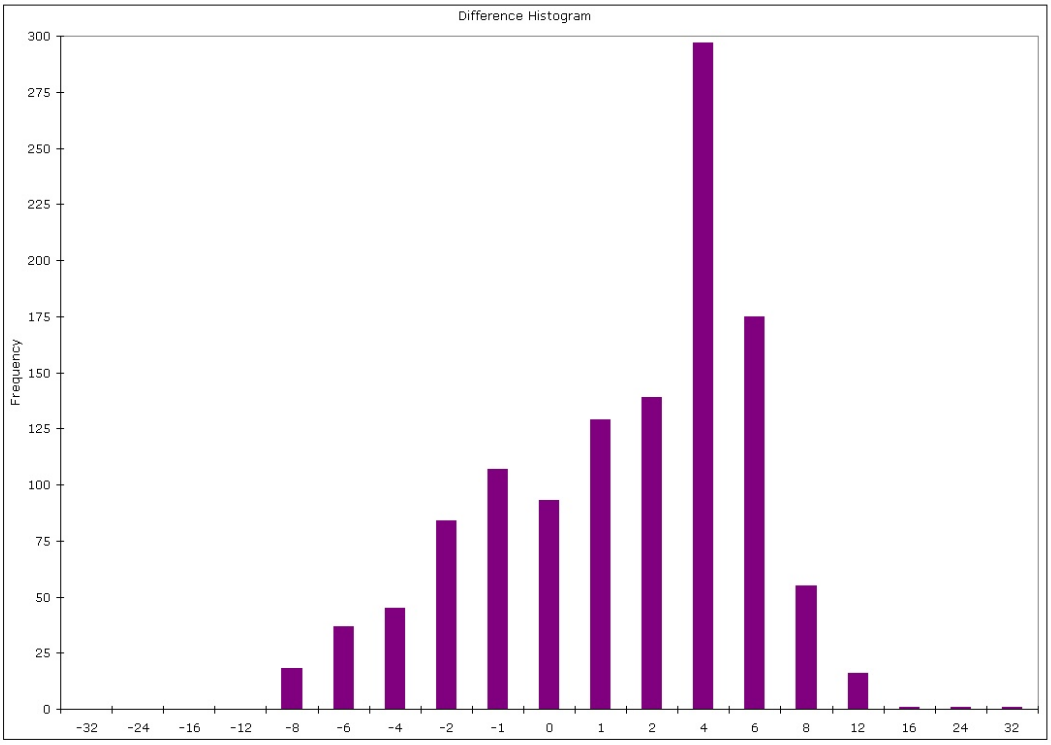


Figure 42. Height difference distribution between the DEM and the PSM points relative to the AHD71 vertical datum.

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 7.582 m at the 95th percentile with a RMS error of 3.868 in open, flat terrain. Ninety-nine percent of points are within a height difference of less than 9.602 m. There are eight points with a height difference of more than 10 m, most of which occur in high elevations on 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 m interval based on the AHD71 vertical datum, covering an area south of Lake Tinaroo in the Atherton Tablelands (Figure 43).

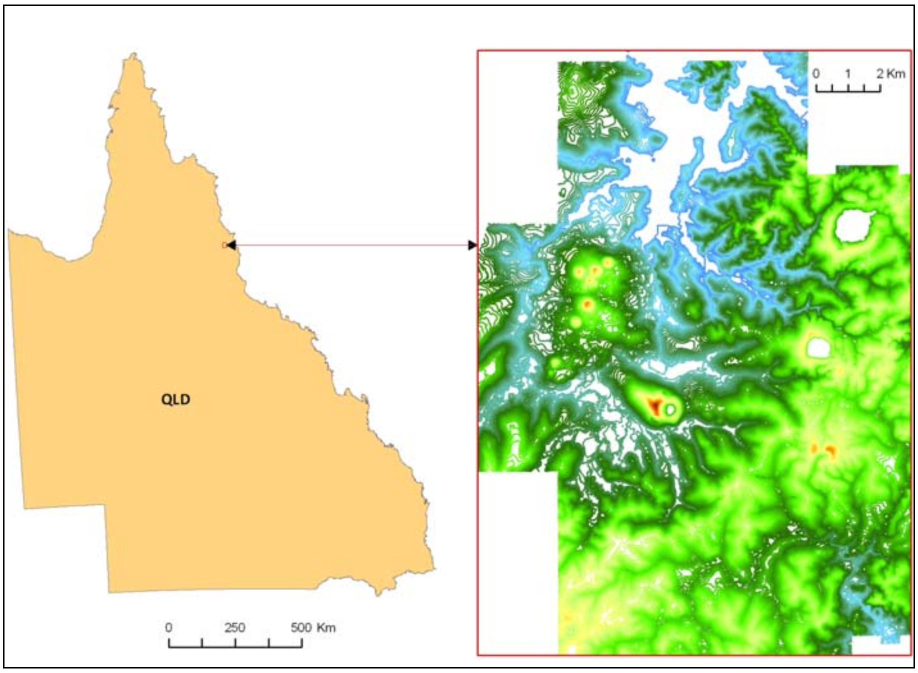


Figure 43. Location of Atherton Tablelands 2 m Contour Data.

The contours were used to create a surface which was then compared with the 1 second DEM, producing the difference surface shown in Figure 44. 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

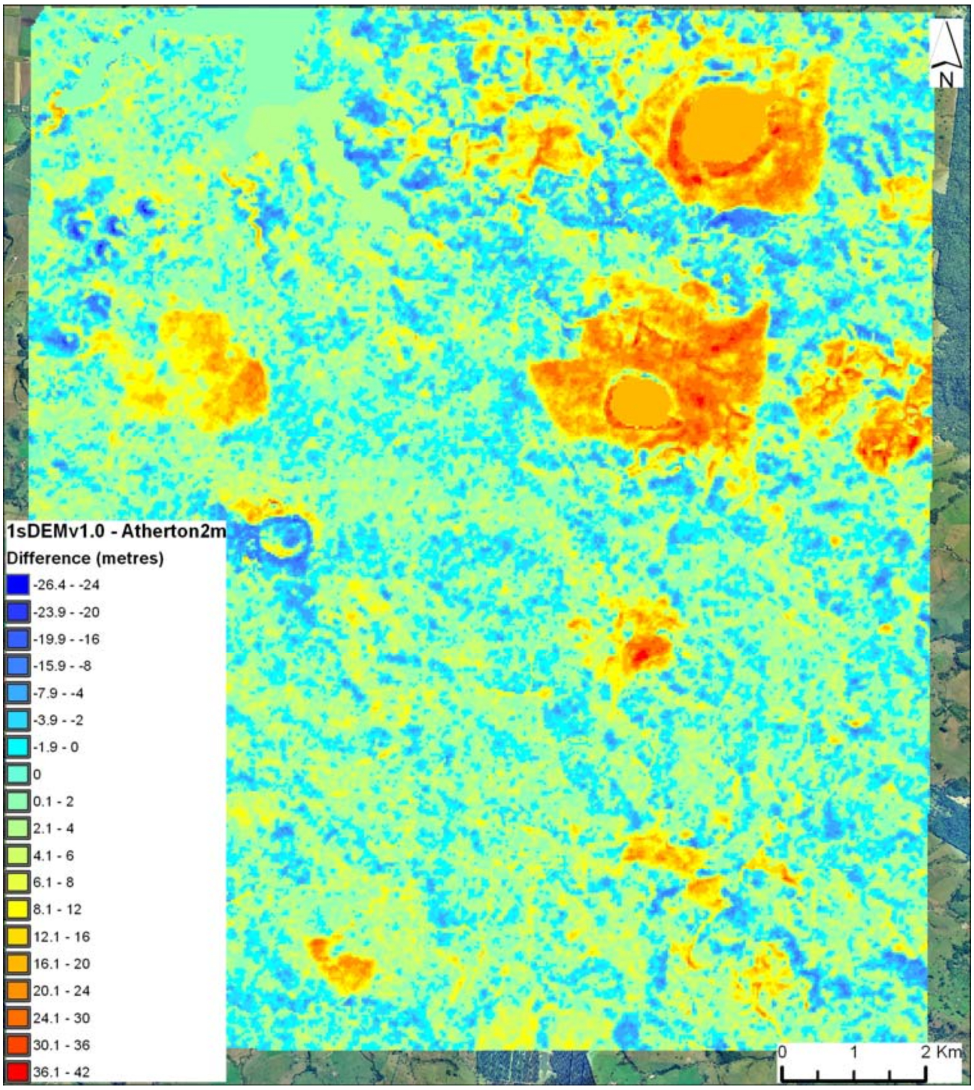


Figure 44. Atherton difference grid 145.604E, 17.303S.

A total of 7881 points were randomly generated across the surface for statistical analysis. Figure 45 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 -3 m to +6 m except in densely vegetated areas or lakes where the DEM has under-estimated the heights by 8-40 m. This results in the mean difference being much higher than the average height difference over non-vegetated areas which is closer to 0-2 m for the majority of the sample area.

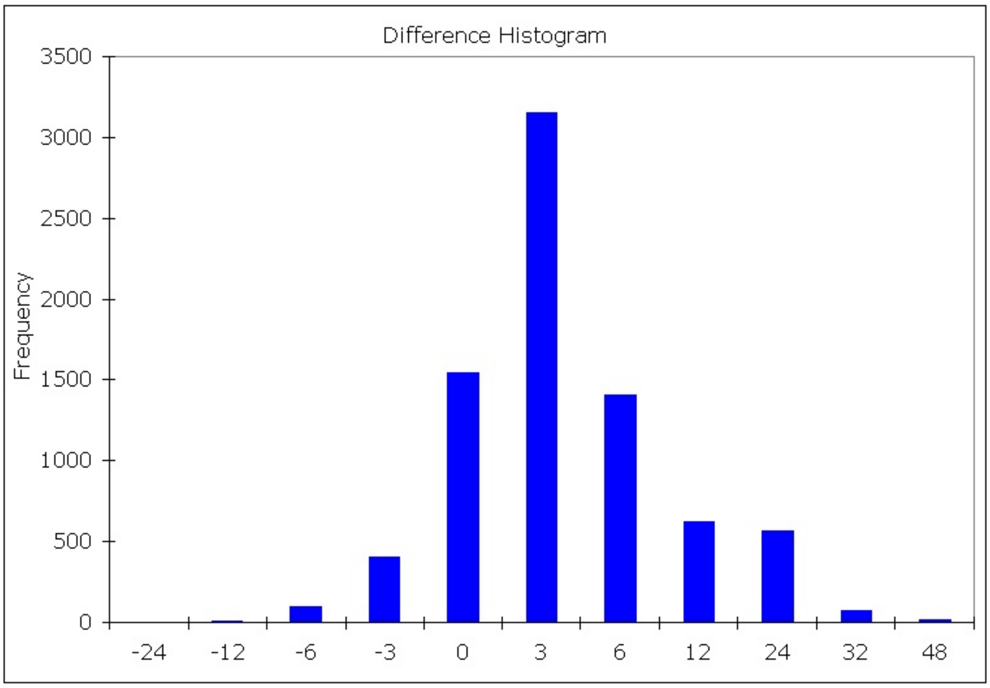


Figure 45. Difference Histogram between Atherton Tablelands elevations and SRTM heights.

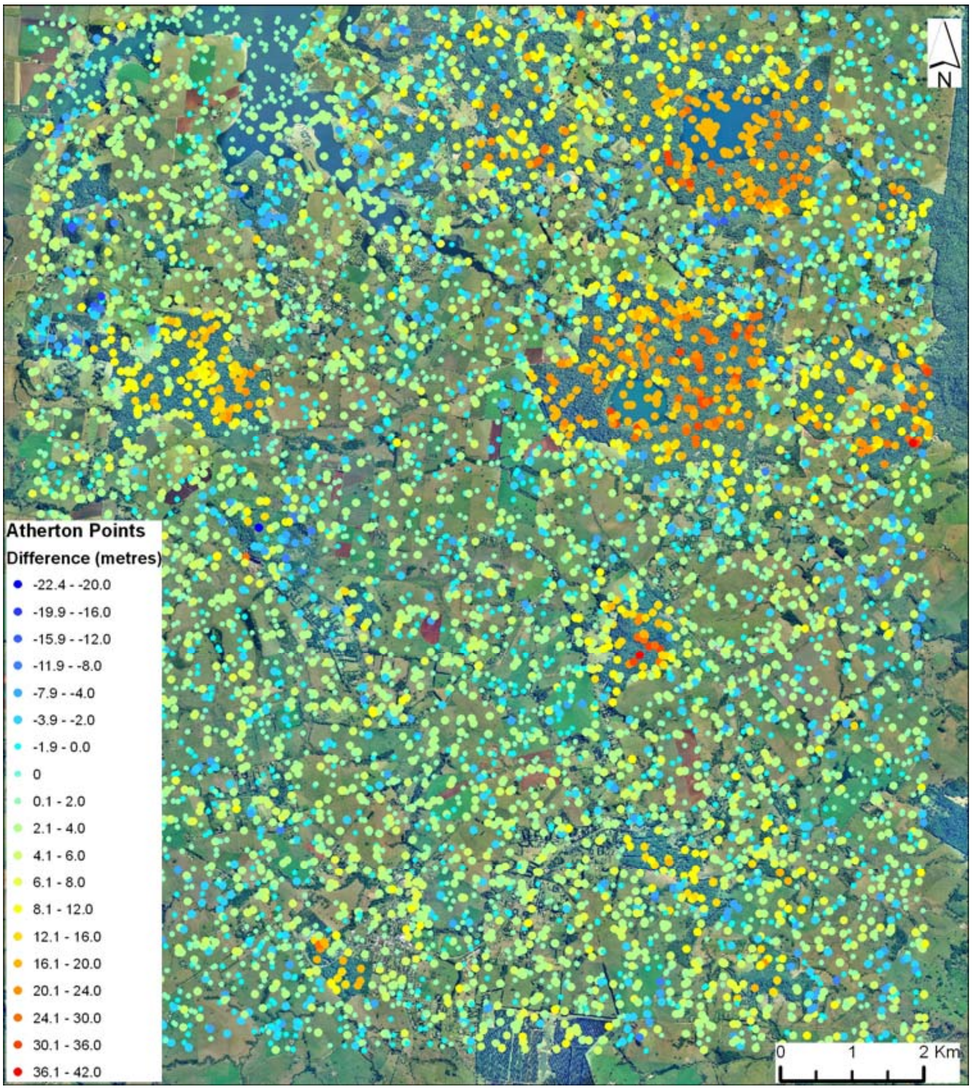


Figure 46. Atherton Grid difference points, 145.604E, 17.303S.

The areas of large difference between the 1 second DEM and the Atherton surface (Figure 46) are primarily forested areas and water surfaces (Lake Eacham and Lake Barrine, both lakes in volcanic craters). The differences in 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 indicate that the vegetation offset has been significantly under-estimated in those areas.

Comparison with Other Elevation Datasets

VicMap Elevation

The VicMap 20 m DTM coverage extends across the whole of Victoria and 10 km into bordering States (Figure 47).The dataset consists of a wide variety of input source data varying in currency from 1974 to 2006. The DTM is hydrologically enforced to represent the mapped surface drainage system.

The spatial accuracy for VicMap Elevation DTM 20 m and DTM 10 m 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 10-20 m Contours & Relief. Therefore the positional accuracy for VicMap Elevation DTM 20 m and DTM 10 m is 12.5 m horizontally and 5 m (AHD71) vertically or better, barring known significant errors in those data.

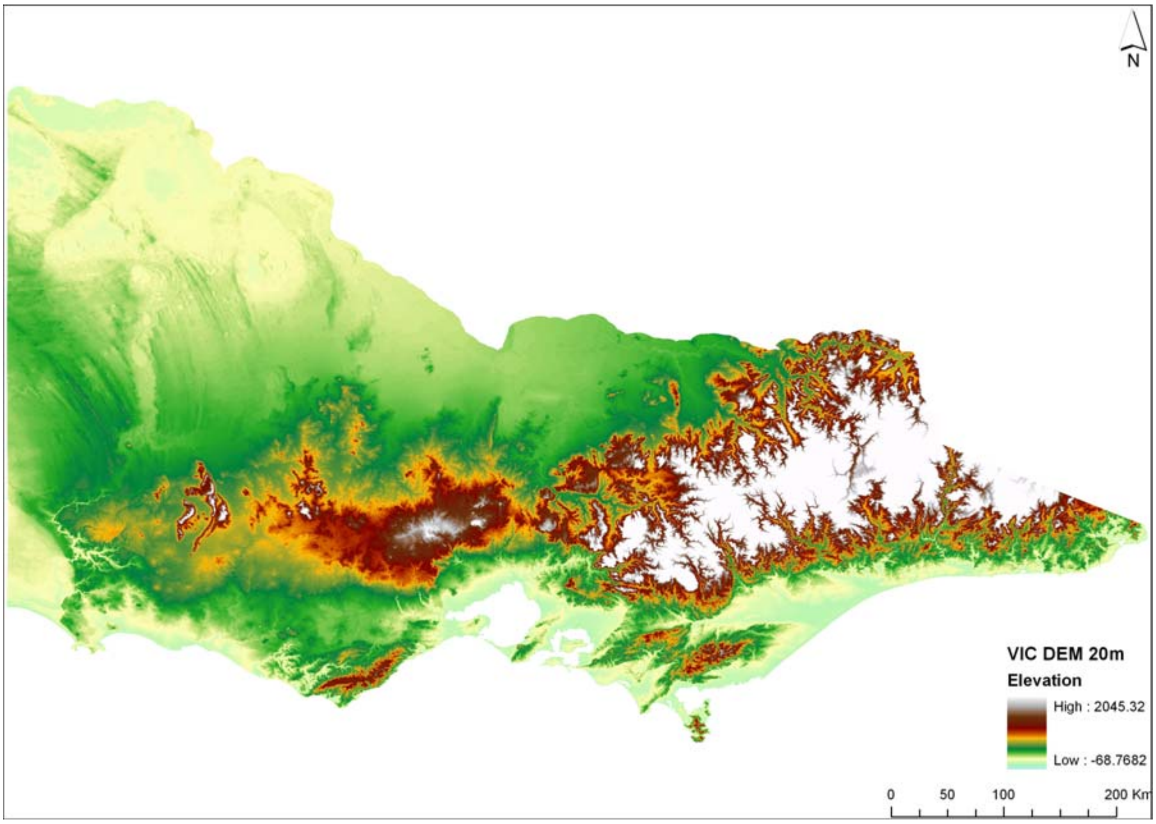


Figure 47. Extent of VicMap DTM 20 m 141.306E, 38.049S.

The VicMap DTM was subtracted from the SRTM-derived DEM to produce a difference surface (Figure 48). The differences are due to a number of factors (numbers correspond to approximate location on the figure below):

1. Riparian vegetation along the Murray River is a known area of inadequate vegetation removal in the 1 second DEM and has an over-estimated elevation by 4-16 m.
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 GEODATA 9 second 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 1-2 m.

5 The Orange – Red colour (16-24 m) 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 it used other readings lower than the high water mark

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

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

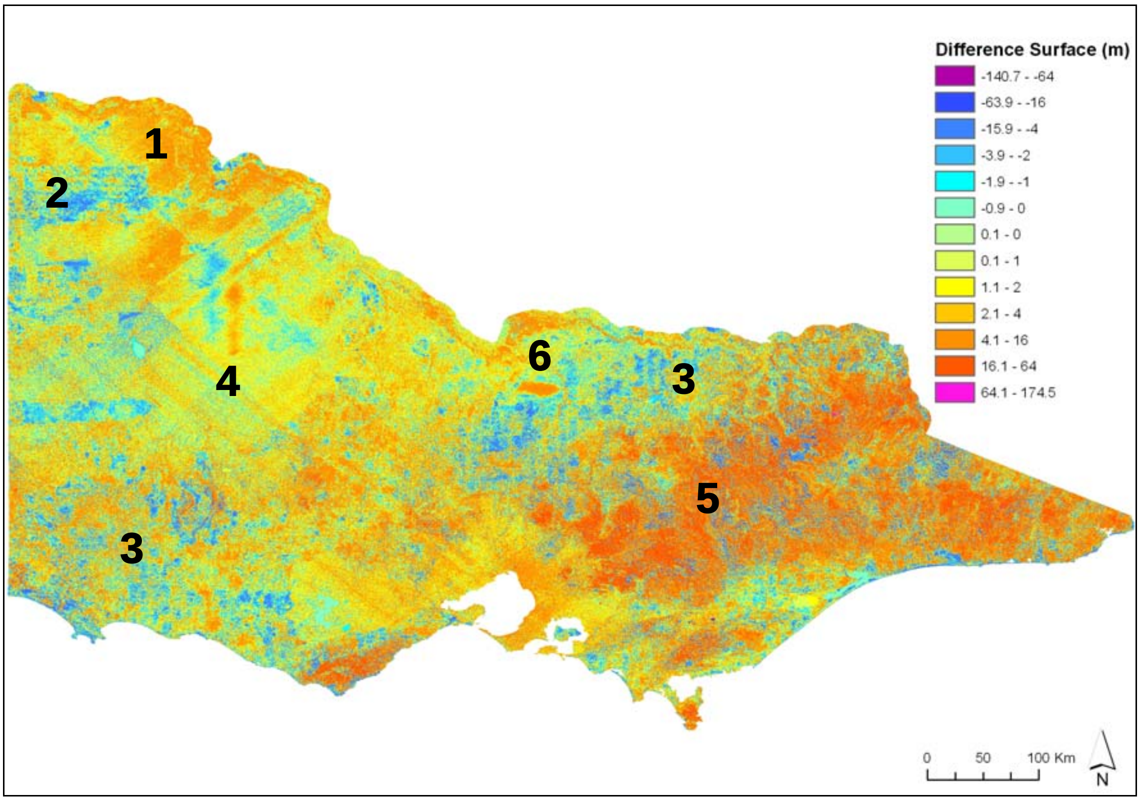


Figure 48. DEM – VicMap DTM Difference Surface 141.306E, 38.049S.

Significant differences were observed between the VicMap DTM and the SRTM-derived DEM (see table below). A total of 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 49).

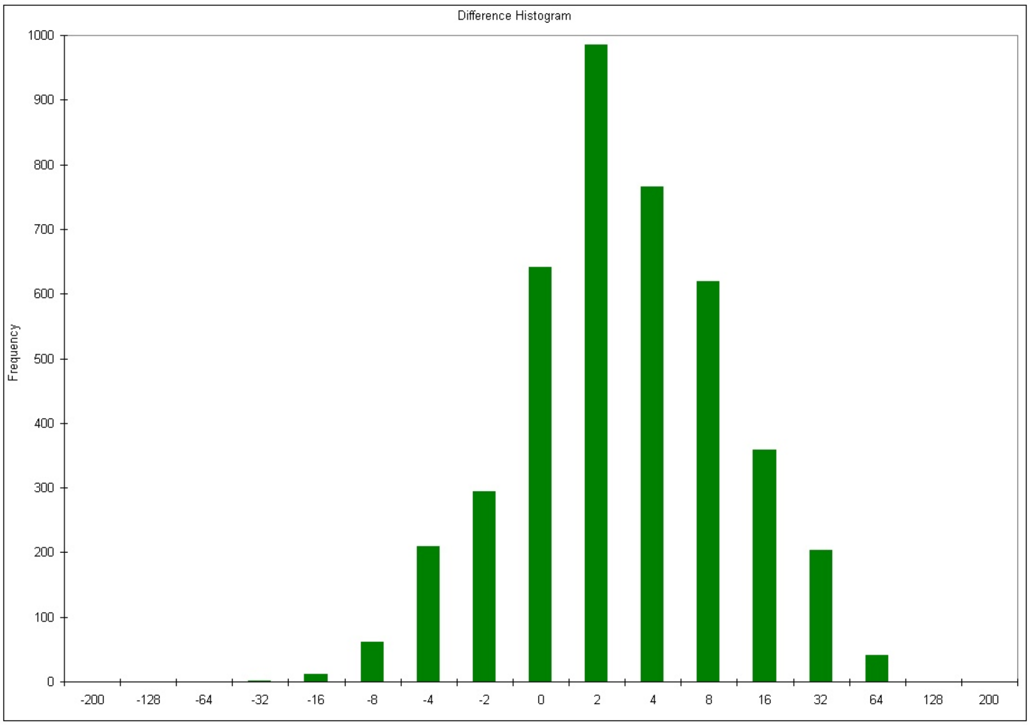


Figure 49. DEM – VicMap DTM Sample Points Histogram.

Lower Darling LiDAR

The Lower Darling LiDAR comparison comprises a 5 m grid 'bare-earth' DEM derived from LiDAR data acquired in mid-2009 (Figure 50) 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 <15 cm (95% confidence).

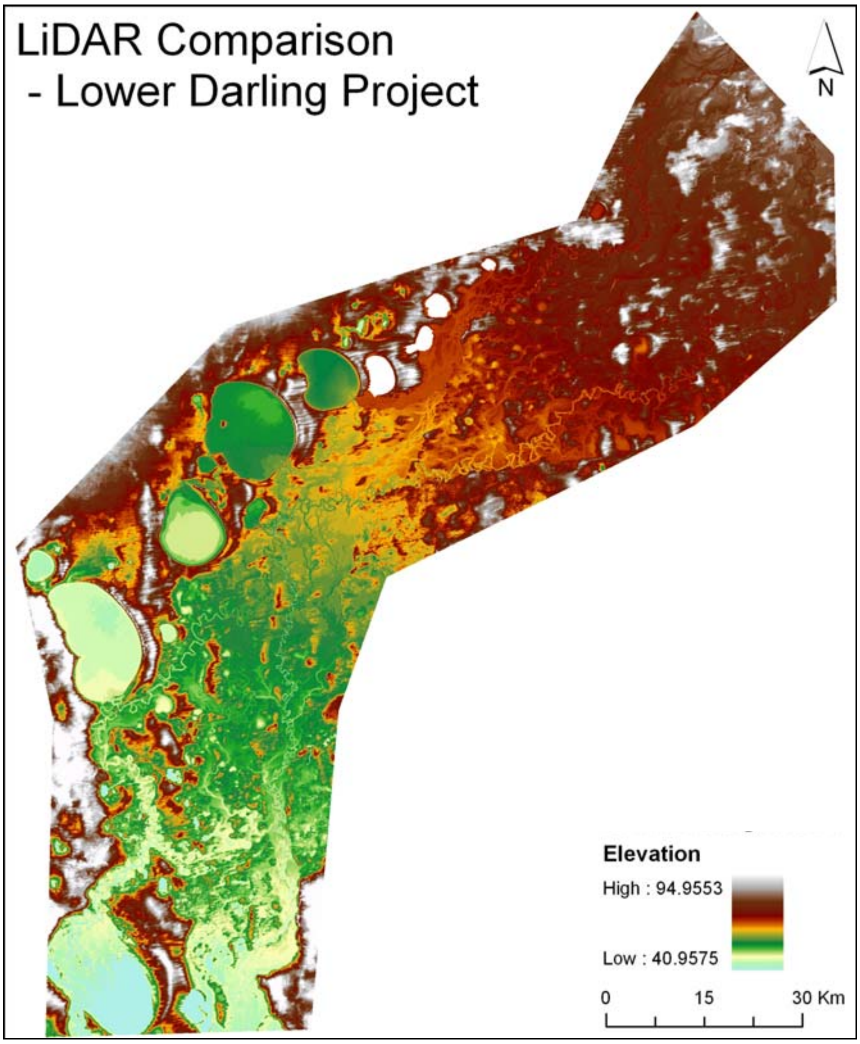


Figure 50. Lower Darling 5 m Grid 142.625E, 32.477S.

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

Lower Darling LiDAR statistics

A difference surface (Figure 51) was created by subtracting the LiDAR-generated 5 m 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.

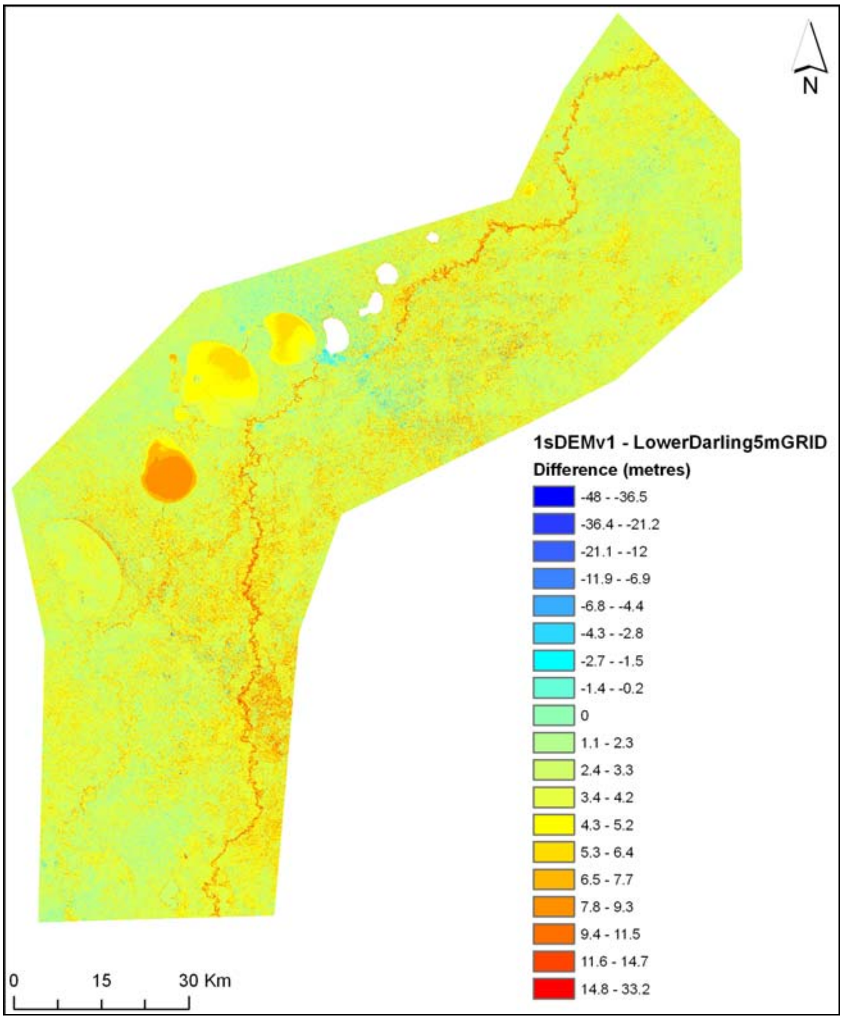


Figure 51. Lower Darling Difference Grid (DEM – LiDAR) 142.625E, 32.477S.

Some 10,000 points were randomly selected across the project area to extract values for further statistical analysis (Figure 52). 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

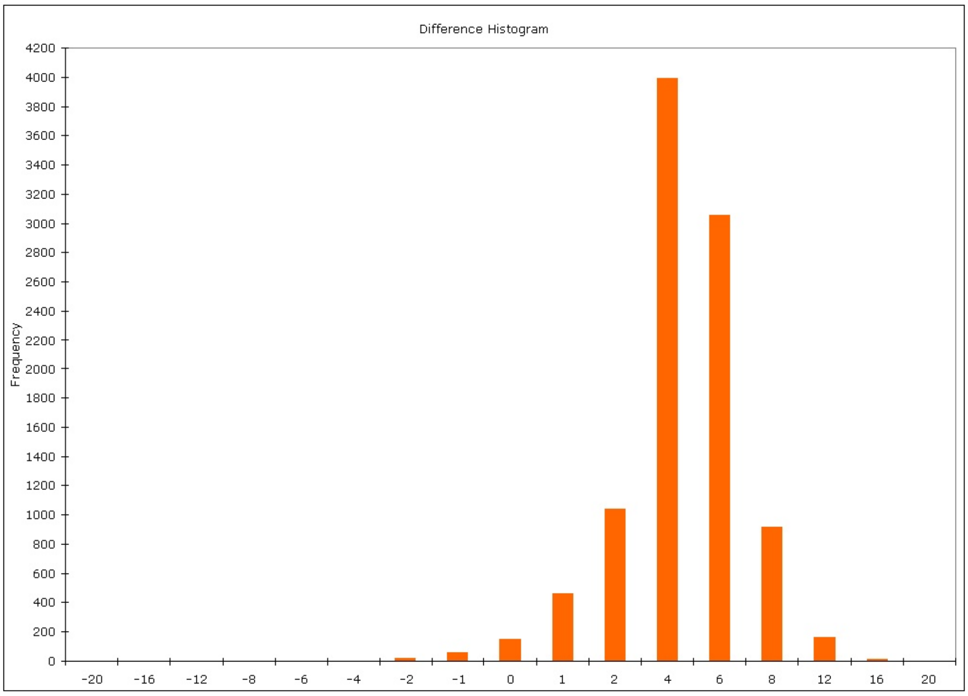


Figure 52. Histogram of Difference in Elevation between Lower Darling LiDAR and SRTM DEM.

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 has not been removed from the SRTM DEM. Also the striping apparent in the SRTM is visible in the difference surface (see Striping Section).

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 data is a derived product, there are inherent improvements in the 3 second products also. This does not include the DEM-H which has not been produced at a 3 second resolution and should be not resampled to a coarser resolution as the drainage would be affected. Refer to the above section for further information. Below is the coverage of the 3 second DEM-S (Figure 53).

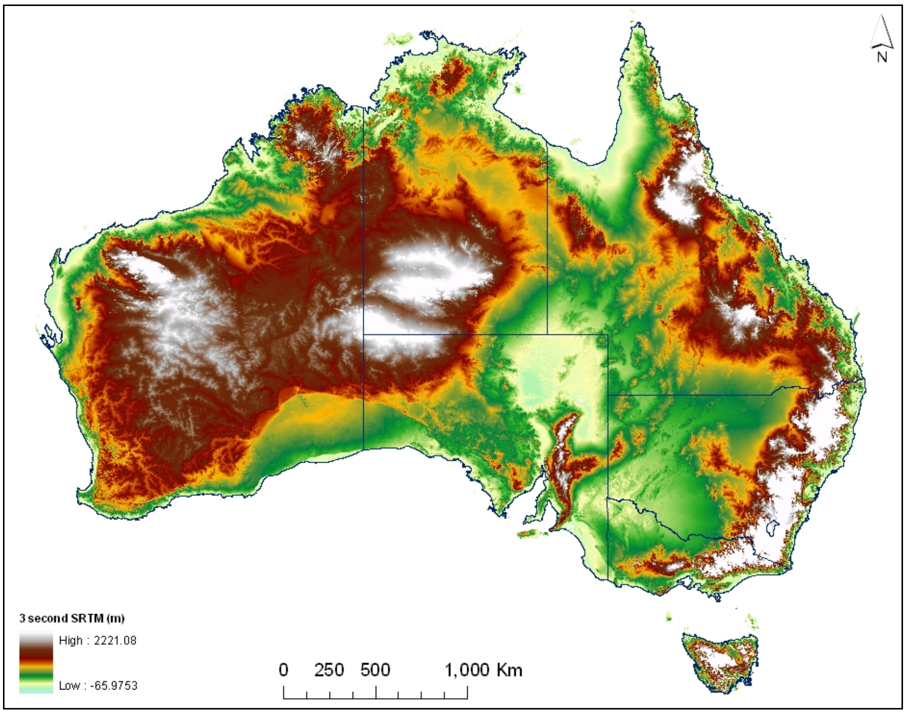


Figure 53. 3 second National DEM coverage.

Resampling the data to 3 seconds from the 1 second product was completed in ESRI ArcGIS software with an 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. the mean value of the 3x3 input cells).

The 3 second DSM and DEM products have been converted to integer format to reduce the file size; this is considered to have little impact on accuracy for these products. The DEM-S has been retained in floating point format to preserve the subtle variations in height that the adaptive smoothing method produces.

Accuracy Assessment

The same Permanent Survey Mark (PSM) data 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 14.54 m at the 95th percentile with a RMS error of 7.029 in open, flat terrain. Ninety-nine percent of points are within a height difference of less than 29.97 m.

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 Correct 3 Second Product

Given the accuracy of the 3 second product, it is advised that you consider the desired application of the data and which of the 3 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 greater than the specified vertical accuracy of approximately ±21m.

There is currently no hydrologically enforced 3 second product. If you require a hydrologically enforced product, use either the 1 second DEM-H or the 9 second GEODATA3 DEM which are available through the GA Sales Centre, although these have a poorer accuracy. A 3 second DEM-H may be produced in the future if there is sufficient demand.

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 2012. Product information will be added to the Geoscience Australia Digital Elevation Data webpage as it becomes available. http://www.ga.gov.au/topographic-mapping/digital-elevation-data.html

Feedback

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

References

Ehlschlaeger, C. R. (1989) Using the AT search algorithm to develop hydrologic models from digital elevation data. *Proceedings of the International Geographic Information System (IGIS) Symposium*, Baltimore, MD, 275-281. http://chuck.ehlschlaeger.info/older/IGIS/paper.html

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

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., & et al. (2007). The shuttle radar topography mission. Reviews of Geophysics, 45, RG2004.

Hutchinson, M. F. (1988) Calculation of hydrologically sound digital elevation models. Proceedings of the Third International Symposium on Spatial Data Handling, August 17-19, 1988, Sydney, Australia. 117-133. International

Geographical Union, Commission on Geographical Data Sensing and Processing, Ohio State University, Columbus, Ohio.

Hutchinson, M. F. (1989) A new procedure for gridding elevation and stream line data with automatic removal of spurious pits, Journal of Hydrology 106 pp 211-232.

Hutchinson, M. F. (2009) ANUDEM Version 5.2. Fenner School of Environment and Society, Australian National University. Available online at: http://fennerschool.anu.edu.au/publications/software/anudem.php (last accessed January 2011).

Hutchinson, M.F., Stein, J.A., Stein, J.L. and Xu, T. (2009) Locally adaptive gridding of noisy high resolution topographic data. In Anderssen, R.S., R.D. Braddock and L.T.H. Newham (eds) 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, July 2009, pp. 2493-2499. ISBN: 978-0-9758400-7-8. http://www.mssanz.org.au/modsim09/F13/hutchinson.pdf

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 Topography Mission (SRTM) derived Digital Surface Model (DSM) Version 1.0 is a 1 arc second (~30 m) 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) and hydrologically enforced DEM (DEM-H, ANZCW0703014615). It is available under a government restricted licence only on request from elevation@ga.gov.au. An alternative DSM available under Creative Commons licensing is a resampled 3 second (~90m) version (part of the 3 second product set).

ANZLIC search words:
LAND Topography Models
ECOLOGY Landscape

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, 2011) and Quality Assessment layers, and to incorporate improvements in the Digital Surface Model.

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 1 second DSM 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 and may be provided upon request to elevation@ga.gov.au.

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 were produced by NASA from radar data collected by the Shuttle Radar Topography 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 0.2 m to nearly 4 m. The wavelength of the striping is approximately 800 m. 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 GEODATA 9 second data were refined to 1 second resolution using ANUDEM 5.2 without drainage enforcement. The 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 were 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 1 m 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 1 cm above the water surface. The smaller offset (1 cm rather than 1 m) 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.

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

- A de-stripe mask indicating which ¼ × ¼ degree tiles have been affected by destriping and which have not been de-striped
- A striping magnitude layer showing the amplitude of the striping at 0.01 degree (~ 1km) resolution (Restricted Licence for Government Use Only)
- 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 7.2 m 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 9.8 m for Australia. Errors in height are still mostly due to random variation (noise) that is spatially uncorrelated beyond distances of about 100 m, but there are some broader scale errors. The noise component is typically about +/- 2 m 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 0.3 m 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 GEODATA 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 m. 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 descend 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 DSM covers all of continental Australia and near coastal islands, with 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 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 south-western corner of the tile.

Contact information

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Metadata information

Metadata Created date: 2009-12-23
Metadata Updated date: 2010-08-30
Metadata Updated date: 2011-09-01

Additional metadata

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 are 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. Vegetation offset Removal Grids are for government use only and will be supplied with the DSM if approved by elevation@ga.gov.au

References

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

Geoscience Australia and CSIRO (2011) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0.4. 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, A.M., Gallant, J.C. and Dowling, T.I. (in prep) Destriping and void filling the 1 second SRTM DEM for 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.

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:
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or GA Sales on 02 6249 9966

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

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 Topography Mission (SRTM) derived Digital Elevation Model (DEM) Version 1.0 is a 1 arc second (~30 m) 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, 2011). 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 (DEM-H, ANZCW0703014615) was released in October 2011. The three products (DEM, DEM-S and DEM-H) have been released under Creative Commons licensing since October 2011.

ANZLIC search words:
LAND Topography Models
ECOLOGY Landscape

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, 2011) and Quality Assessment layers, and to incorporate improvements in the Digital Elevation Model.

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:
From October 2011 this data is released under the Creative Commons Attribution 3.0 Australia Licence for use by government and the public.
http://creativecommons.org/licenses/by/3.0/au/
Copyright © Commonwealth of Australia (Geoscience Australia) 2010.

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 were produced by NASA from radar data collected by the Shuttle Radar Topography 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 is based on the 1 second SRTM derived Digital Surface Model (DSM) that was itself derived from the 1 second Shuttle Radar Topography 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, 2011).

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. The Delta Surface Fill Method (Grohman et al., 2006) was adapted for this task, using GEODATA 9 second DEM as the 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 1 m 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 were set to at least 1 centimetre above the water surface. The smaller offset (1 cm rather than 1 m) 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, and relies on the detection of artefacts by edges.

The issues identified were:
- vegetation offsets are still visible (not fully removed)
- vegetation offset over-estimated
- 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, 2011).

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 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 7.582 m at the 95th percentile with a RMS error of 3.868 in open, flat terrain. Ninety-nine percent of points are within a height difference of less than 9.602 m.

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 0.3 m 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, 2011).

Height accuracy is likely to be poorer in areas where voids have been filled using the GEODATA 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 m.

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 descend 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, with 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 south-western corner of the tile.

Contact information

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Facsimile: +61 2 6249 9960
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Metadata information

Metadata Created date: 2009-12-23
Metadata Updated date: 2010-08-30
Metadata Updated date: 2011-09-01

Additional metadata

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 are 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, J.C., Read, A.M., Dowling, T.I. and Austin, J.M. (in prep) Removing vegetation offsets from the 1 second SRTM DEM for Australia.

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO (2011) 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, A.M., Gallant, J.C. and Dowling, T.I. (in prep) Destriping and void filling methods used in the 1 second SRTM DEM for 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.

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.

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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 Topography Mission (SRTM) derived smoothed Digital Elevation Model (DEM-S) Version 1.0 is a 1 arc second (~30 m) 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 curvature 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). The DEM-S was used to create the hydrologically enforced product DEM-H; ANZCW0703014615).

The three 1 second products (DEM, DEM-S and DEM-H) were released under Creative Commons licensing from October 2011.

ANZLIC search words:

LAND Topography Models
ECOLOGY Landscape

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:

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 Topography 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 is based on the 1 second SRTM derived Digital Surface Model (DSM) that was itself derived from the 1 second Shuttle Radar Topography 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 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 were also removed from the DEM (set to 'null') before the smoothing operation to prevent them unduly affecting the land elevations. 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, 2011).

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 7.582 m at the 95th percentile with a RMS error of 3.868 in open, flat terrain. Ninety-nine percent of points are within a height difference of less than 9.602 m.

The smoothing process estimated typical improvements in the order of 2-3 m. This would make the DEM-S accuracy to be of approximately 5 m. 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, 2011).

Height accuracy is likely to be poorer in areas where voids have been filled using the GEODATA 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 descend 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, with 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 south-western corner of the tile.

Contact information

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Metadata information

Metadata created date: 2010-08-30
Metadata Updated date: 2011-09-01

Additional metadata

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, J.C. (2011) An adaptive smoothing method for improving noisy DEMs. http://geomorphometry.org/2011

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO (2011) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0.4. 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.

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Appendix D – 1 second DEM-H 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: ANZCW0703014615
Title: 1 Second SRTM Derived Hydrological Digital Elevation Model (DEM-H) Version 1.0

Custodian

Custodian: Geoscience Australia
Jurisdiction: Australia

Description

Abstract:
The 1 second SRTM derived DEM-H Version 1.0 is a 1 arc second (~30 m) gridded digital elevation model (DEM) that has been hydrologically conditioned and drainage enforced. The DEM-H captures flow paths based on SRTM elevations and mapped stream lines, and supports delineation of catchments and related hydrological attributes. The dataset was derived from the 1 second smoothed Digital Elevation Model (DEM-S; ANZCW0703014016) by enforcing hydrological connectivity with the ANUDEM software, using selected AusHydro V1.6 (February 2010) 1:250,000 scale watercourse lines (ANZCW0503900101) and lines derived from DEM-S to define the watercourses. The drainage enforcement has produced a consistent representation of hydrological connectivity with some elevation artefacts resulting from the drainage enforcement. A full description of the methods is in preparation (Dowling *et al.,* in prep).

This product is the last of the Version 1.0 series derived from the 1 second SRTM (DSM, DEM, DEM-S and DEM-H) and provides a DEM suitable for use in hydrological analysis such as catchment definition and flow routing. The 1 second products (DEM, DEM-S and DEM-H) have been released under Creative Commons licensing since October 2011.

ANZLIC search words:

- LAND Topography Models
- ECOLOGY Landscape
- WATER Hydrology

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 DEM-H is complete as at 15 April 2011.

Maintenance and update frequency:
Updates and revisions are anticipated to resolve some of the issues identified in the User Guide (Geoscience Australia and CSIRO, 2011) and Quality Assessment layers, and to incorporate improvements in the source smoothed Digital Elevation Model, DEM-S, and the DEM and DSM it is derived from. Updates incorporating finer scale stream line

data provided by State and Territory agencies are also anticipated progressively, on a catchment-by-catchment basis.

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 (Farr *et al.*, 2007), 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 Topography 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. AusHydro V1.6 1:250,000 watercourse lines.

DSM processing
This DEM is based on the 1 second SRTM derived Digital Surface Model (DSM) that was itself derived from the 1 second Shuttle Radar Topography 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).

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 DEM metadata (ANZCW0703013355).

DEM-S adaptive smoothing
The DEM was smoothed by averaging elevations over distances ranging from 90 m to several kms, depending on the level of noise and the local relief. The smoothing removes most of the local noise and allows measurement of slopes down to less than 0.1%. Further details are provided in the DEM-S metadata (ANZCW0703014016).

Drainage enforcement

The 1 second Hydrological Digital Elevation Model (DEM-H) was derived from the 1 second Smoothed Digital Elevation Model (DEM-S) using the ANUDEM software (Hutchinson, 1988, 1989, 2009), version 5.2.5, dated 1 December 2010. This version of ANUDEM was modified to work effectively on the SRTM data, as briefly described in Hutchinson *et al.* (2009). ANUDEM uses a spline interpolation method that smooths the surface, enforces continuous descent along supplied drainage lines and removes sinks consistent with the accuracy of the source elevation data (DEM-S).

The 1:250,000 scale stream line data used to produce the GEODATA 9 second DEM Version 3 was chosen as the source of drainage line data, as it was the only available source of cleaned and correctly oriented drainage lines and it covered the entire continent. This 1:250,000 scale data, with a spatial accuracy of about 200 m, was significantly coarser than the 1 second DEM-S that is accurate to 50 m or better. In low relief landscapes the spatial error of the 1:250,000 stream lines is not a significant problem but in steeper areas the spatial offsets result in drainage lines being incised into hillslopes rather than valley floors. To prevent this, the mapped stream lines were used only where slope in DEM-S was less than 10 degrees. The excised segments were replaced with infilling stream lines derived from DEM-S using a version of the AT search algorithm (Ehlschlaeger, 1989; known primarily as its implementation in GRASS as r.watershed) method that constructs flow lines through depressions without first filling the depressions to the outlet level.

The ANUDEM software cannot process the entire continent, or entire drainage basins at the 1 second resolution in a single pass. Drainage enforcement was therefore performed separately for each 1×1 degree tile using ½ degree overlaps on each side. The resulting 2×2 degree tiles were trimmed to a 100 cell overlap, mosaicked with adjacent trimmed tiles then clipped to the 1×1 degree tile.

The mosaicking process does not guarantee the preservation of continuous descent along drainage lines so a final descent enforcement step was applied using the CheckStreamDescent program written for that purpose. CheckStreamDescent processes all tiles as a single data set so that continuous descent of all stream lines to their termination points was ensured.

As a final step, the ocean areas were set to 'no data'. Other water bodies have not been altered after drainage enforcement and most water bodies include a drainage line through them reflecting the connectors in the AusHydro data. Note that this is in contrast to the finishing of the DSM, DEM and DEM-S which all contain flattened water bodies and used the SRTM edit rules to ensure that land adjacent to water bodies is at a higher elevation than the water.

Overview of quality assessment

Differences in height between DEM-S and DEM-H were examined to identify areas where defects were created by the drainage enforcement process. Some large elevation differences, up to 290 m, were due to valid drainage enforcements in canyons. Other significant differences are related to various problems including:

- Excessive height reductions on steep slopes due to multiple parallel infill stream lines e.g. 152.295°E, 30.943°S.
- Excessive smoothing (lowering of hilltops and raising of lower slopes) in some areas (e.g. the eastern peaks of the Stirling Range, WA, around 118.28°E 34.36°S, with hilltops lowered by around 200 m).
- Drainage enforcements to the level of open-cut mines traversed by mapped stream lines resulting in deep incisions extending long distances downstream of the mines, with the worst instance being from the coal mines in Latrobe Valley, Victoria, to the outlet of the Gippsland Lakes, to an elevation of about -60 m for about 180 km.
- A few extraneous infill stream lines in inland areas creating long stream lines where none were mapped (e.g. in tile e129s25)
- Errors in the 1:250,000 stream lines (e.g. 148.29°E, 35.35°S)

Note that only the last two issues (extraneous infill lines and stream line errors) affect the hydrological quality of DEM-H; the other problems create incorrect elevations but the hydrological connectivity is correctly represented.

DEM-H ancillary data layers
Flow direction grids along watercourses have been included in 1 degree tiles.

Positional accuracy:

The positional accuracy of watercourses in flatter areas is the same as for the 1:250,000 stream line data, about 200 m. For other features the horizontal positional error is generally 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:

The primary purpose of a hydrological DEM is to support hydrological analysis related to connectivity of flow paths and hydrological properties of catchments and stream lines. The combination of ANUDEM and the CheckStreamDescent analysis ensures that DEM-H V1.0 correctly represents flow pathways as defined by the AusHydro 1:250,000 mapping, modified by the infill streams defined from DEM-S.

Flow paths where there are no mapped streams reflect the surface topography as represented in DEM-S, so will be affected by errors in that DEM. In particular, areas where removal of vegetation offsets (to produce the DEM) was ineffective will exhibit incorrect flow pathways.

Drainage enforcement modifies elevations and surface form significantly in some areas, and applications that are concerned with landforms and elevations where drainage connectivity is not a critical factor, should use DEM-S in preference to DEM-H.

The elevation error for DEM-H is difficult to characterise. In general it will be similar to the raw SRTM 1 second data, with 90% of tested heights within 9.8 m for Australia (Rodriguez *et al., 2006*) but significant changes to elevation have occurred due to the smoothing and drainage enforcement processes. As noted in the Quality Assessment section above, errors as large as 200 m occur in some areas.

Further information on known errors is provided in the User Guide (Geoscience Australia and CSIRO, 2011).

Logical Consistency:

The DEM-H represents heights of the land surface modified to ensure that elevations decrease continuously in the downstream direction along drainage lines. Smaller sinks have been cleared as part of the process but a large number of sinks remain where indicated by the elevation data. Most of these are genuine topographic depressions but some are due to data errors.

There are no voids and there are no discontinuities due to tile boundaries.

Completeness:

The DEM-H covers all of continental Australia and near coastal islands, with 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-H:

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 south-western corner of the tile.

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Metadata information

Metadata Created date: 2011-04-15
Metadata Updated date: 2011-09-01

Additional metadata

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

References

Dowling, T. I., Read, A. M., Hutchinson, M. F., and Gallant, J. C. (in prep) Drainage enforcement of the 1 second SRTM DEM for Australia.

Ehlschlaeger, C. R. (1989) Using the AT search algorithm to develop hydrologic models from digital elevation data. Proceedings of the International Geographic Information System (IGIS) Symposium, Baltimore, MD, 275-281. http://chuck.ehlschlaeger.info/older/IGIS/paper.html

Farr, T.G., Rosen, P.A., Caro, E., Crippen, R., and others (2007). The shuttle radar topography mission. Reviews of Geophysics, 45, RG2004.

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

Geoscience Australia and CSIRO (2011) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0.4. Geoscience Australia.

Hutchinson, M. F. (1988) Calculation of hydrologically sound digital elevation models. Proceedings of the Third International Symposium on Spatial Data Handling, August 17-19, 1988, Sydney, Australia. 117-133. International Geographical Union, Commission on Geographical Data Sensing and Processing, Ohio State University, Columbus, Ohio.

Hutchinson, M. F. (1989) A new procedure for gridding elevation and stream line data with automatic removal of spurious pits, Journal of Hydrology 106 211-232.

Hutchinson, M. F. (2009) ANUDEM Version 5.2. Fenner School of Environment and Society, Australian National University. Available online at: http://fennerschool.anu.edu.au/publications/software/anudem.php (last accessed January 2011).

Hutchinson, M.F., Stein, J.A., Stein, J.L. and Xu, T. (2009) Locally adaptive gridding of noisy high resolution topographic data. In Anderssen, R.S., R.D. Braddock and L.T.H. Newham (eds) 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, July 2009, pp. 2493-2499. ISBN: 978-0-9758400-7-8. http://www.mssanz.org.au/modsim09/F13/hutchinson.pdf

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.

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Appendix E – 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 (~90 m) Shuttle Radar Topography Mission (SRTM) derived Digital Surface Model (DSM) Version 1.0 was derived from resampling the 1 arc second (~30 m) 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

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 Topography 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 Topography 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 and CSIRO, 2010).

De-striping
SRTM data contains striping artefacts oriented approximately NE-SW and NW-SE that vary in amplitude from about 0.2 m to nearly 4 m. The wavelength of the striping is approximately 800 m. 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. The Delta Surface Fill Method (Grohman et al., 2006) was adapted for this task, using GEODATA 9 second DEM as the 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 1 m 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 1 cm above the water surface. The smaller offset (1 cm rather than 1 m) 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 the 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 de-stripe mask indicating which ¼ × ¼ degree tiles have been affected by de-striping and which have not been de-striped
- 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

Re-sampling to 3 seconds
The 1 second SRTM derived Digital Surface Model (DSM) mosaic was resampled to 3 seconds of arc (90 m) in ArcGIS software using an 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. the 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, 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 9.8 m for Australia, which makes the 3 second DSM accuracy about 29 m. Errors in height are still mostly due to random variation (noise) that is spatially uncorrelated beyond distances of about 100 m (1 second DSM), but there are some broader scale errors. The noise component is typically about +/- 2 m (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 0.3 m 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 GEODATA 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 m.

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 descend 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 DSM covers all of continental Australia and near coastal islands, with 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.

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Metadata information

Metadata date: 2010-08-30
Metadata Updated date: 2011-09-01

Additional metadata

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 integer values, as the decimal values are well below any effect 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 (2011) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0.4. 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, A.M., Gallant, J.C. and Dowling, T.I. (in prep) Destriping and void filling methods used in SRTM 1 Second processing.

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.

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Appendix F – 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 (~90 m) Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) version 1.0 was derived from resampling the 1 arc second (~30 m) 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, 2011). 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 as a product set (DSM; ANZCW0703014216, DEM-S; ANZCW0703014217).

ANZLIC search words:
- LAND Topography Models
- ECOLOGY Landscape

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 Topography 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 re-sampled 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 Topography 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 GEODATA 9 second DEM data were 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 1 m 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 were set to at least 1 cm above the water surface. The smaller offset (1cm rather than 1 m) 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 the 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 over-estimated
- 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

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, 2011).

Resampling to 3 seconds
The 1 second SRTM derived Digital Elevation Model (DEM) was resampled to 3 seconds of arc (90 m) in ArcGIS software using an 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. the 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, 2011).

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 22 m.

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 7.582 m at the 95^{th} percentile with a RMS error of 3.868 in open, flat terrain. Ninety-nine percent of points are within a height difference of less than 9.602 m.

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 0.3 m 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, 2011).

Height accuracy is likely to be poorer in areas where voids have been filled using the GEODATA 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 m.

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 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, with 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 south-western corner of the tile.

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Metadata information

Metadata date: 2010-08-30
Metadata Updated date: 2011-09-01

Additional metadata

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 integer values, as the decimal values are well below any effect 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, J.C., Read, A.M., Dowling, T.I. and Austin, J.M. (in prep) Vegetation Removal methods used in SRTM 1 Second processing.

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO (2011) 1 Second SRTM Derived Digital Elevation Models User Guide. Version 1.0.4. 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, A.M., Gallant, J.C. and Dowling, T.I. (in prep) Destriping and void filling methods used in SRTM 1 Second processing.

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.

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Appendix G – 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 (~90 m) 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 the Creative Commons attribution.

The 1 second DSM and DEM that form 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

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 Topography 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 Topography 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 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 were 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.

Re-sampling to 3 seconds
The 1 second SRTM derived smoothed Digital Elevation Model (DEM-S) was re-sampled to 3 seconds of arc (90 m) in ArcGIS software using an 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. the 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, 2011).

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 Permanent Survey Marks (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 14.54 m at the 95^{th} percentile, with an RMS error of 7.029 m in open, flat terrain. Ninety-nine percent of points are within a height difference of less than 29.97 m.

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, 2011). The smoothing process estimated typical improvements of the order of 2-3 m in the 1 second DEM-S.

Height accuracy is likely to be poorer in areas where voids have been filled using the GEODATA 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 descend 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 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, with 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.

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Metadata information

Metadata date: 2010-08-30
Metadata Updated date: 2011-09-01

Additional metadata

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, J.C. (in prep) An adaptive smoothing method for improving noisy DEMs. http://geomorphometry.org/2011

Geoscience Australia (2008) GEODATA 9 Second DEM Version 3

Geoscience Australia and CSIRO (2011) 1 Second SRTM derived Digital Elevation Models User Guide. Version 1.0.4. 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.

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Appendix H – Loading the data

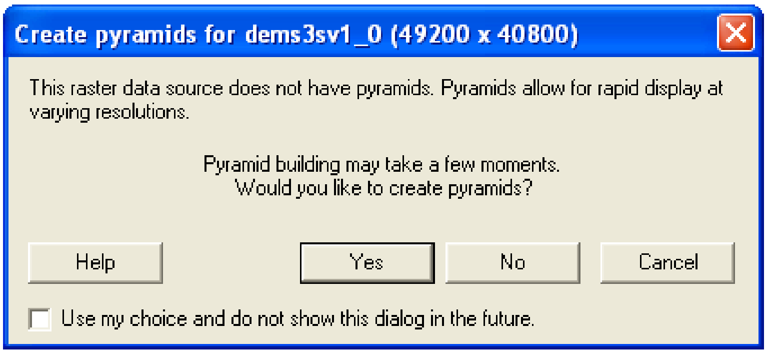
To assist you in loading and viewing the data into your preferred software, some basic instructions are described as a guide if you are unfamiliar with raster data. This is a guide only and there may be other ways to import the data. Geoscience Australia is able to provide further information on the product and data format, 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.

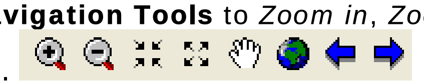
Into ESRI ArcGIS

To 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.

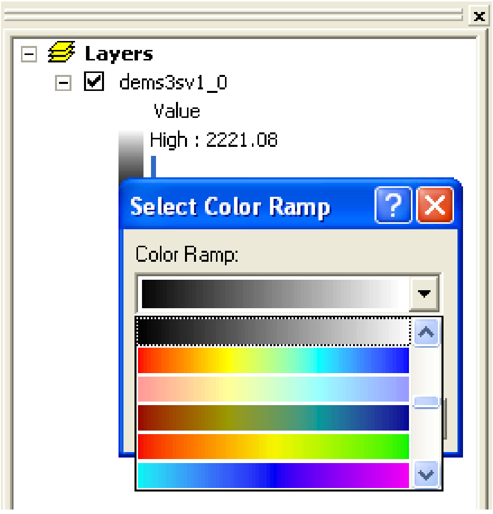
When asked if you would like to **Create Pyramids,** it is advised that you click yes. This will take some time now, but will save time when viewing the files later. Please note that Building Pyramids almost doubles the file size but at a later stage you can delete the pyramids if needed.

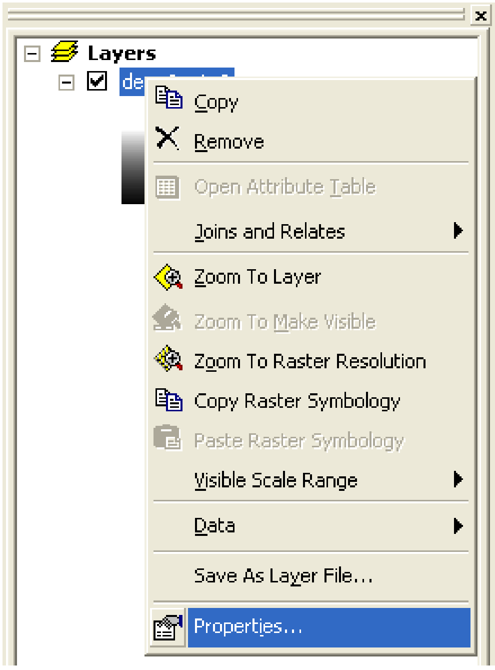


Once the file opens, you use the **Navigation Tools** to *Zoom in*, *Zoom Out*, *Zoom to Full Extent*, *Zoom to Previous* etc. 

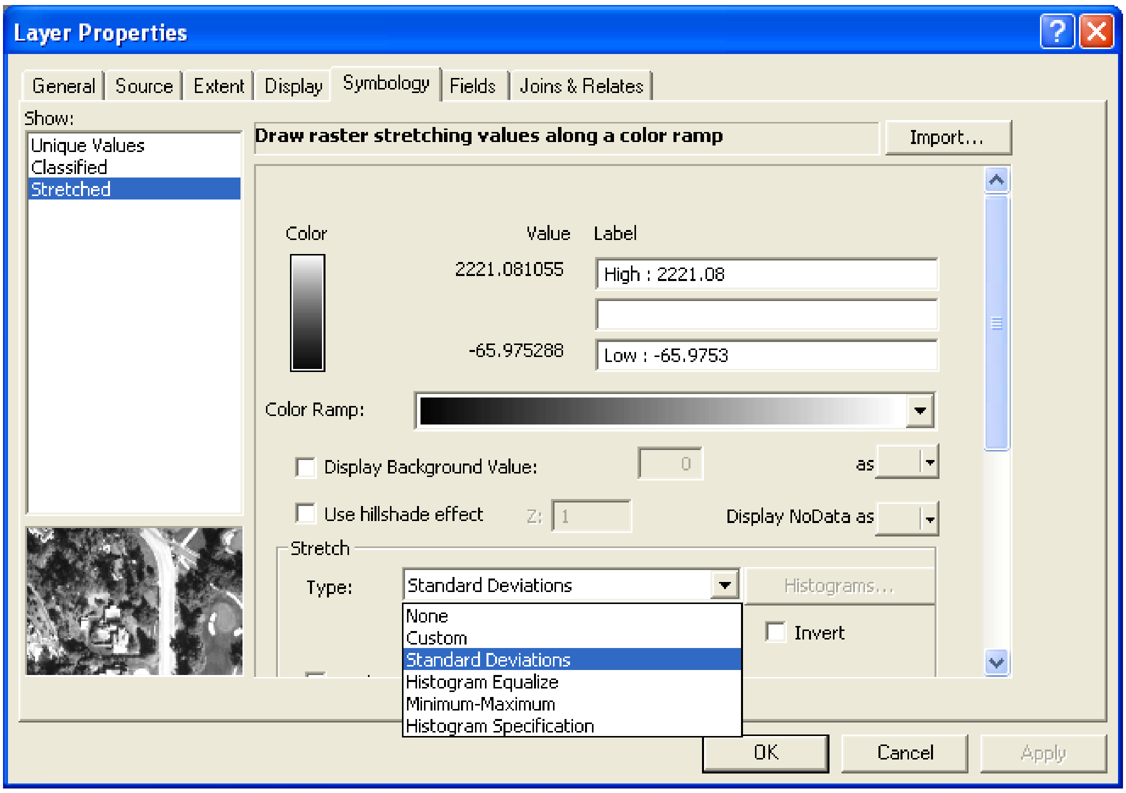
To load this toolbar, right-click in the black area at the top of ArcMap and scroll down until you get to *Tools* and tick to turn it on – then position it in the window to suit.

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 layer's name), then under *Symbology* tab for further options.





Once in the Properties Layer, the min/max values or other values can be altered as desired, or you can 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', with the 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 have not connected to a drive, click the Connect to Folder button  to view a drive. You will be asked to Build Pyramids if you have not already done this (see above).

Into Pitney Bowes MapInfo

Open MapInfo Professional.

Go to File > Open. Select ESRI grid and then navigate to the location of the 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.

Please consult your software company for technical support if required.