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Australian Bathymetry and Topography Grid

June 2009

T.G. Whiteway

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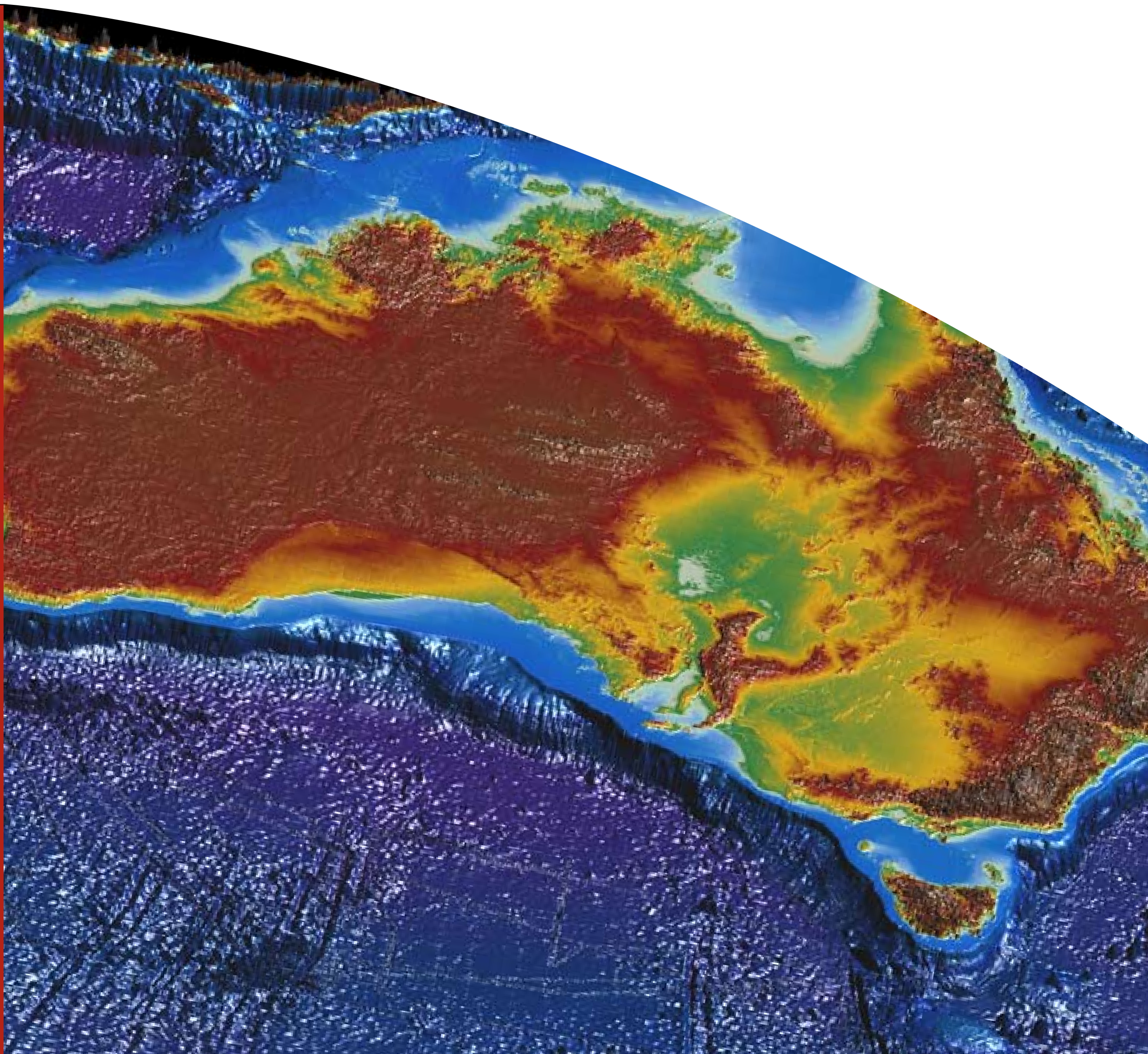

APPLYING GEOSCIENCE TO AUSTRALIA'S MOST IMPORTANT CHALLENGES

Australian Bathymetry and Topography Grid, June 2009

GEOSCIENCE AUSTRALIA
RECORD 2009/21

by

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1. Abstract

In 2005 Geoscience Australia and the National Oceans Office undertook a joint project to produce a consistent, high-quality 9 arc second (0.0025° or ~250m at the equator) bathymetric grid for Australian waters. In 2009 a number of new datasets were included in an updated version of the grid.

The 2009 bathymetric grid of Australia has been produced to include recently acquired datasets, and solutions to issues identified in the previous version. The revised grid has the same extents as its 2005 counterpart, including the Australian water column jurisdiction lying between 92° E and 172° E, and 8° S and 60° S. The waters adjacent to the continent of Australia and Tasmania are included, as are areas surrounding Macquarie Island, and the Australian Territories of Norfolk Island, Christmas Island, and Cocos (Keeling) Islands. The area selected does not include Australia's marine jurisdiction offshore from the Territory of Heard and McDonald Islands and the Australian Antarctic Territory.

This report details the datasets and procedures used to produce the 2009 bathymetric grid of Australia. As per the 2005 grid, the 0.0025 decimal degree (dd) resolution is only supported where direct bathymetric observations are sufficiently dense (e.g. where swath bathymetry data or digitised chart data exist) (Webster and Petkovic, 2005). In areas where no sounding data are available (in waters off the Australian shelf), the grid is based on the 2 arc minute ETOPO (Smith and Sandwell, 1997) and 1 arc minute ETOPO (Amante and Eakins, 2008) satellite derived bathymetry. The topographic data (on shore data) is based on the revised Australian 0.0025dd topography grid (Geoscience Australia, 2008), the 0.0025dd NZ topography grid (Geographx, 2008) and the 90m SRTM DEM (Jarvis et al, 2008).

The final dataset has been provided in ESRI grid and ER Mapper (ers) formats. An associated shapefile has been produced so that the user can identify the input datasets that were used in the final grid.

IMPORTANT INFORMATION

This grid is not suitable for use as an aid to navigation, or to replace any products produced by the Australian Hydrographic Service. Geoscience Australia produces the 0.0025dd bathymetric grid of Australia specifically to provide regional and local broad scale context for scientific and industry projects, and public education.

The 0.0025dd grid size is, in many regions of this grid, far in excess of the optimal grid size for some of the input data used. On parts of the continental shelf it may be possible to produce grids at higher resolution, especially where LADS or multibeam surveys exist. However these surveys typically only cover small areas and hence do not warrant the production a regional scale grid at less than 0.0025dd.

There are a number of bathymetric datasets that have not been included in this grid for various reasons. Comments or queries about the data included in the grid (or excluded) can be directed to: IDEASRequests@ga.gov.au.

2. Introduction

Geoscience Australia (GA) has been acquiring and collating bathymetric survey, seismic and sampling data for the Australian jurisdiction since 1963 (Webster et al, 2005). GA is also the national custodian of bathymetric data for Australia and as such holds data acquired by a range of other sources including scientific institutions, universities, oil exploration companies and the Australian Hydrographic Service. The data sources and quality vary greatly from digitised hydrographic charts (less accurate and often with digitising errors), to the more accurate multibeam datasets including swath and Laser Airborne Depth Sounder (LADS).

Buchanan (1998) compiled Geoscience Australia's first digital bathymetry grid based on the data sets available at the time. This grid covered 9°S - 45°S, 108°E - 160°E, and was produced at a 30 arc second (approximately 1km) cell size. In 2000 Petkovic and Buchanan created a revised version of the 1998 bathymetry grid. In 2005 Webster and Petkovic released new bathymetric grid, created using a different methodology, with the addition of new data sets.

While much of the original data and the processes used to create the 2009 grid are similar to those used in the 2005 grid, the 2009 grid described in this document has been compiled using a slightly different methodology. It also contains additional multi-beam data, but still lacks many of the available LADS datasets.

This report documents the procedures used to construct the bathymetric grid to the extents: 92˚ E – 172˚ E and 8˚ S – 60˚ S (Figure 1). Additionally, in order to provide users with information on the source data at each grid cell, a lineage shapefile has been created to provide the source of the data at any given point.

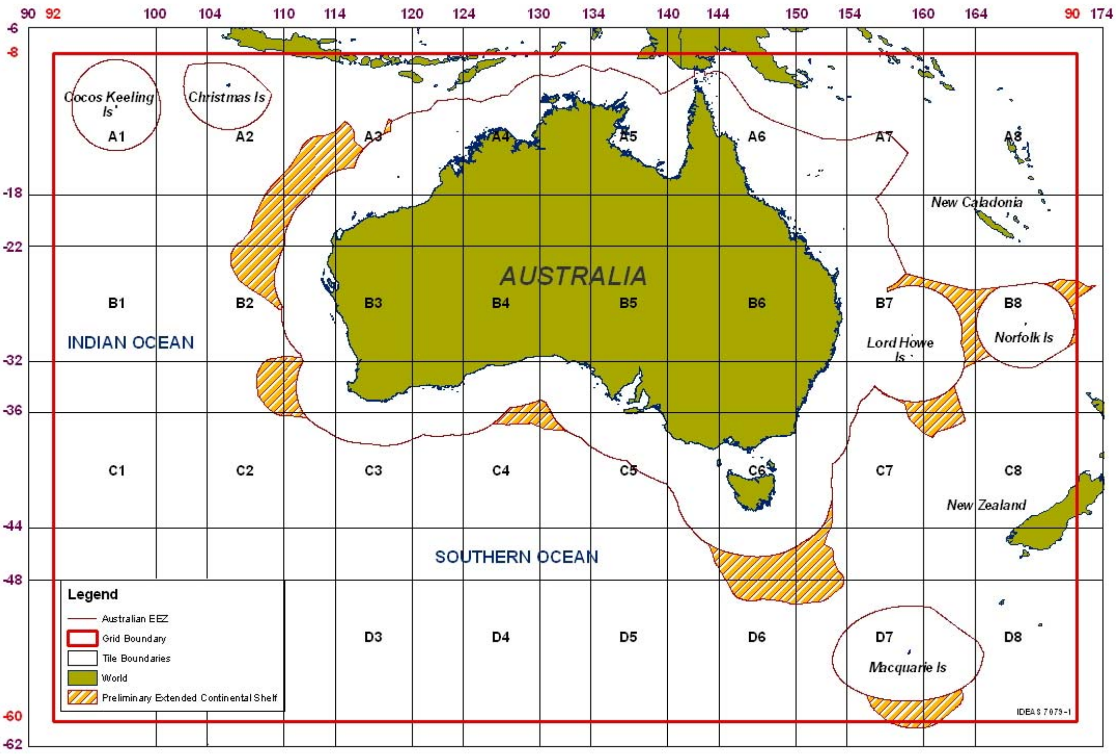


FIGURE 1: Extent of the 2009 Bathymetric grid of Australian (red boundary) and tiles (black lines)

3. Input Datasets

The following text describes each dataset used in the production of the 2009 grid. The input datasets used to create the final grid varied greatly in resolution, source and data type. In this revised version of the Australian bathymetry grid the following datasets were used:

- Multibeam
- Fairsheets and 1:250,000 Series
- Laser Airborne Depth Sounder (LADS) (Only those LADS datasets that had previously been converted from LAT were used in this grid)
- Satellite altimetry measurements – ETOPO2v2g
- Australian topography
- New Zealand topography
- SRTM DEM

Single beam datasets were not used in the creation of the 2009 grid (see below). All datasets once gridded were shifted to ensure cell alignment matched the Australian DEM prior to mosaicing to ensure the accuracy of the Australian DEM was maintained. Methodologies used in these processes are outlined in Part 4.

SINGLE BEAM DATA

Measurements of water depth particularly in deep oceans were nearly impossible to gather prior to the development of echosounder tools. Echosounders are a form of active sonar that create a sound (or ping) that is bounced off the ocean floor. On the ping's return, the transducer (antenna) receives the signal and based on the speed of return and the known speed of sound through the water column, the water depth is calculated. Single beam echo sounders collect bathymetry data along a ships path (often referred to as ship track data).

In previous Australian bathymetry grids single beam has been included particularly for areas of deep ocean where there are limited other sources of data. In the 2009 grid, the single beam dataset was considered for inclusion, but was not used due to issues emerging from its use in previous grids, specifically:

- The inclusion of single beam data in previous grids has resulted in lines/stripes of high resolution data running through the lower resolution ETOPO data. This causes artefacts that look like channels and ridges running through the grid
- There are also issues associated with the quality of the raw data. These include:
    - levelling and historic navigation issues which means the data is often inaccurate, and;
    - limited time available to clean the data, which means 'dirty' areas of data in the single beam datasets still exist.

Additionally, a majority of the single beam data covers the shelf. In the majority of shelf areas, there are better quality datasets available including multibeam and LADS that can be used to produce a more accurate and consistent grid. The compliment of issues surrounding the use of the single beam data has led to its exclusion from the 2009 version of the grid.

MULTIBEAM (SWATH) BATHYMETRY

Multibeam echosounders map the seabed using a 'fan-shaped swath' of sonar beams. This allows for large areas of seabed to be mapped in a relatively short time, making them a more efficient tool than single beam echosounders.

Multibeam or swath datasets are an extremely valuable source of bathymetric data, providing highly accurate broad coverage for both on and off shelf areas. As the national custodian for bathymetric data, GA holds data from government organisations, academic and foreign institution multi-beam survey data. Appendix 1 lists the swath surveys used in this grid (Figure 5).

All GA swath datasets are initially cleaned in CARIS HIPS/SIPS software and are exported as xyz files for use in gridding packages. The swath datasets used in this grid have not been decimated or averaged prior to gridding.

DIGITAL BATHYMETRY FROM NATMAP 1:250,000 SERIES AND AHS FAIRSHEETS

The following section has been extracted from Webster and Petkovic (2005).

"In 1994, GA received a set of charts from the Australian Hydrographic Service, Royal Australian Navy (AHS), sourced from the NATMAP 1:250,000 bathymetric series. These charts included contours on the face of the map and soundings as spot depths on the back. The spot depths for a subset of the charts, mainly for the NW Shelf and Gulf of Carpentaria, were captured digitally by the AHS, and these data were provided to GA. The digitisation of the remainder of the charts was continued by GA and completed in 2001.

At the request of GA, the AHS provided an additional set of charts as scanned images for the shelf in selected regions. These 'fairsheets' displayed hand-written spot depths for surveys completed over various periods of time. To save costs the fairsheets were digitised selectively, leaving out near coastal data points, and, as a general rule, digitising lines to a minimum spacing of 2 nautical miles (~3.7 km). Some charts of high interest to clients were digitised in entirety. There are 1049 charts in the collection."

These raw datasets have been collected in a range of different Datums, and due to time constraints many of these have not been converted back to a single datum (MSL). The raw data points are stored in GA's Oracle database and can be extracted by location as required.

LASER AIRBORNE DEPTH SOUNDER

The following section has been extracted from Webster and Petkovic (2005).

"The AHS has been operating its Laser Airborne Depth Sounder (LADS) systems since 1993. The system uses red and green laser light emitted from a stabilised platform inside a fixed wing aircraft. The light pulses reflected from the sea surface (red) and sea floor (green) are separately detected, and the time difference between the sea surface and sea floor returns allows calculation of the water depth.

Data are typically acquired at a rate of 900 soundings in a 240 m wide x 5 m long swath per second. The system works best in clean water of the pristine coral reefs of the Coral Sea down to 70m depth. Shallower maximum depths are achieved in other areas, such as Great Barrier Reef, Bass Strait, Timor Sea (40-50m), South Australia (30-35m), Torres Strait (15-25m), and anywhere waters are not clear."

The LADS data is of particular importance to the large scale 0.0025° bathymetry grid because;

- it fills the area between the coastline (Australian DEM) and the offshore datasets such as swath, and
- it provides excellent edge boundaries for reefs, coastlines and islands.

"AHS provided GA with LADS data around Australia, including 1773 LADS datasets. In order to be included in the gridding process, each dataset needed to be converted from HTF format into XYZ, be datum converted from LAT to MSL and, each dataset needed to be imported into Intrepid™ as an Intrepid™ database. Due to time constraints only the LADS data used previously in the 2005 Australian bathymetry grid was used for this grid. The LADS datasets used included data from Queensland waters particularly around the Great Barrier Reef."

Only limited LADS datasets were used in the production of the 2009 grid due to the limited coverage they provide, and lack of conversion time and storage available to convert these datasets from the LAT to MSL Datum.

SATELLITE MEASUREMENTS – ETOPOV2G AND ETOPO1

The 2 arc minute ETOPO2v2g (U.S. Department of Commerce, 2006) data based on predicted bathymetry from satellite altimetry (Smith and Sandwell, 1997) was used as base data for the grid where more accurate data sources were not available (i.e. for much of the deep ocean).

In 2008 during development of the revised Australian bathymetric grid, a 1 arc minute version of ETOPO, ETOPO1 (Amante and Eakins, 2008) was released. In the Australian region, this dataset is based primarily on GEBCO estimated Seafloor bathymetry. It was used as a late inclusion to replace data in the top left of the Australian bathymetry grid where both he Australian, and ETOPO2v2g data were inaccurate.

The ETOPO grids were resampled to 0.0025dd using a bilinear conversion as the nearest neighbour method created grid artefacts including striations. In the 2009 version of the grid the ETOPO data appears to be less smooth and less detailed than the ETOPO data in the 2005 bathymetry grid. In the 2005 bathymetry grid the ETOPO data was reinterpolated in Intrepid, in the 2009 version there was no interpolation in order to keep the values consistent with those produced in the original ETOPO data.

This predicted bathymetry (Figure 2) was included in areas where the high-resolution data (swath and digitised charts) were not available, and was not used on the Australian shelf. All other datasets were mosaiced on top of the ETOPO data. The predicted bathymetry contributes the characteristic artefact of rippled noise which has a wavelength of about 25km and amplitude of about 200m in the deep water.

AUSTRALIAN TOPOGRAPHY

The Australian 9" DEM (Geoscience Australia, 2008) (Figure 3) was used as the topographic dataset for the Australian Continent and surrounding islands. This is GA's 4th edition DEM and has been calculated using ANUDEM v 5.2.2.

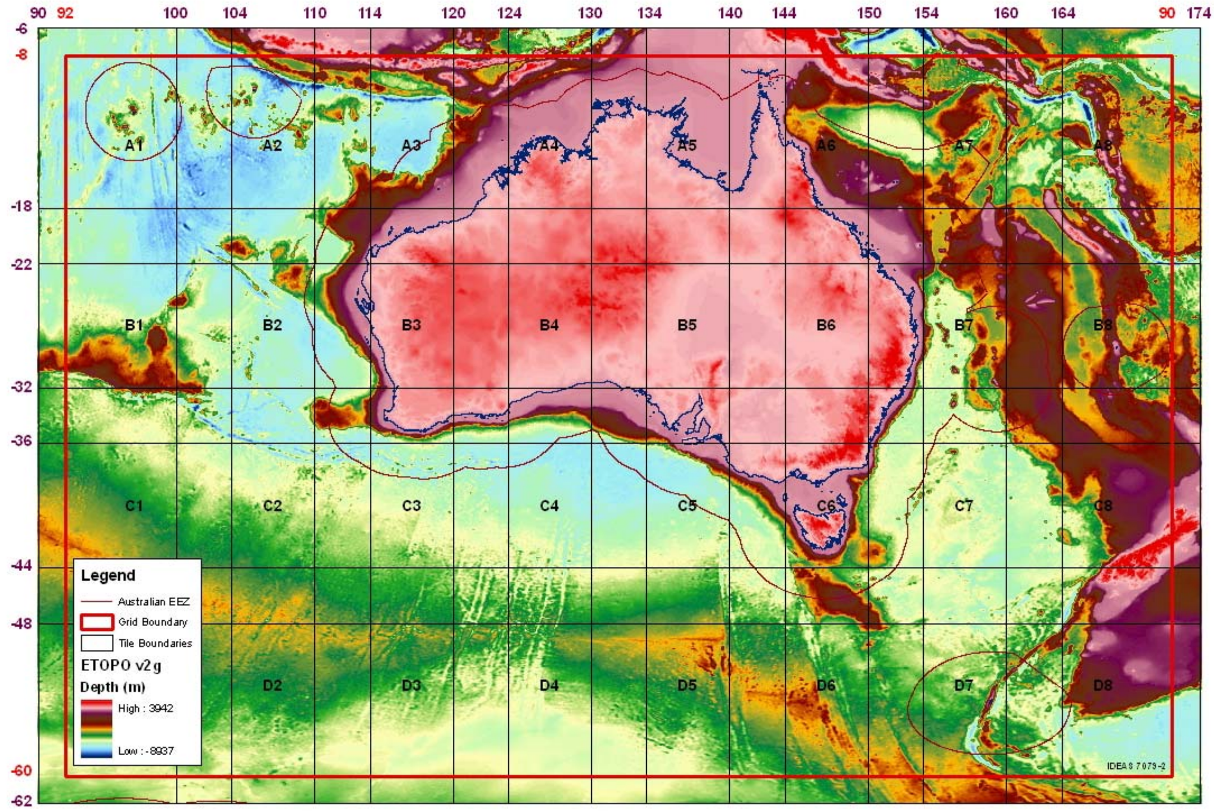


FIGURE 2: ETOPO2v2g (U.S. Department of Commerce, 2006)

NEW ZEALAND TOPOGRAHY

The 250m New Zealand DEM was sourced from Geographx (NZ) Ltd (2008) in Ascii format, non-projected, NZ Mercator datum (Figure 3). The projection of this dataset was modified to WGS84 and, as with the Australian DEM, was then directly mosaiced over the other datasets without feathering or smoothing.

SRTM DEM

The 90m Shuttle Radar Topography Mission (SRTM) DEM (Figure 3) was sourced for the southern areas of Papua New Guinea and Indonesia from the CGIAR Consortium for Spatial Information (CIGAR-CSI) in the WGS84 datum in the ASCII format. The individual datasets were mosaiced and then resampled to 0.0025dd using ArcGIS nearest neighbour method, and values below 0m were removed so that only land based values were used. The SRTM data was then directly mosaiced over the other datasets without feathering or smoothing.

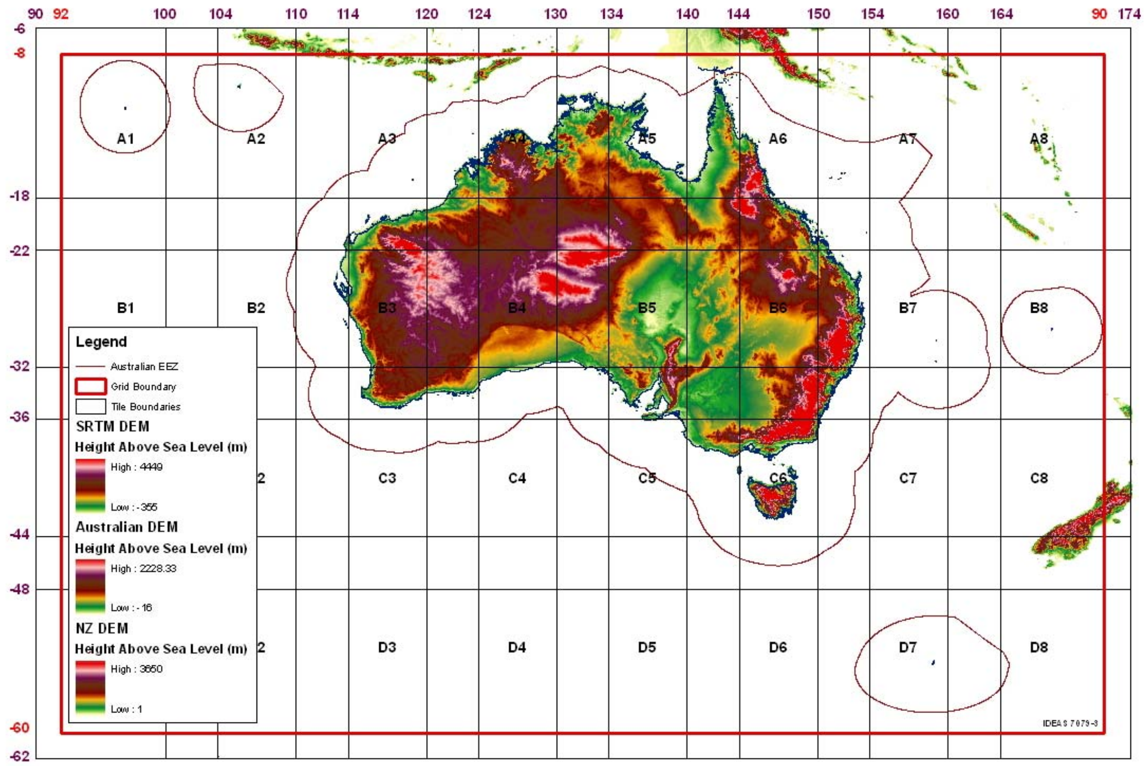


FIGURE 3: Australian (GA, 2008), NZ (Geographx, 2008) and SRTM (Jervis et al., 2008) Digital Elevation Models (DEM's) used in the production of the 2009 bathymetric grid of Australia

CHRISMAS, COCOS AND LORD HOWE ISLAND BATHYMETRIC GRIDS

For the Christmas, Cocos and Lord Howe Islands, bathymetric grids had been produced with hand edited data. Fledermaus with the 3D editor were used to compare input data points, and points not consistent with the higher accuracy datasets (swath and LADS) were deleted prior to gridding. The island datasets have been gridded in Intrepid and have been incorporated into the revised bathymetry grid to improve accuracy in these regions.

GRID FOR THE GULF OF PAPUA AND ADJACENT AREAS

The grid in the region of the Gulf of Papua (Figure 4) was created using a combination of processes from GMT (Generic Mapping Tools) to average the input data points and ANUDEM to grid the final product (Daniell, 2008). The Gulf of Papua grid comprises the following input datasets:

- Multibeam sonar
- Australian Hydrographic Service (AHS) Fair sheet and survey data
- Ship Track and Miscellaneous data (including external surveys)
- SRTM
- Landsat derived Bathymetry

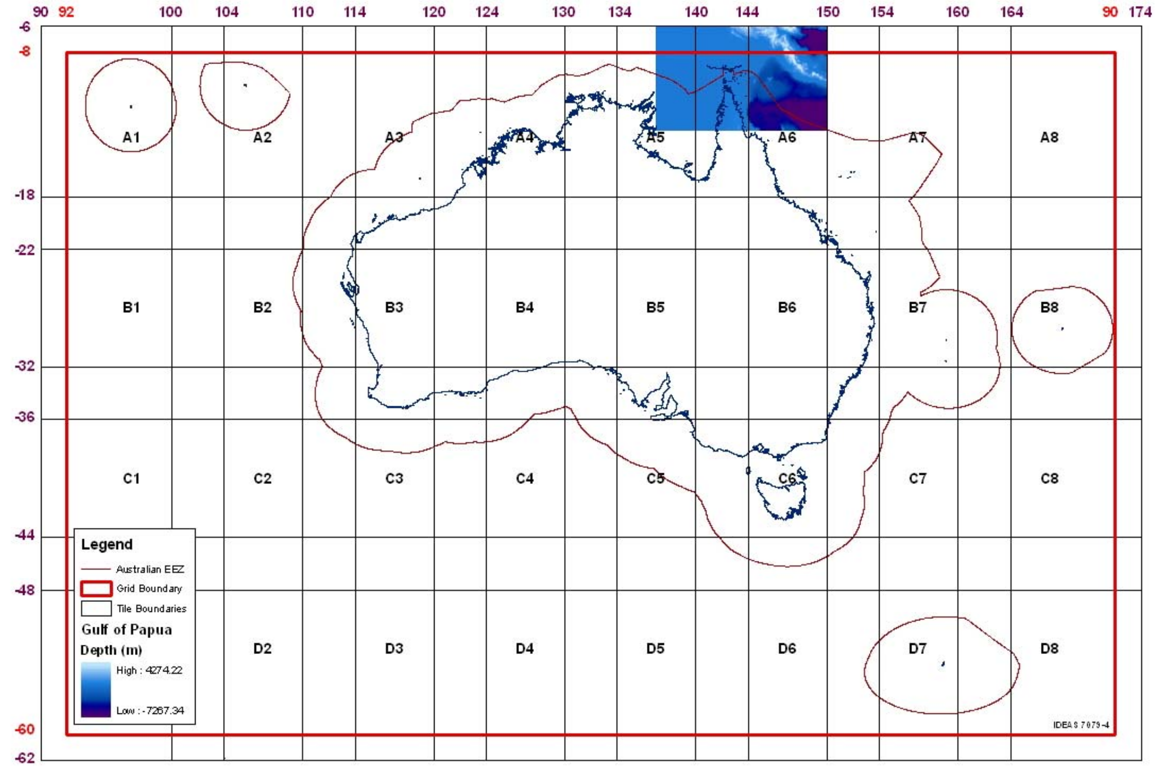


FIGURE 4: Gulf of Papua and adjacent areas grid (Daniell, 2008) used in the production of the 2009 bathymetric grid of Australia

4. The Process

A number of programs were used to create the 2009 revised Australian bathymetry grid, in particular:

- **ArcGIS** for review of gridded data, mosaicing without feathering and the creation of the lineage shapefile.
- **ER Mapper** for gridding replacement data in problem areas, and for data review.
- **Intrepid™** for initial raw data editing for Fairsheets, gridding and mosaicing with feathering.

The process used to develop the grid is summarised in Table 1, which defines an eleven step sequence.

Table 1 – Summary of steps and processes used to create the 2009 bathymetric grid

STEP / INTERIM GRID PROCESSES	ANALYSIS TYPE	INPUT PARAMETERS
STEP 1 – AREA OF INTEREST		
STEP 2 – DATA PREPARATION		
STEP 3 – IMPORT DATA INTO INTREPID™ DATABASES		
STEP 4 – CREATE TILE GRIDS, CLIP AND MERGE TILED GRIDS INTO A SINGLE GRID		
Surveys grid • LADS • Swath • Fairsheets with AHD Datum • Fairsheets with Non-AHD datums • Fairsheets with Unknown datums • Reef s lines	Gridded together (Intrepid™) Tiles clipped and mosaiced in ArcGIS	• Cell Size = 0.0025 • Minimum Curvature tension = 0.5 • Maximum Iterations = 100 • Maximum Residual = 1.0 m • Extrapolation = 10 cells • Additional Smoothing = No • Initial Cell Assignment = Nearest Neighbour • Output Precision = IEEE4ByteReal
STEP 5 – CLEANING SURVEY GRIDS		
Surveys grid cleaned	Cleaned in ER Mapper	• Erroneous data set to null using region editing
STEP 6 – FILLING ON-SHELF ZONES AND HOLES		
Australian DEM	Sourced Internally	

NZ DEM	Sourced from Geographix	• Resampled to 0.0025dd cell size • Shifted to match the Australian DEM
SRTM DEM	Sourced from CGIAR	• Resampled to 0.0025dd cell size • Shifted to match the Australian DEM
Surveys with Land • Fairs heets/swath/LADS mosaiced dataset • Australian DEM (values set to 0m) • NZ DEM (values set to 0m) • SRTM DEM (values set to 0m)	Mosaic with no feathering (ArcGIS)	N/A
On-shelf filled grid • Fairs heets/swath/LADS mosaiced dataset • Filled on-shelf areas	Mosaic with no feathering (ArcGIS)	• Holes in on-shelf zones filled using ER Mapper's gridding tool parameters: • Boundary Tension = 0% • Interior Tension = 0% • Convergence speed = 40% • Convergence Limit = 0.1 • Minimum No Iterations = 255 • Aspect Ratio = 1 • Filled areas mosaiced under Fairsheets/swath/LADS dataset
STEP 7 – MOSAICING ALL GRIDS		
Gulf of Papua grid	Sourced Internally (Daniell, 2008)	• Shifted to match the Australian DEM
Christmas Island Grid	Sourced Internally and data added	• Shifted to match the Australian DEM • Converted to point • Re-gridded in Topogrid (ArcMap) with additional data (GA2476)
Cocos Island Grid	Sourced Internally	• Shifted to match the Australian DEM
Lord Howe Island Grid	Sourced Internally	• Shifted to match the Australian DEM
ETOPO2v2g Grid	Sourced from US Departmen t of Commerce	• Resampled to 0.0025dd cell size • Shifted to match the Australian DEM

Higher accuracy grid • Gulf of Papua grid • Christmas, Cocos and Lord Howe Island grids • On-shelf filled	Mosaic with no feathering (ArcGIS)	N/A
Higher accuracy and ETOPO2v2g • Higher accuracy grid • ETOPO2v2g	Mosaic with no feathering (ArcGIS)	N/A
High resolution/ETOPO2v2g and Land • Australian DEM • NZ DEM • SRTM	Mosaic with no feathering (ArcGIS)	N/A
STEP 8 – CLEANING MOSAICED GRID		
Cleaned grid • High resolution/ETOPO2v2g and Land	Cleaned in ER Mapper	• Erroneous data set to null using region editing • Holes filled using ER Mapper's gridding tool parameters: • Boundary Tension = 0% • Interior Tension = 0% • Convergence speed = 40% • Convergence Limit = 0.1 • Minimum No Iterations = 255 • Aspect Ratio = 1
Cleaned mosaiced grid • High resolution/ETOPO2v2g and Land cleaned • Fill areas	Mosaic with no feathering (ArcGIS)	N/A
STEP 9 – FINAL ADDITIONS		
Final Additions • Cleaned mosaiced grid • GA2476 leg 3 • GA2447 • GA2413	Mosaic with no feathering (ArcGIS)	N/A
STEP 10 – CLEANING FINAL ADDIITIONS GRID		
ETOPO1 Grid	Sourced from US Department of Commerce	• Resampled to 0.0025dd cell size • Shifted to match the Australian DEM

Addition of ETOPO1 data • Final Additions grid	Mosaic with no feathering (ArcGIS)	N/A
Cleaned grid • Final Additions grid	Cleaned in ER Mapper	• Erroneous data set to null using region editing • Holes filled using ER Mapper's gridding tool parameters: • Boundary Tension = 0% • Interior Tension = 0% • Convergence speed = 40% • Convergence Limit = 0.1 • Minimum No Iterations = 255 • Aspect Ratio = 1
Cleaned mosaiced final grid • Final Additions Grid • Fill areas	Mosaic with no feathering (ArcGIS)	N/A
STEP 11 – FINAL PREPARATION OF PRODUCTS		
Integer grid	Integer (ArcGIS)	• Grid values set to integer, as the cell size and data quality does not support sub-metre accuracy
Clipped grid	Clip (ArcGIS)	• Grid clipped to final extents (9°S - 45°S, 108°E - 160°E)

STEP 1 – AREA OF INTEREST

The Area of Interest was defined to match the 2005 Bathymetry grid. Two degrees were added to each edge of the grid and removed at the end of processing to reduce edge effects. In figure 1 the outer red boundary represents the final outer boundary of the grid. The initial grids were interpolated to the outer black boundary prior to clipping.

AOI extents: 92, 172, -8, -60
Extended AOI extents: 90, 174, -6, -62

STEP 2 – DATA PREPARATION

Raw Data

Raw data points used in this grid included swath, fairsheets and LADS datasets. Due to the large extent of raw data and limited computing capacity, the area of interest was divided into 32 tiles, 14 degrees wide by 11 degrees long, with 4 degrees of overlap (trimmed before merging). All raw datasets were converted to XYZ files from the database (in tiles as represented in figure 1), and each input dataset was exported to XYZ format on a tile by tile basis.

ETOPO2v2g

ETOPO2v2g has a cell size of 0.033dd. In order to incorporate the data into the bathymetry grid the data was resampled to a 0.0025dd cell size using bilinear interpolation in ArcGIS. The bilinear interpolation process interpolates the new values of each smaller cell using a bilinear function. Original values of the ETOPO2v2g data have not been preserved, as a result.

ETOPO1

ETOPO1 has a cell size of 0.0167dd. In order to incorporate the data into the bathymetry grid the data was resampled to a 0.0025dd cell size using bilinear interpolation in ArcGIS. The bilinear interpolation process interpolates the new values of each smaller cell using a bilinear function. Original values of the ETOPO2v2g data have not been preserved, as a result.

Australian Topography

The Australian topography grid required no conversions and was used as the base grid to which all other grid were shifted to maintain a single cell configuration throughout the processing.

New Zealand Topography

The projection of this dataset was modified from NZ Mercator datum to WGS84. Values below 0m were removed so that only land based values were used.

SRTM DEM

The SRTM data was downloaded as individual blocks of data. These datasets were mosaiced and then resampled from a cell size of 0.00083dd to 0.0025dd using ArcGIS nearest neighbour method. Values below 0m were removed so that only land based values were used.

Christmas, Cocos and Lord Howe Island Bathymetric grids

The Christmas, Cocos and Lord Howe Island Bathymetric grids required no conversions.

Gulf of Papua and Adjacent Areas Bathymetric grid

The Gulf of Papua and Adjacent Areas Bathymetric grid required no conversions.

STEP 3 – IMPORT DATA INTO INTREPID™ DATABASES BASED ON TILES

Each raw XYZ file was imported into an Intrepid™ database using WGS84 datum with geodetic projection. Intrepid was chosen because it is widely used within GA as a geophysical processing tool, and the gridding tool allows considerable flexibility of parameter control, grid masking, and auxiliary operations such as stitching, merging and editing (Billings and Fitzgerald, 1998).

STEP 4 – CREATE TILE GRIDS, CLIP AND MERGE TILED GRIDS INTO A SINGLE GRID

Gridding

The datasets gridded in this process included:

- Multibeam – swath
- Fairsheets with AHD Datum
- Fairsheets with Non-AHD datums
- Fairsheets with Unknown datums
- LADS

The multibeam, fairsheet and LADS datasets were gridded together to minimise the propagation of edge effects where the different datasets meet. The grids were computed using Intrepid software, which requires data to be present in an Intrepid database or set of databases.

"Intrepid was chosen because of its ease of use with large datasets, its combination of GUI and batch operation, fine control over parameter setting, large user base within the organisation, associated grid manipulation utilities, and mature version history. To create the present grid Intrepid was used in batch mode accessing several databases sequentially. These same databases can be updated as the need requires, and grids of any specification can be created from them.

Intrepid was originally designed to deal with potential field data, and uses the minimum curvature algorithm which is not well suited to topography. Other software such as that of Hutchinson (1989) deals effectively with stream-lines and roughness, for example, but doesn't allow masking, which is essential to the present task.

In order to simulate the roughness of topographic character in Intrepid, the minimum curvature tension parameter was set to mid-way between pure minimum curvature and pure minimum potential. This avoids some of the over-shoot that results from minimum curvature surface fitting in areas of poor control, while at the same time doesn't produce severe cusps at data points. Inspection of test grids indicates that this compromise setting gives sufficiently smooth results yet retains some of the characteristic roughness of topographic data.

Billings and Fitzgerald (1998) discuss some of Intrepid's gridding options and its limitations. The main gridding parameters are given in the table below." (Webster and Petkovic, 2005)

Table 2 - Gridding parameter settings for Intrepid

Parameter	Value
Latitude range	8° S – 60° S
Longitude range	92° E – 172° E
Cell size	0.0025° (9")
Minimum curvature tension	0.5
Maximum iterations	100
Maximum residual	1.0 m
Extrapolation	10 cells (~1.5 km)
Setting no-data areas to null	Yes
Additional Smoothing	No
Initial cell assignment	nearest neighbour
Output precision	IEEE4ByteReal

Clip and Mosaic

Each grid was clipped in ArcGIS to remove the 2 degrees of excess (or 4 degrees of overlap) per tile. The final clipped grids were then mosaiced together using the 'mosaic to new raster' function in ArcGIS (Table 1). This is a direct overlay process with no feathering or smoothing used to produce a grid of the entire area (figure 5). The final grid mosaiced in this process is from here on called the 'surveys grid'.

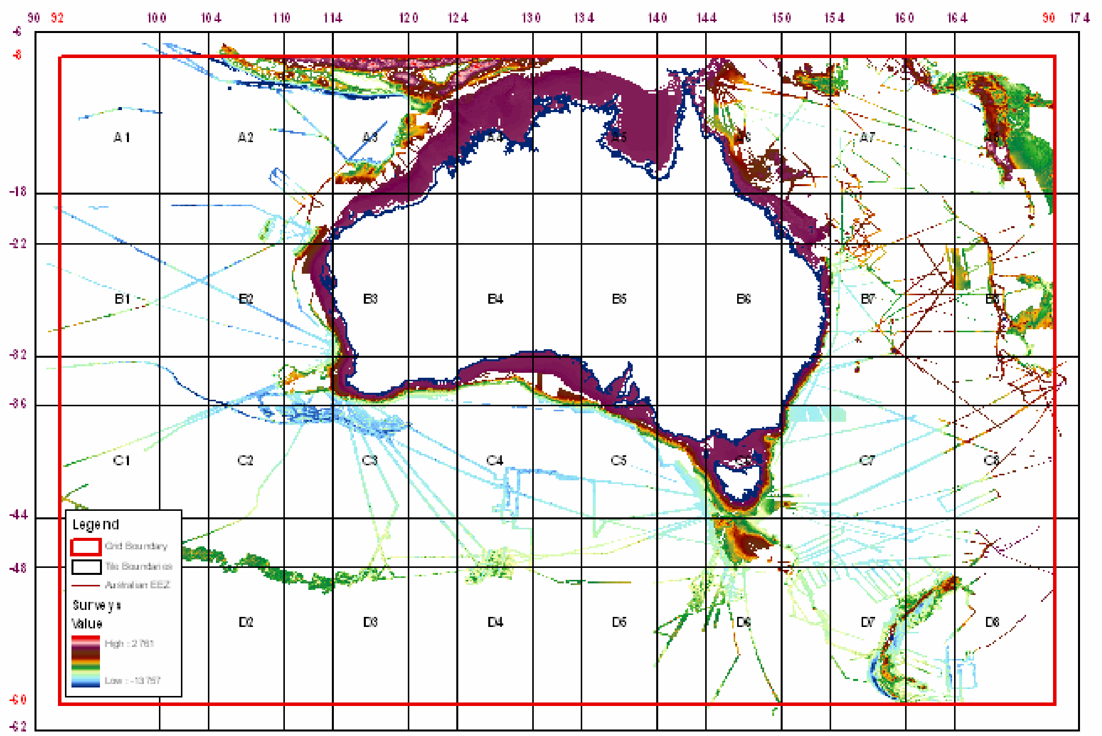


FIGURE 5: Surveys grid

STEP 5 – CLEANING SURVEYS GRID

All grids created from raw data had data errors that required editing or removal. In the case of Fairsheet data there were a number of digitising errors (in the raw data) that were identified after the first gridding process. These included extreme low and high points in areas of gentle slope. The erroneous points identified were checked against the original Fairsheets (which have previously been scanned and rectified). Where a digitising error was confirmed, the point was corrected (through editing in Intrepid™) prior to gridding, and the Australian Hydrographic Office was sent the x, y and z coordinates of any digitising errors for review.

In all other datasets the raw data was not modified due to the dataset size. The size of the datasets meant that editing program (Intrepid™) could not handle the datasets without regular crashing. Therefore, inaccurate data areas identified in any dataset (including some unresolved areas in the Fairsheets) were removed from the grided datasets using a clip process.

The removal of inaccurate data was undertaken in two steps:

1. For each grid the areas where data values were less than -9999m depth or greater than 1000m were set to null.
2. For each dataset a vector file (ER Mapper) of data errors to be removed was created, and used to clip out errors using the region set to null.

STEP 6 – FILLING ON-SHELF ZONES AND HOLES

In the on-shelf zone of Australia, and in some off-shelf areas, the data was dense enough that there were only small holes with no data coverage. In initial versions of the bathymetric grid, the ETOPO data was mosaiced behind the greater accuracy datasets to fill these gaps. However, in many cases the ETOPO data was vastly different to the higher quality data and caused spurious holes or ridges. Consequently in this version of the grid, areas where on-shelf gaps occurred were filled with data interpolated in ER Mapper™.

In previous versions there have also been issues caused by filling holes through interpolation that are connected to land areas. When ER Mapper interpolates between high land values and low ocean values the interpolation can create areas where ocean values are higher than the land.

In order to minimise these issues in this version of the grid, all values of the land grids (including Australia, SRTM and New Zealand) were set to 0m. These grids were then mosaiced (with no feathering) into the swath/LADS/fairsheets combination to set a value of 0m on the coast. An interpolation process was then run to fill the gaps between the sea values and land values.

The use of this process creates a secondary artefact in that there will always be a smooth interpolation from ocean values to the land (i.e.) deep water drop offs may be removed. However, this process does remove the occurrence of land values (i.e. > 0m) in the ocean area. The collection of data along the coast (both land and ocean) is vitally important to reduce errors in this part of the grid for future products.

A number of interpolation methods and input parameters were trialled including *tin to raster* and *topo to raster* in ArcGIS, Intrepid's *nearest neighbour* interpolation and ER Mapper's *tin* and *minimum curvature* interpolation techniques. The process selected was minimum curvature interpolation in ER Mapper. This process was able to grid large datasets effectively and created fewer artefacts than many other interpolation options.

A number of parameters for the minimum curvature technique were also trialled. The final parameters chosen minimised the tension requirements while ensuring that the tension was great enough to prevent the data from fluctuating wildly, as per the ER Mapper default values.

- Boundary Tension = 0%
- Interior Tension = 0%
- Convergence speed = 40%
- Convergence Limit = 0.1
- Minimum No Iterations = 255
- Aspect Ration = 1

The Minimum Curvature interpolation process re-interpolates all input data. Consequently the data from the interpolated grids was used to fill the holes only.

STEP 7 – MOSAICING ALL GRIDS

Grids were mosaiced with the highest accuracy grids on top and the lowest accuracy on the bottom. All grids were shifted prior to mosaicing to match the Australian DEM to ensure that both major products released from Geoscience Australia have common topography. Note that as a result the NZ DEM and SRTM DEM datasets will have been shifted slightly and will not line up perfectly with their original location.

In this grid the Gulf of Papua, Lord Howe, Christmas Island, ETOPO2v2g and Cocos Island grids were mosaiced with the surveys grid with a feathering process to reduce edge effects. The feathering process smooths the edges so that one grid mosaics with another grid without the large steps seen when no feathering is applied. The feathering process has been minimised so that only cells adjacent to the joins are feathered. The parameters used were:

- Overlap limit = 20m
- Filter length = 2500m
- Smoothing iterations = 100
- Smoothing residual = 1

All other grids (New Zealand Digital Elevation Models, the SRTM DEM) were mosaiced without feathering. These grids were directly overlaid with no smoothing to retain cliff lines and their original data values. If smoothing were undertaken on the DEM, cliff edges would be smoothed as part of the process.

STEP 8 – CLEANING THE MOSAICED GRID

Following the completion of a mosaiced version of the bathymetry grid, a number of edge effects and flaws in theof data required editing. These areas of data were located and set to no-data using region identification in ER Mapper. The holes created were then interpolated using the ER Mapper Gridding tool (with parameters as set in Step 7) and these fill areas were mosaiced with no feathering.

STEP 9 – FINAL ADDITIONS

On completion of the grid three additional datasets were identified that needed to be added. These datasets (GA2413, GA2477 and GA2476 – Leg3) were mosaiced into the final dataset without feathering in ArcGIS.

STEP 10 – FINAL CLEANING PROCESS

Following addition of new datasets a final version of cleaning was undertaken to ensure that there were no remaining edge effects or errors. The cleaning process was undertaken as per those outlined in Step 7.

Additionally in this step the top left section of the grid was removed and replaced with ETOPO1. ETOPO1 is a newly released version of ETOPO data that has higher accuracy, including data in regions plagued by poor data in ETOPOv2g. This data was used to fill areas where both swath and ETOPO2v2g datasets had inaccuracies.

STEP 11 – FINAL PREPARATION OF PRODUCTS

The final version of the bathymetry grid was converted to an integer grid as the 0.0025dd resolution and source accuracy of the data does not support higher accuracy. This version was then clipped to the required extent and projected to WGS84. The final 9" grid was then re-produced in ER Mapper, ESRI grid and ASCII XYZ formats.

5. Final Products

2009 BATHYMETRIC GRID OF AUSTRALIA

The 2009 bathymetric grid of Australia has been produced for modelling, visualisation and map presentation (Figure 6 through 11). Each dataset was gridded at 0.0025dd without smoothing, and overlayed with the best accuracy grids (swath) on top, and the least accurate (ETOPO) grid at the bottom (without feathering).The terrain models for Australia, New Zealand and Indonesia / Papua New Guinea have been directly overlaid with no smoothing to retain the raw data for each grid.

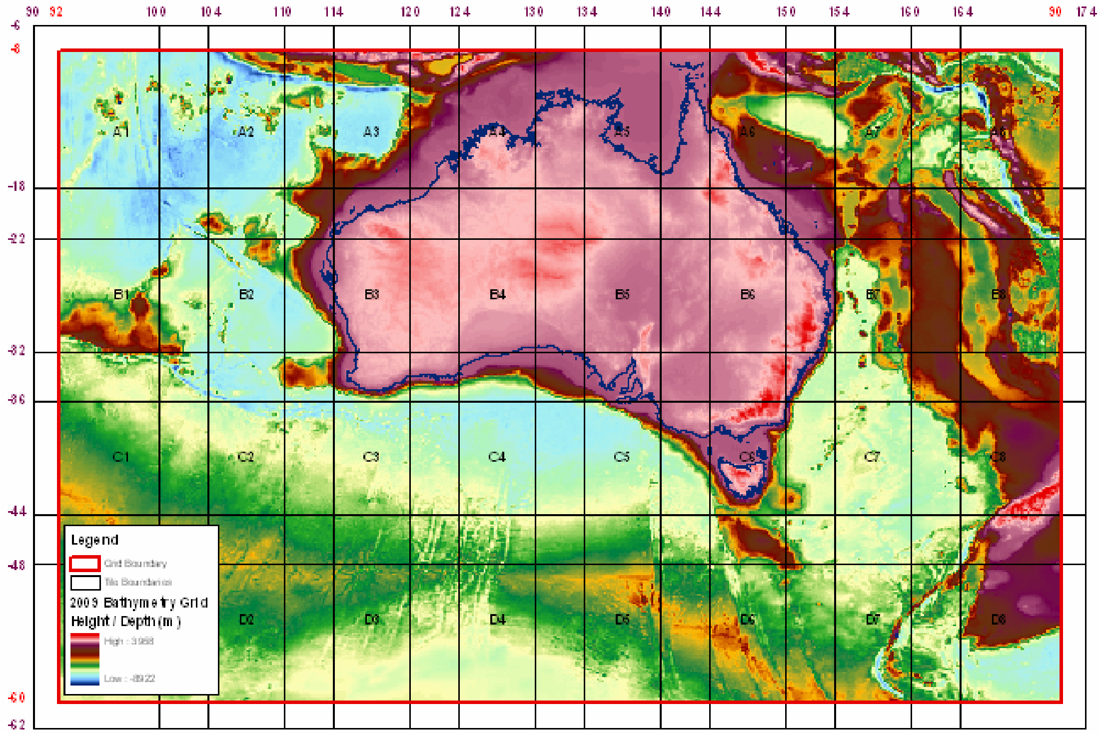


FIGURE 6: 2009 bathymetric grid of Australia

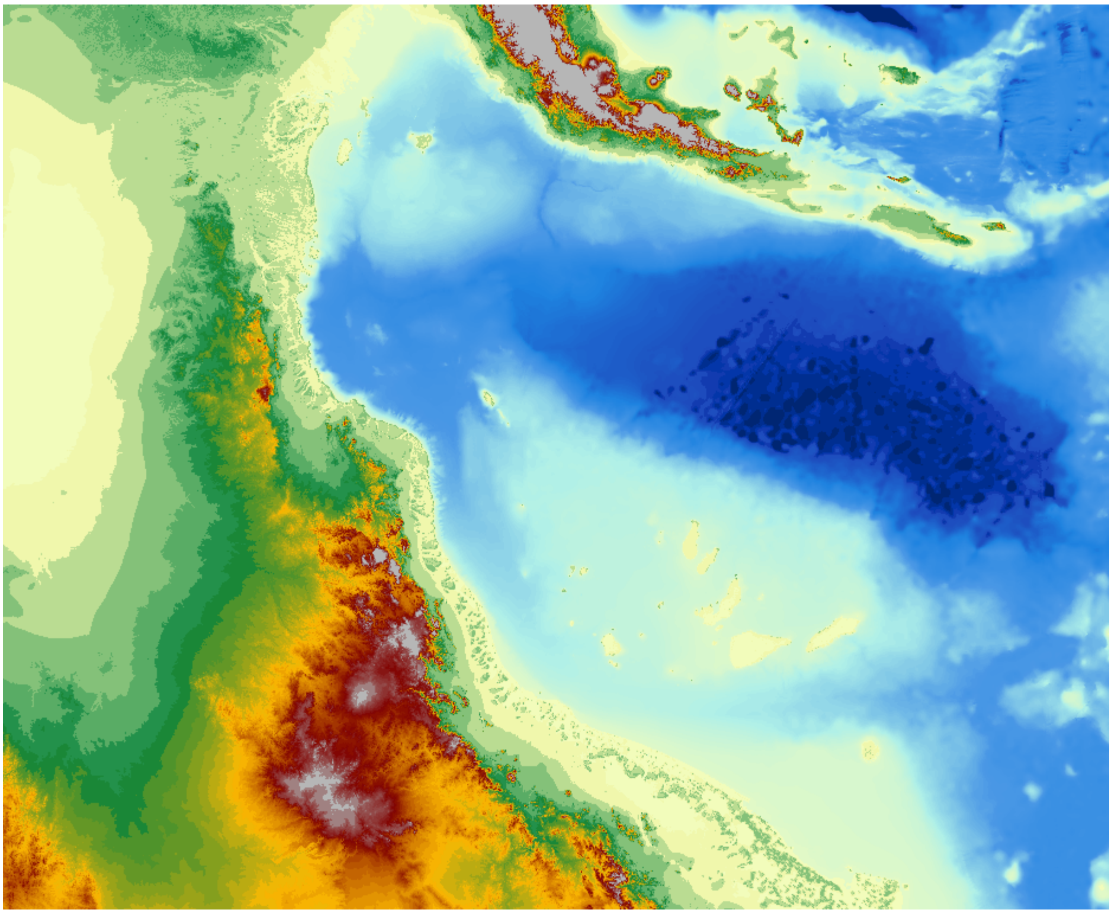


FIGURE 7: 2009 bathymetric grid of Australia - Queensland

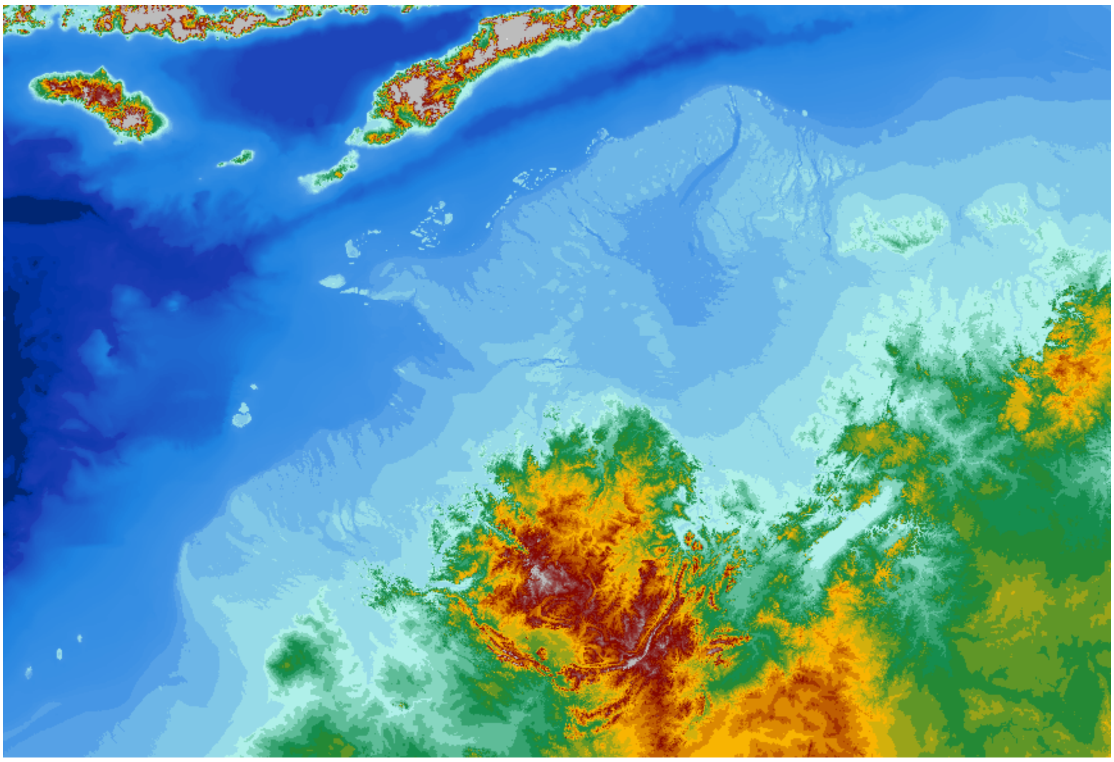


FIGURE 8: 2009 bathymetric grid of Australia – north-west Australia

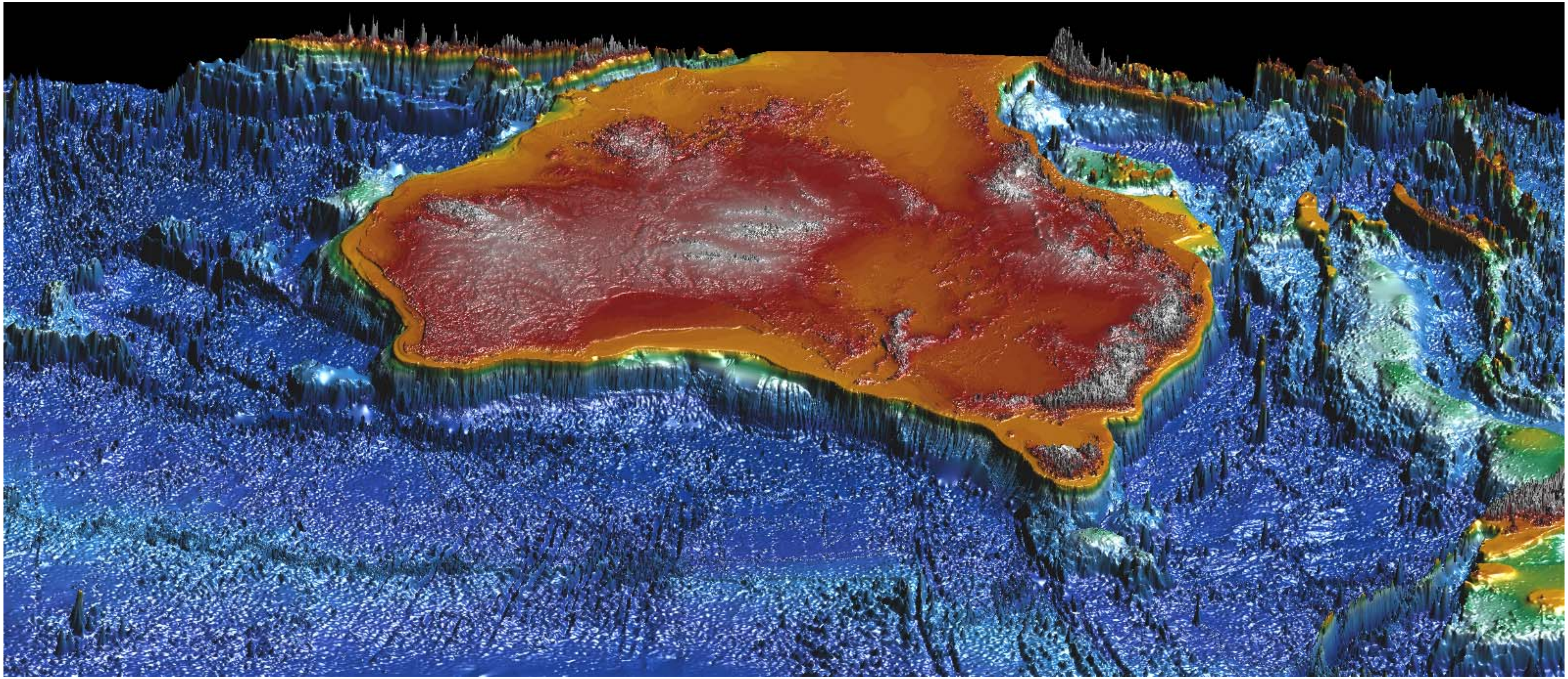


FIGURE 9: 3D view of the 2009 bathymetric grid of Australia – Western Australia

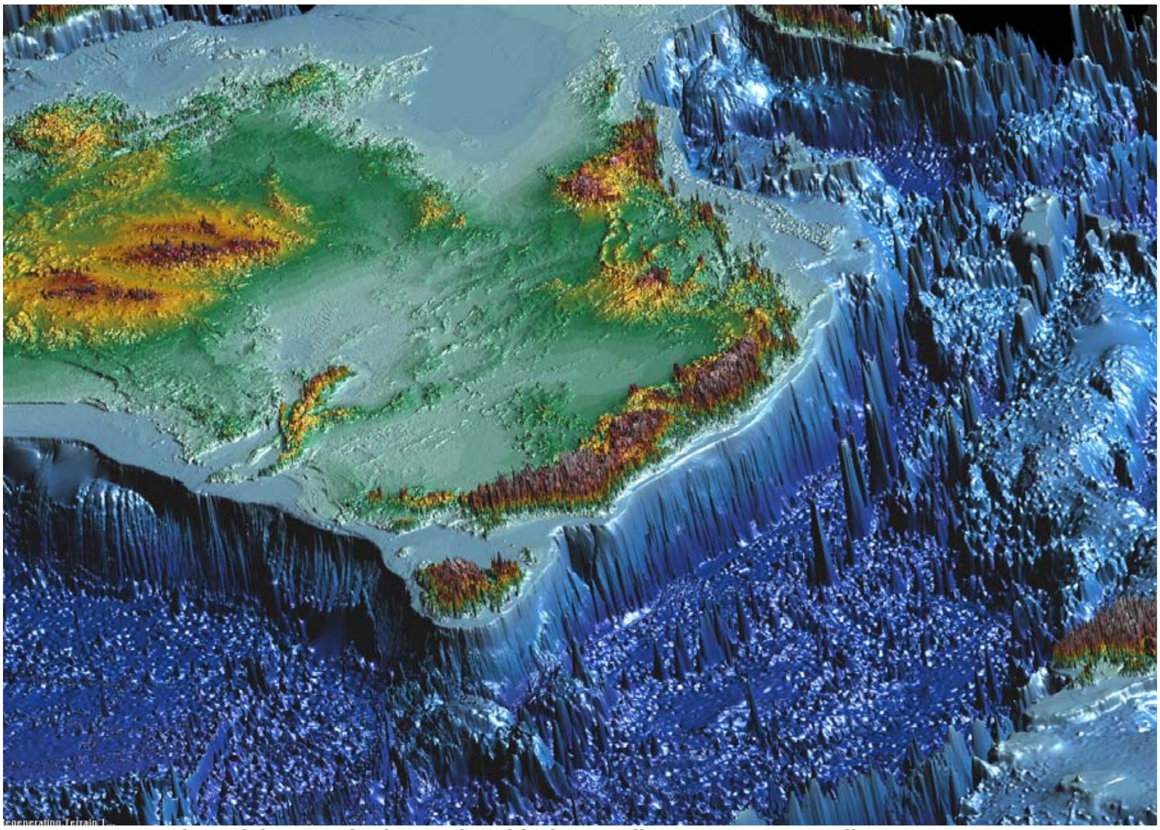


FIGURE 10: 3D view of the 2009 bathymetric grid of Australia – Eastern Australia

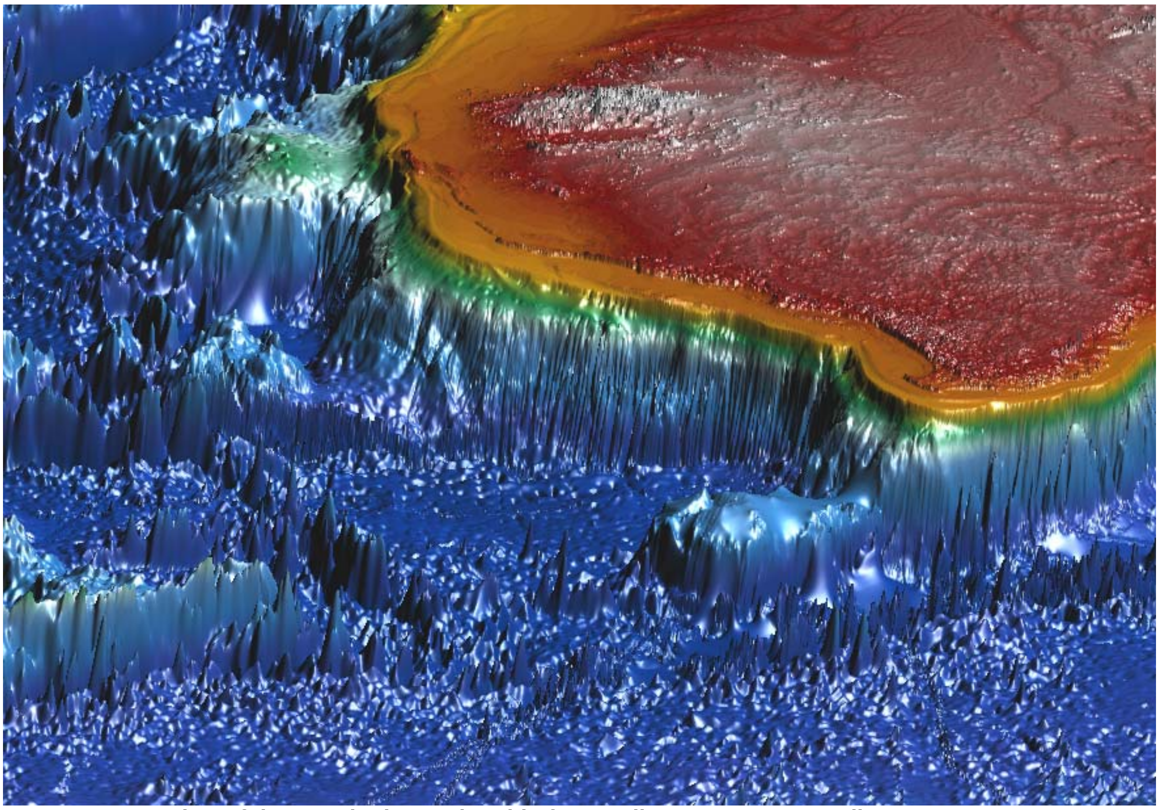


FIGURE 11: 3D view of the 2009 bathymetric grid of Australia – Western Australia

LINEAGE SHAPEFILE

An associated dataset, the lineage shapefile, was created to show the source input datasets for each part of the final grid (Figure 12).

The shapefile was created by converting each grid to an integer grid, and mosaicing these in the same order as the grids were mosaiced to produce the 2009 bathymetry grid. The mosaiced grid was then exported to shapefile. Note that there has been a smoothing process applied to the edges of the swath, fairsheets, LADS and around the island grids to allow for streamlined gradient between each data type. As such the areas where edges of each different dataset meet will not exactly replicate the original data sources in these locations.

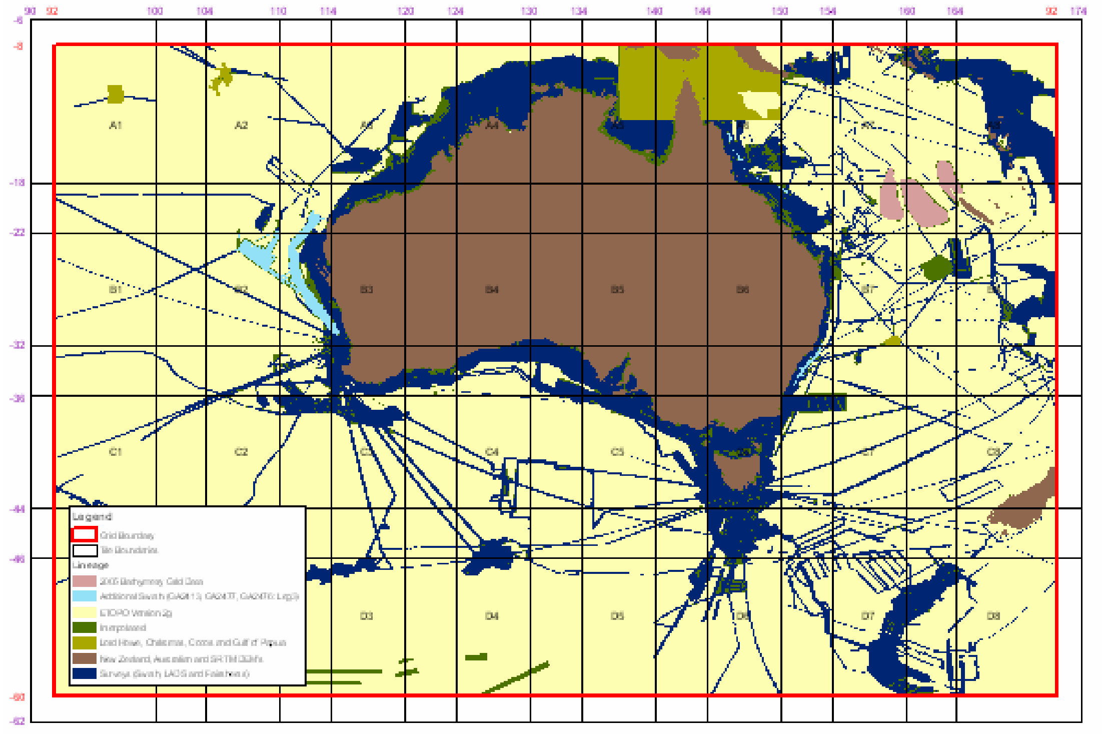


FIGURE 12: Lineage shapefile for the 2009 bathymetric grid of Australia

6. 2005 and 2009 Bathymetric Grids – A Comparison

In creating a revised bathymetric grid, a number of requirements were met. The following outlines the differences between the 2005 and 2009 bathymetric grids of Australia, particularly focussing on the required outcomes for the 2009 grid.

NEW DATA

The 2009 grid incorporates a number of new datasets where available. In particular a number of new Swath datasets were included as illustrated in figures 13 and 14. However no new LADS datasets were included in this grid due to time constraints.

a.

b.

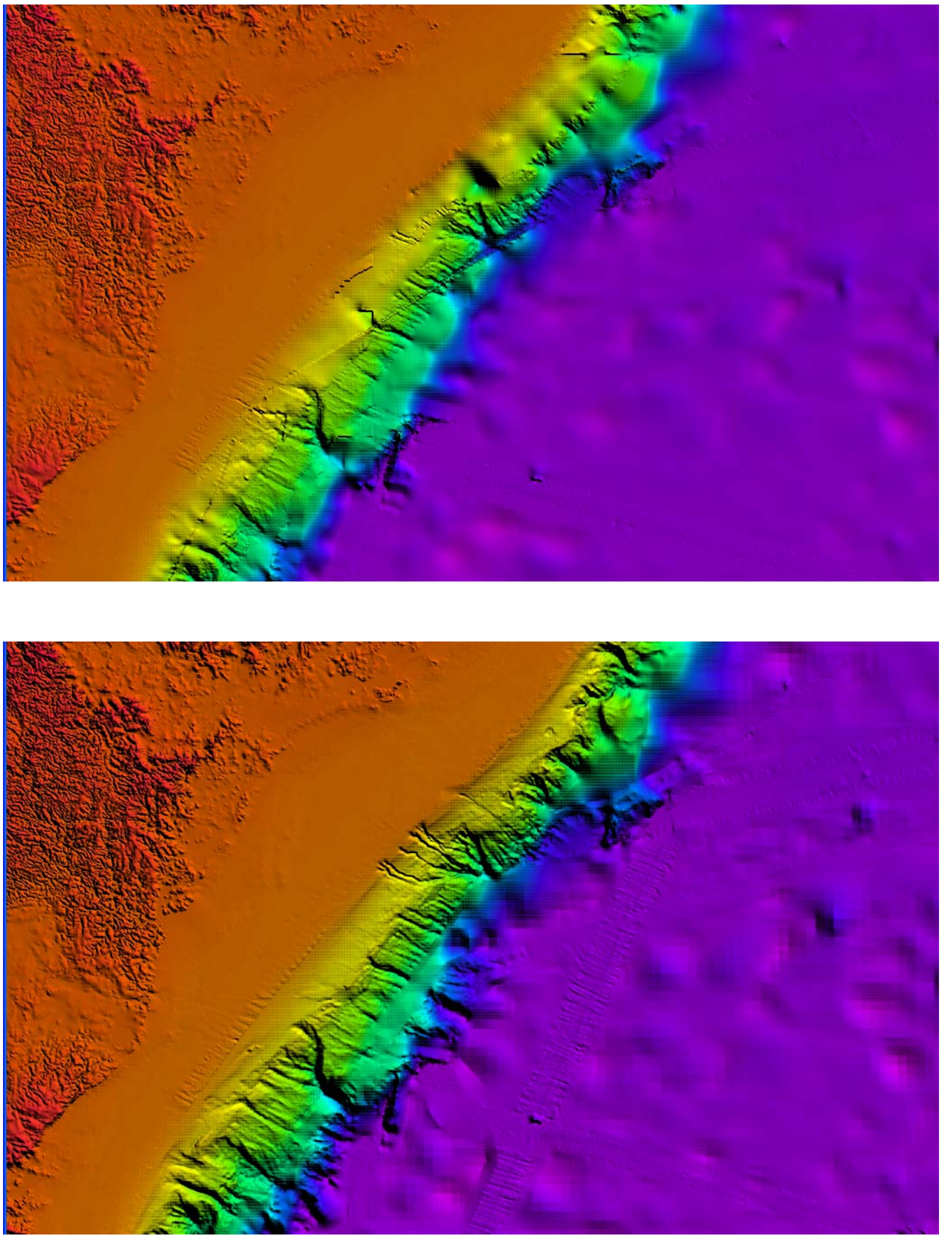
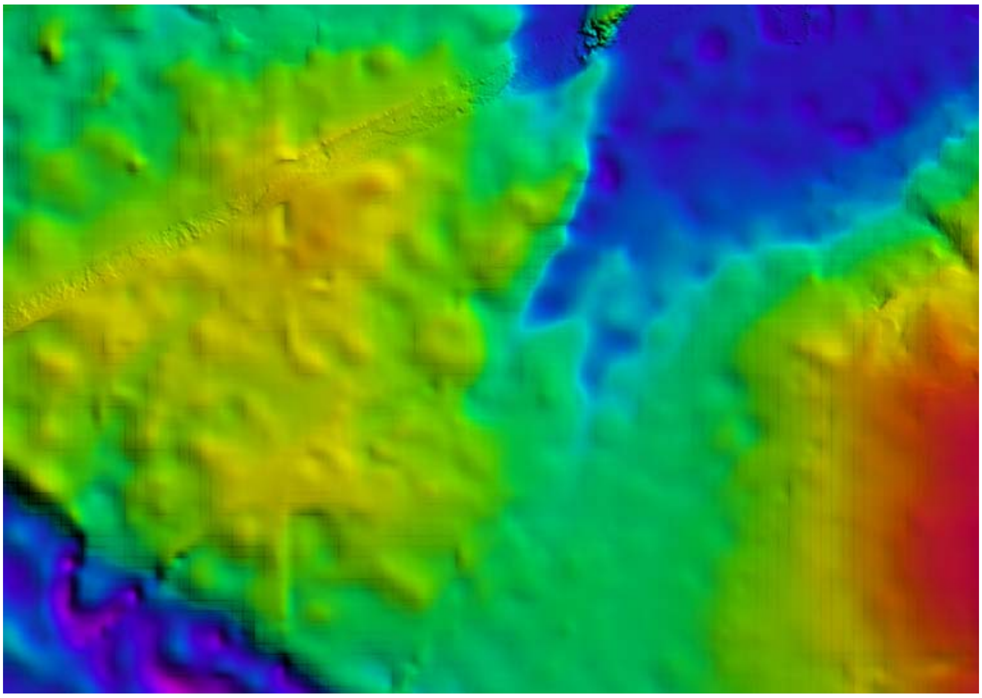


FIGURE 13: Addition of Swath data off the East Australian shelf in the 2009 grid (b) (2005 grid (a))

a.



b.

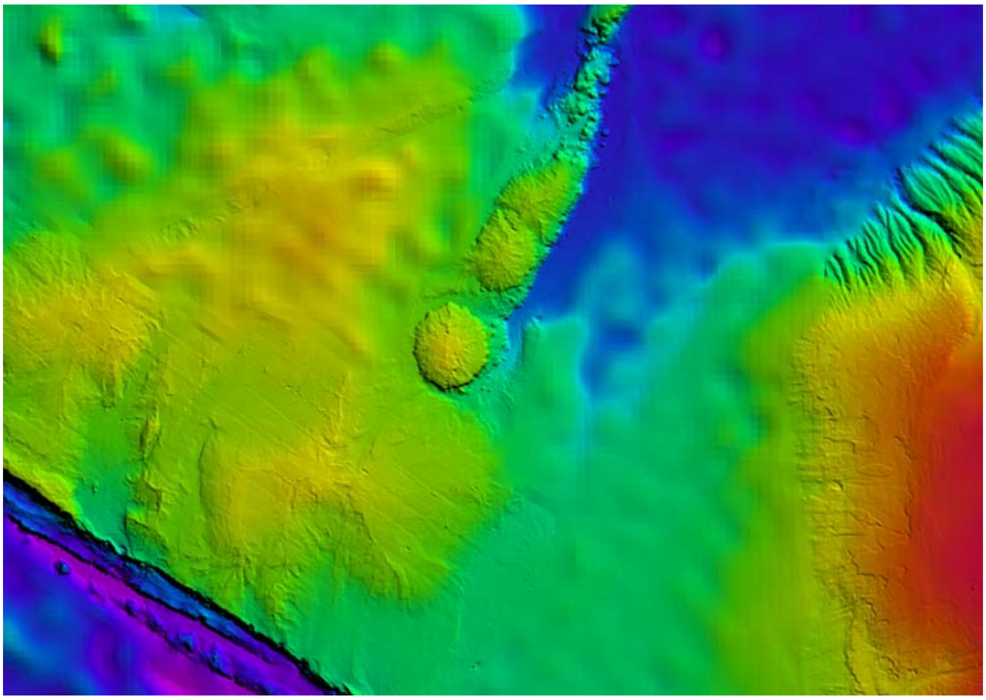


FIGURE 14: Addition of Swath data from Survey GA 2476 in the 2009 grid (b) (2005 grid (a))

A range of improved DEMS were also used in the creation of this grid. The latest DEMs including the new 2008 Australian DEM, the SRTM DEM (figure 15b) and the 250m New Zealand DEM were resampled to match the cell size of the Australian DEM, and were mosaiced directly over the final dataset to give continuity and improved land data accuracy.

a.
b.

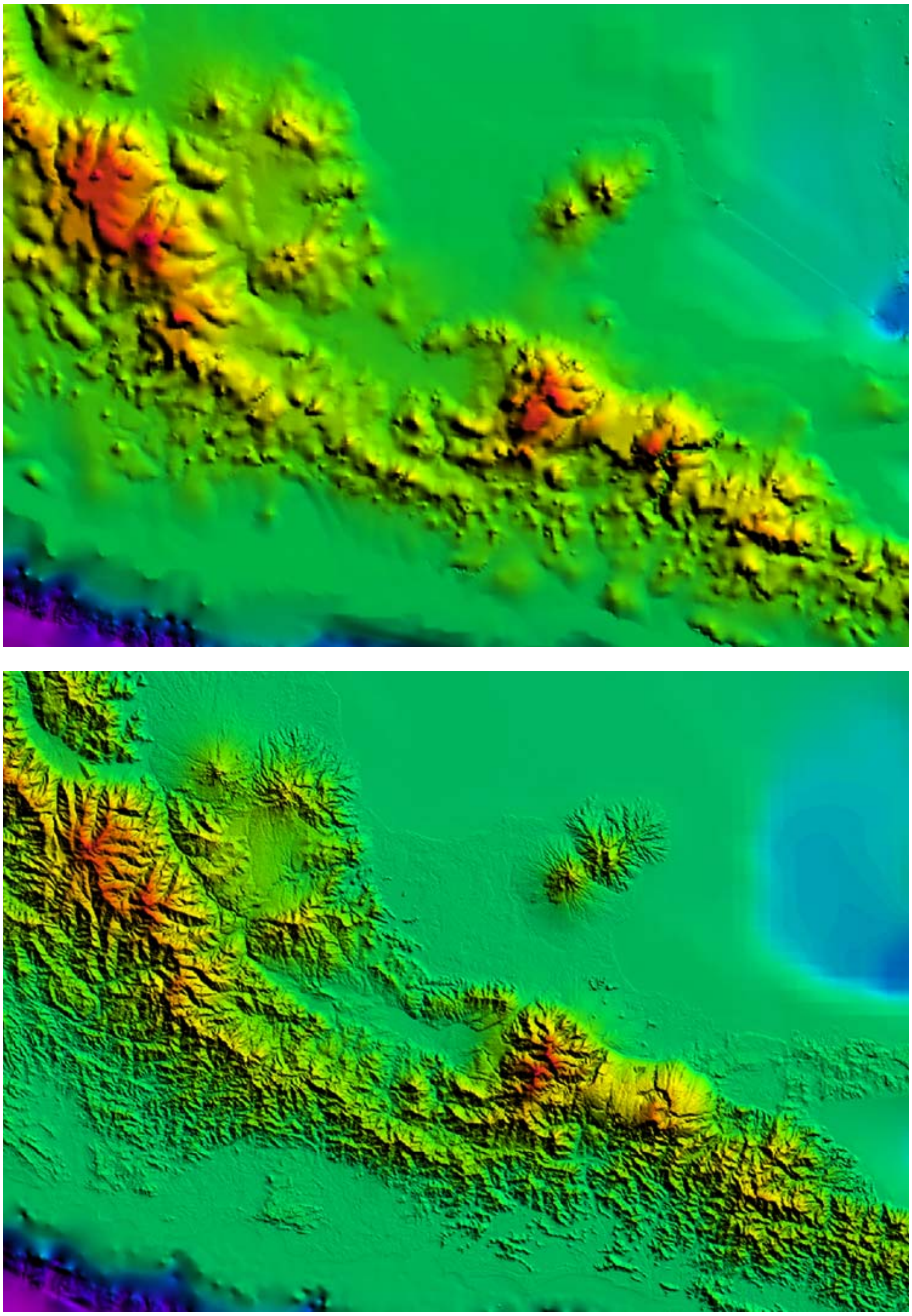


FIGURE 15: Inclusion of high quality DEMs increased the overall quality as seen with the inclusion of the SRTM DEM in the Indonesian area in the 2009 grid (b) (2005 grid (a))

Additionally, a number of higher accuracy bathymetric datasets were also incorporated. Grids produced in separate processes for the Lord Howe Island (figure 16), Gulf of Papua and Christmas Island were a vast improvement on previous grids of these areas. The new datasets were directly overlaid to provide higher quality data for these areas.

a.

b.

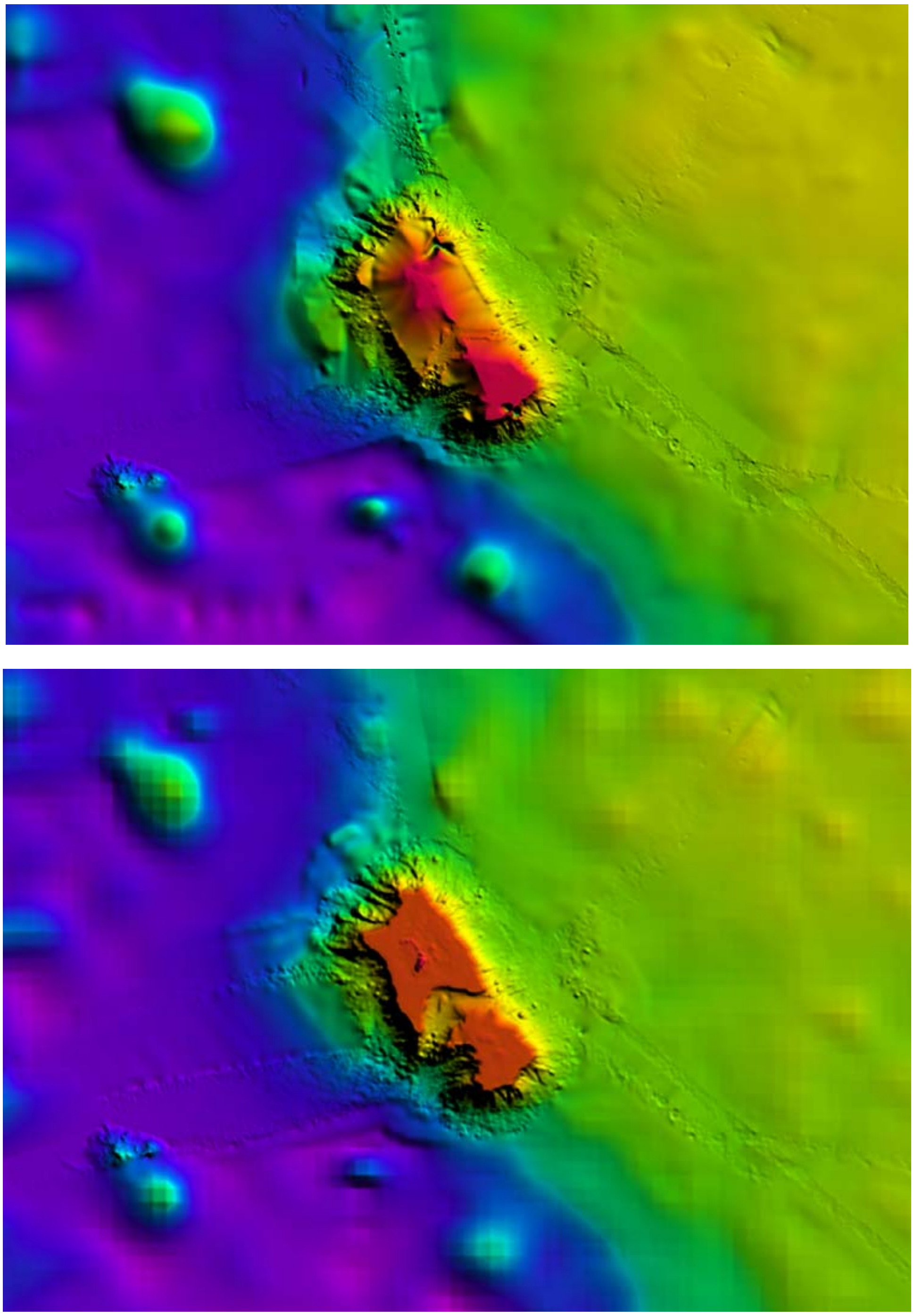


FIGURE 16: Addition of a higher accuracy grids in the 2009 grid (b), including the Lord Howe Island grid in the image above, increased the overall quality (2005 grid (a))

REVISED ETOPO DATA

ETOPO2v2g and ETOPO1 datasets were used as background datasets in the 2009 version of the bathymetric grid of Australia. In the 2005 grid the ETOPO data was resampled to a 0.0025dd cell size using an interpolation process that smoothed the data and added apparent detail (figure 17a). In the 2009 grid the ETOPO data was resampled to 0.0025dd using a bilinear process to minimise interpolation. This means that the ETOPO data in the 2009 grid is coarser and seems to have less detail. However it is more true to its original source (figure 17).

a.

b.

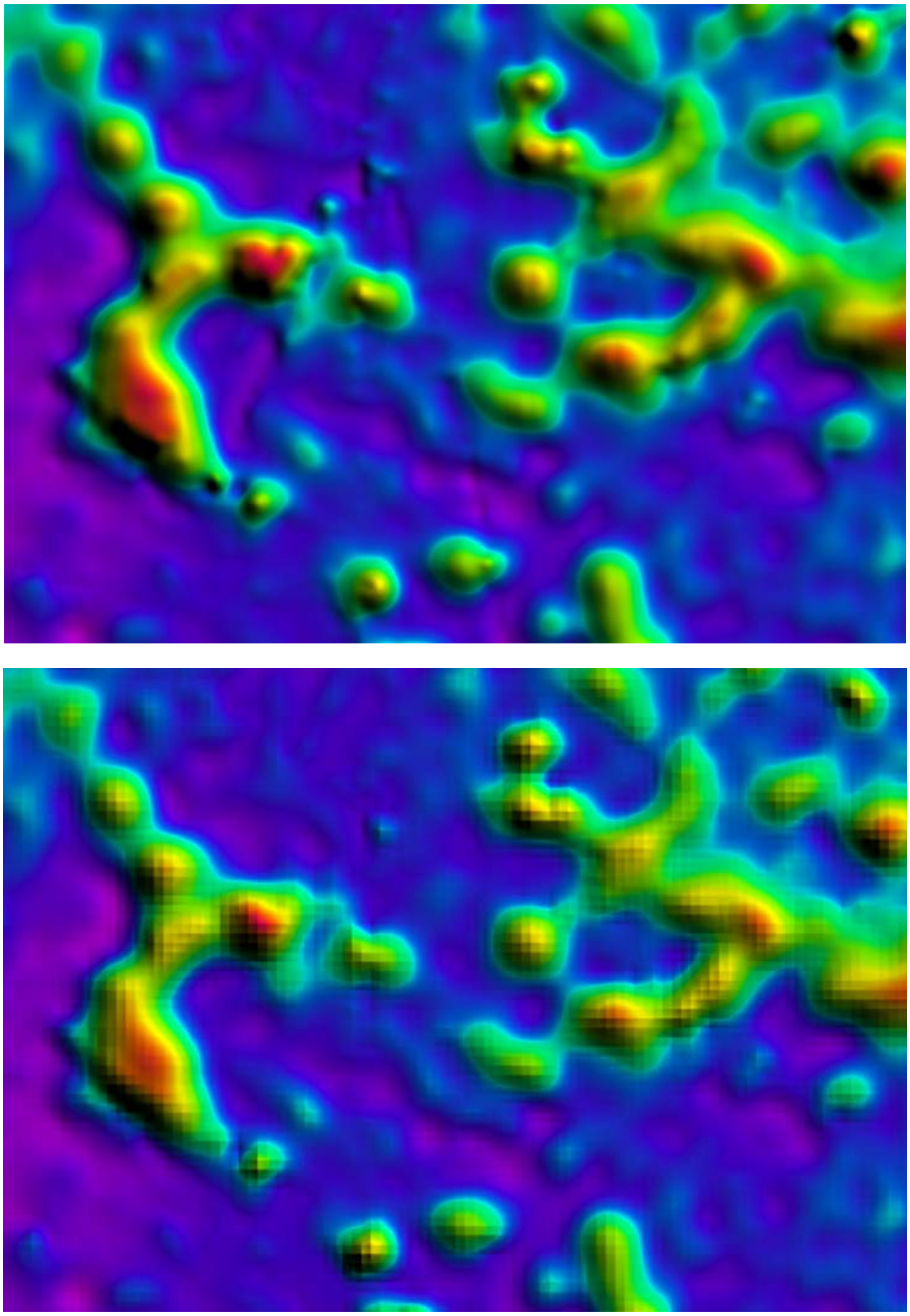


FIGURE 17: The ETOPO data in the 2005 (a) grid is much smoother and appears to show more detail than the 2009 (b) grid as it has been interpolated using a different method.

INTERPOLATION ARTEFACTS

In the 2005 grid a number of coastline interpolation artefacts appeared particularly along the Queensland coastline (figures 18 and 19). In the 2009 grid, coastal bathymetry data was interpolated to meet a DEM with a flat height of 0m. This forced the interpolation to maintain an even rise, minimising interpolation artefacts around the coastline.

a.

b.

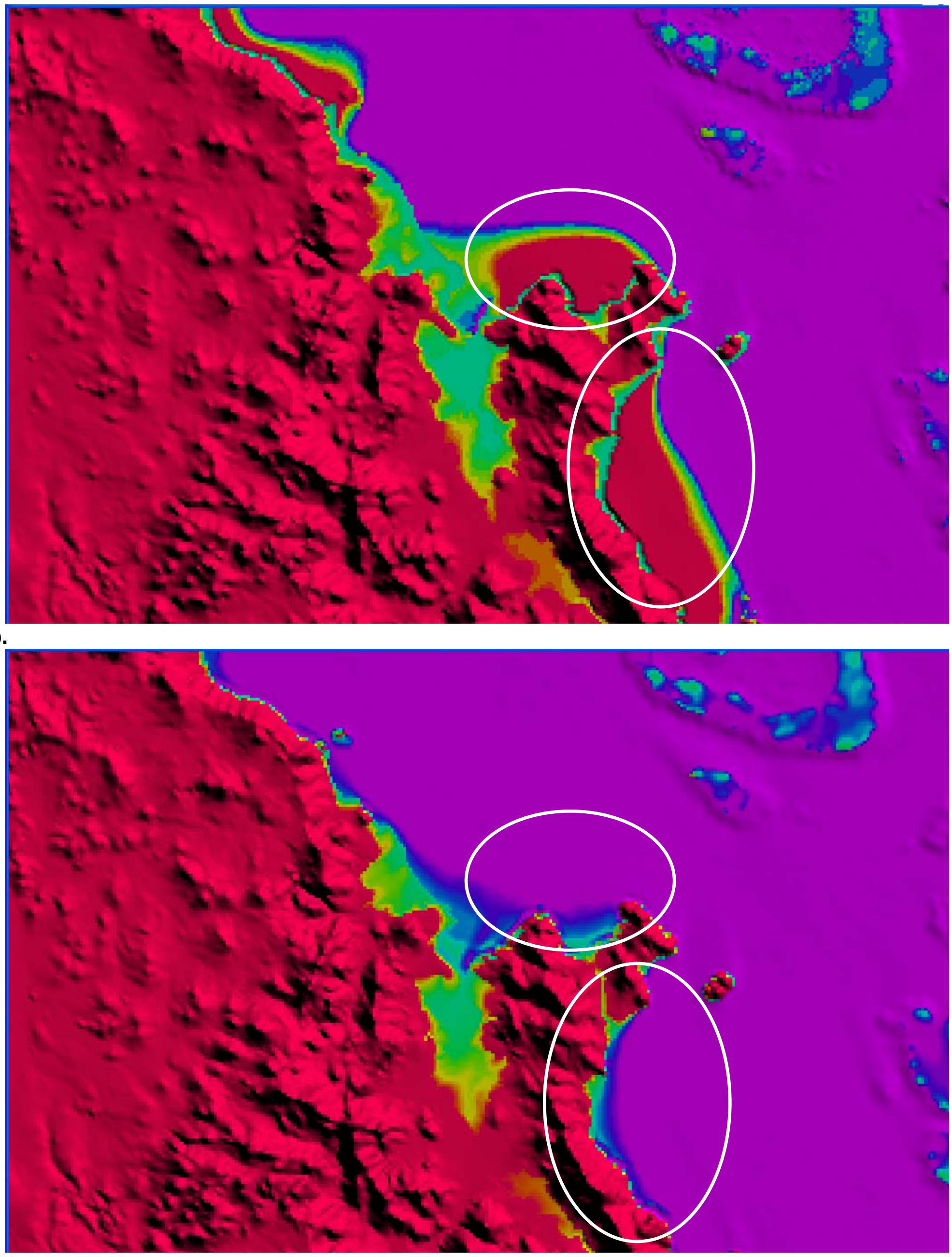
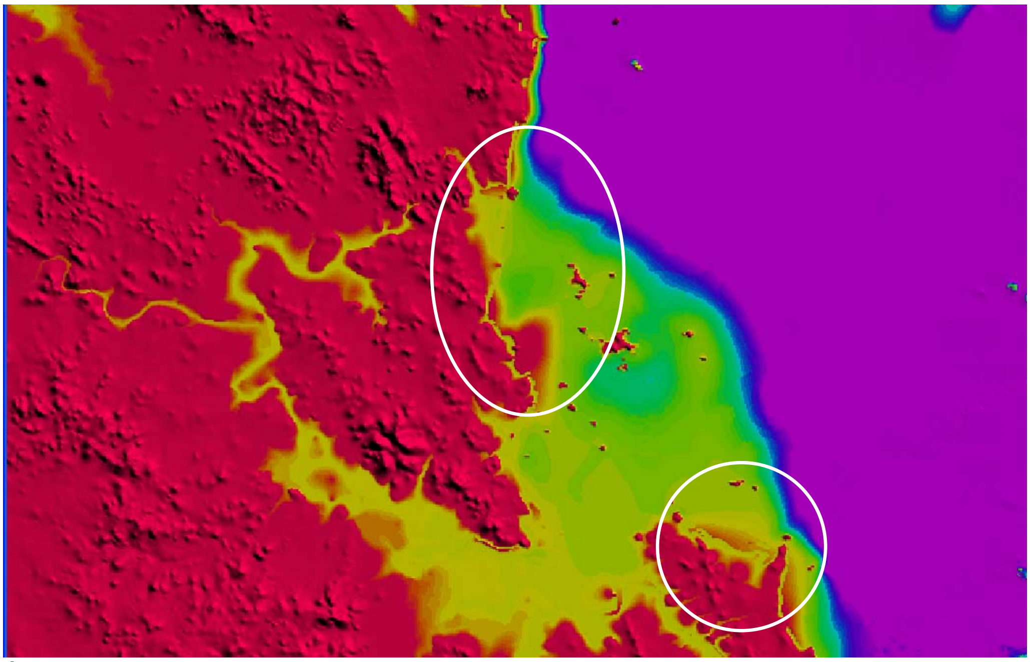


FIGURE 18: Removal of interpolation artefacts in the 2009 grid (b) (2005 grid (a))

a.



b.

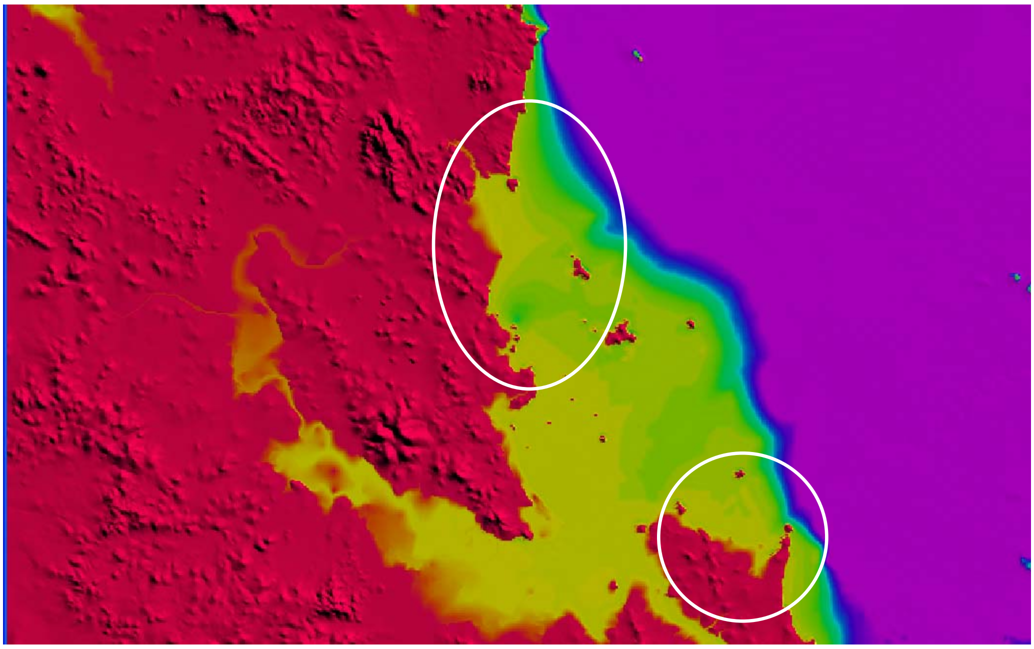
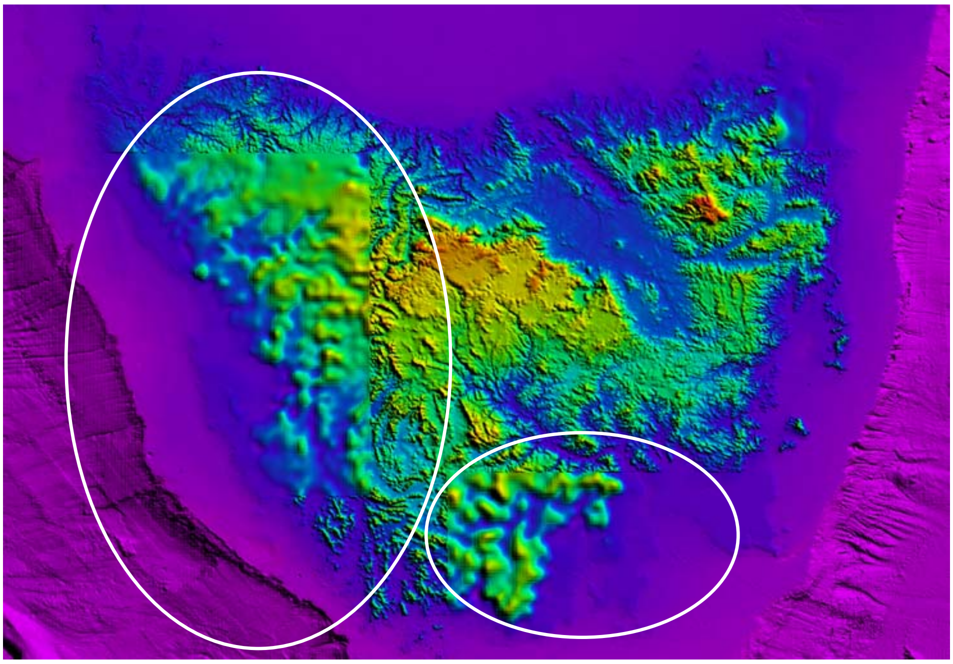


FIGURE 19: Removal of interpolation artefacts in the 2009 grid (b) (2005 grid (a))

There were also areas in the 2005 grid where interpolation processes had been used on the Australian DEM, causing smoothing of the final terrain data (figure 20). These interpolation artefacts were removed by directly overlaying the DEM data for each terrain over the bathymetry data.

a.



b.

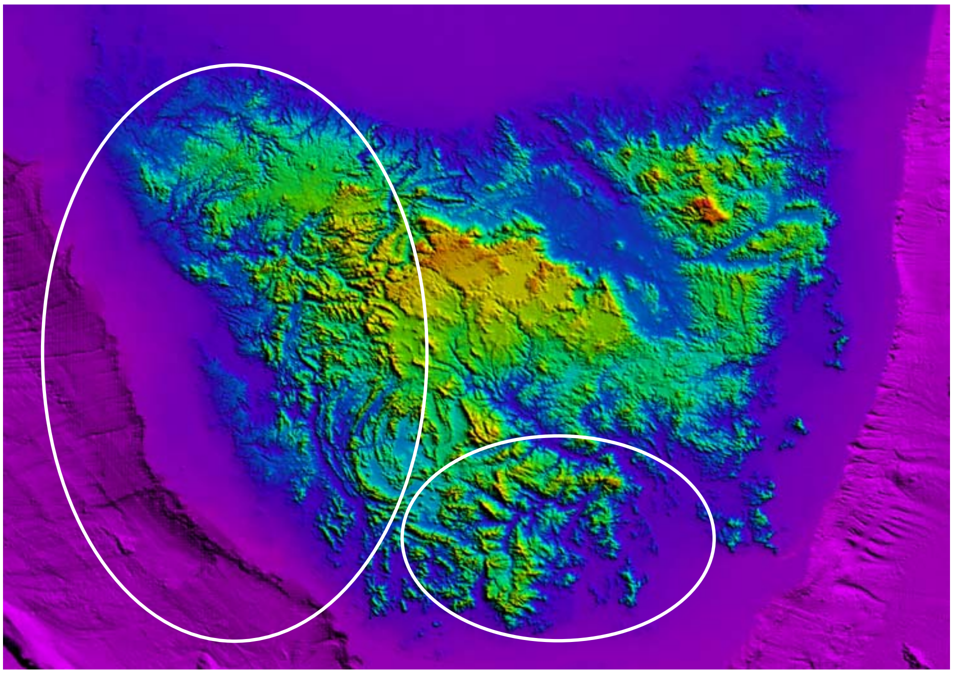
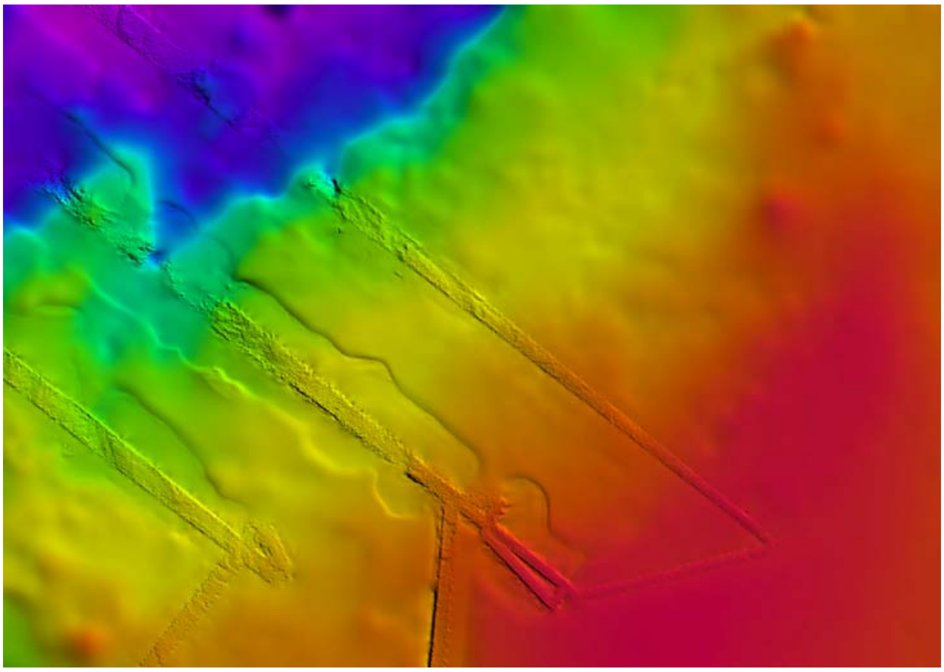


FIGURE 20: Removal of interpolation errors over the DEM from the 2005 grid (a) (2009 grid (b))

METHEDOLOGY ARTEFACTS

When two different quality datasets are gridded together and one has higher values than the other (effects of positional accuracy, depth accuracy, datum issues etc) the interpolation package will interpolate to make the edges of the grids meet. Therefore highs will drop off quickly to meet low values and vice versa (figure 21a).

a.



b.

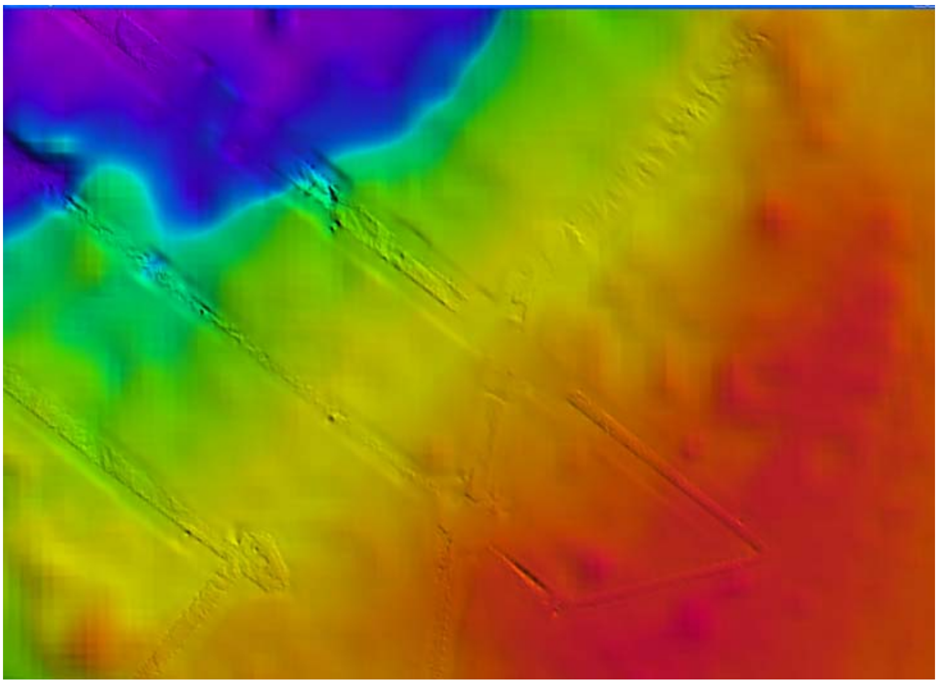


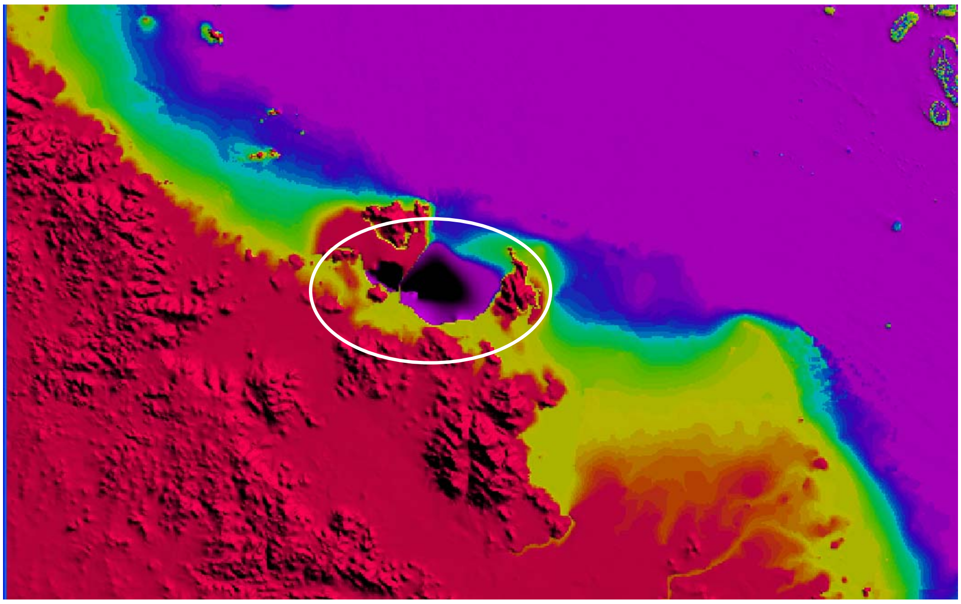
FIGURE 21: The interpolation process for the 2005 grid (a) in many cases produced a longed (less sharp) boundary between the different data types compared to mosaicing and feathering method used in the 2009 grid (b).

In the 2009 grid a different process was applied to allow the production of a shapefile showing the general input dataset for each of the grid cells. The process involved gridding like accuracy datasets in the same process, and feather mosaicing them with other datasets that had been gridded together. This differed from previous grids where all datasets were gridded together. For this reason, there are smoothing artefacts around sections of data that were mosaiced, similar to those seen when all datasets are interpolated together (figure 21b). However, in the 2009 grid, in some areas they will appear sharper, as the boundary change distance has been minimised to avoid smoothing through other higher accuracy datasets.

ERRANEOUS DATA

A range of errors including irregular ship track lines, Swath spikes, ETOPO gravity anomaly highs and Fairsheets digitising errors were identified in the 2005 grid. Generally these errors are products of the raw data, causing high and low anomalies (figure 22), lines of erroneous data (figure 23) and large scale interpolation artefacts (figure 24). Where identified these errors were removed through editing the output grid. However, the en mass errors seen in the single beam data meant that this entire dataset was removed prior to interpolation.

a.



b.

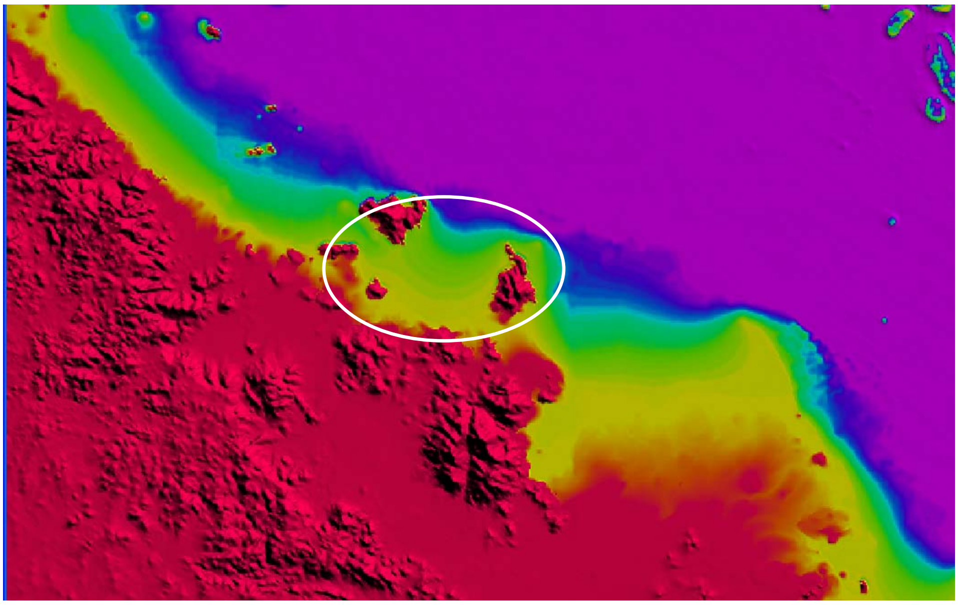


FIGURE 22: Removal of spurious highs and lows seen in the 2005 grid (a) (2009 grid (b))

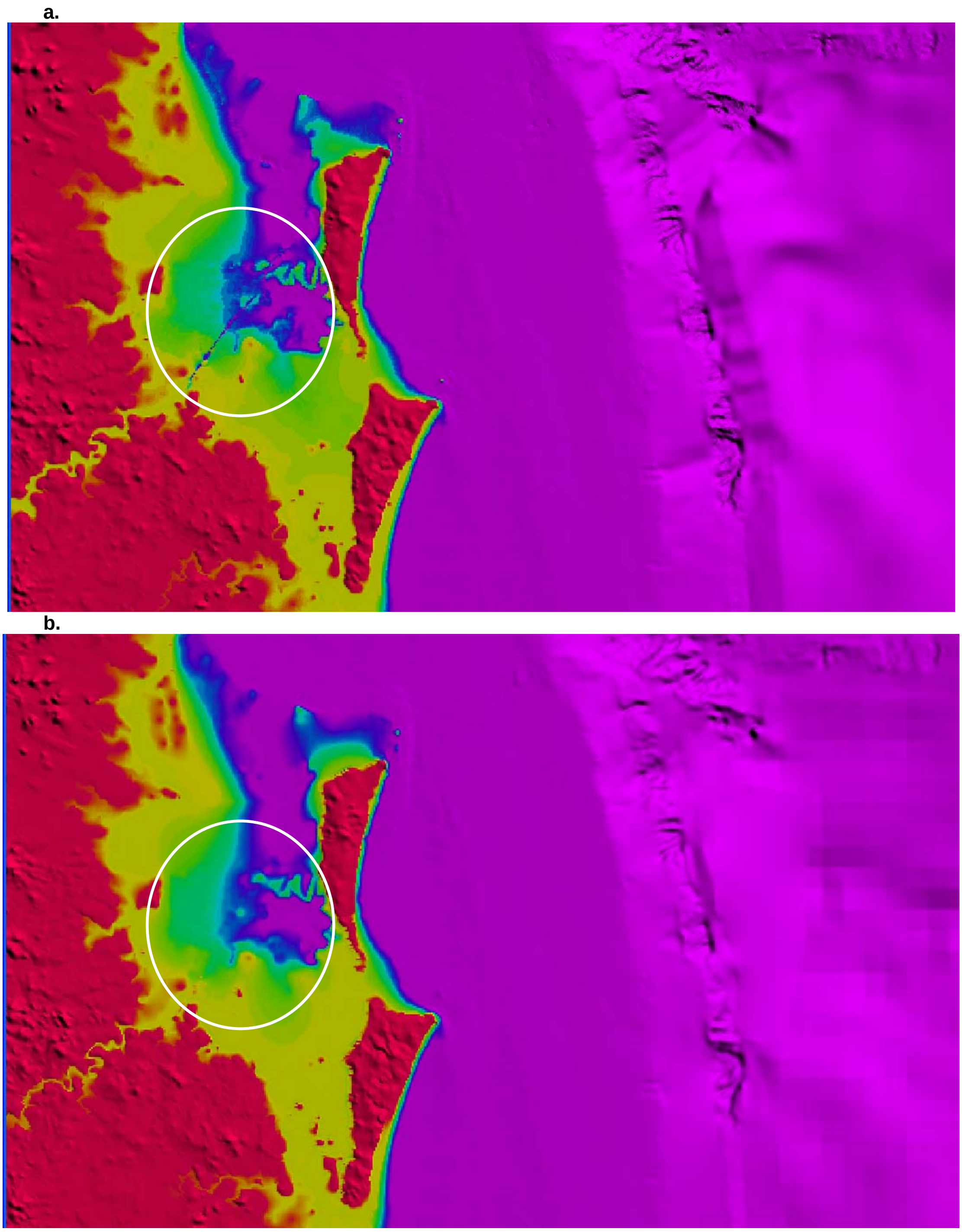


FIGURE 23: Removal of ship track errors seen in the 2005 grid (a) (2009 grid (b))

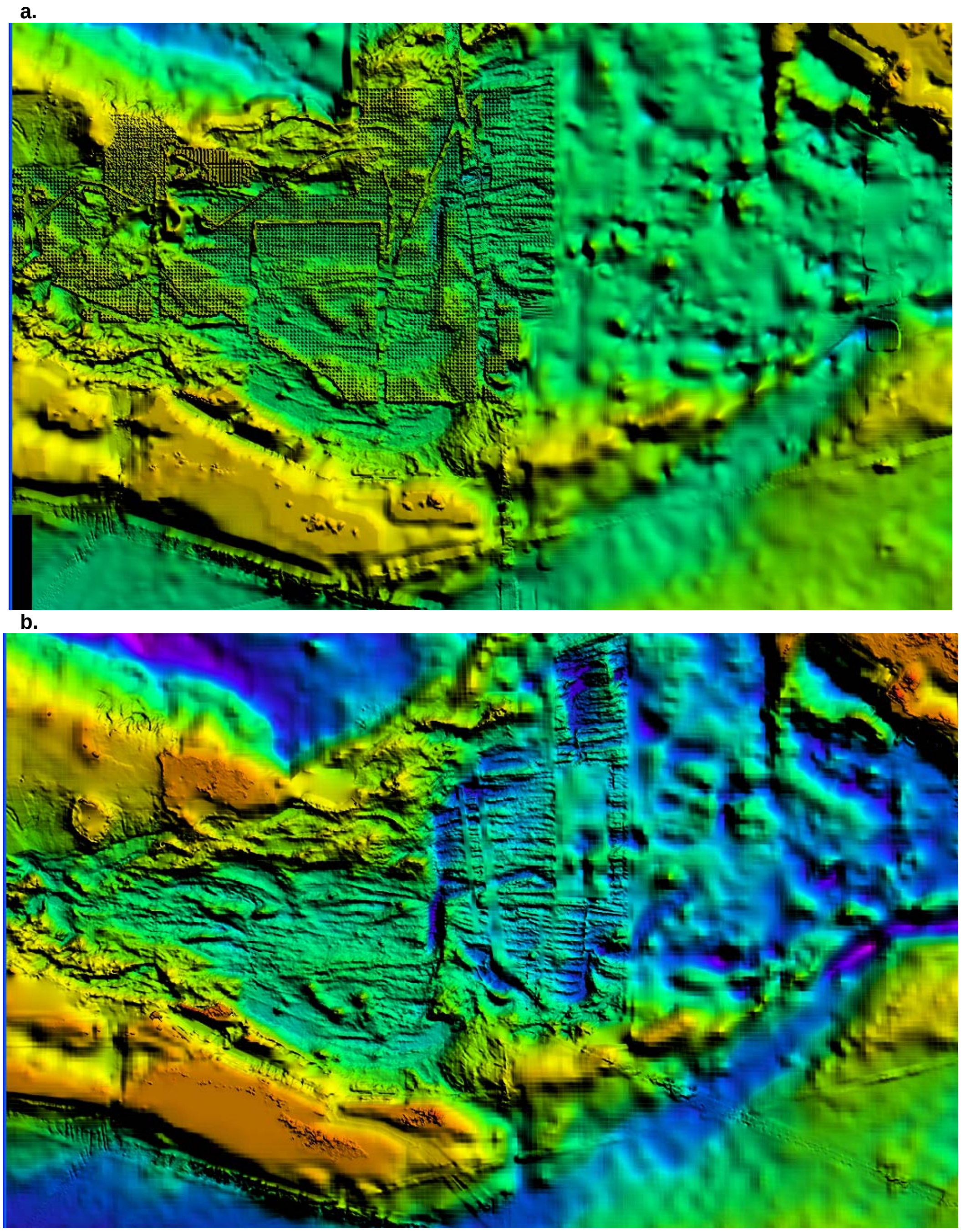


FIGURE 24: Removal of data processing errors seen in the 2005 grid (a) (2009 grid (b))

7. Conclusion

The 2009 iteration of the bathymetric grid has addressed a range of issues seen in the 2005 version, and has included a number of new datasets. The production of an associated lineage file provides users with an indication of the source of the raw data.

The 2009 bathymetry grid provides excellent regional context, and the greater volume of higher accuracy data on the shelf provides an improving local context. However, the production of an Australian region bathymetric grid should be seen as an iterative process of review and re-compilation to fully exploit the latest methods for managing and gridding new data.

8. Acknowledgments

The following people provided advice, data and information during the process:

Mike Sexton, Cameron Mitchell, Cameron Buchanan, Peter Milligan, Murray Woods, Mark Webster, Andrea Cortese, James Daniell, Michael Morse, Peter Petkovic, George Bernadel and Richard Mileczko.

9. References

Amante, C. and B. W. Eakins, ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis, National Geophysical Data Center, NESDIS, NOAA, U.S. Department of Commerce, Boulder, CO, August 2008.

Billings, S.D. and D.J. FitzGerald, 1998. An integrated framework for interpolating airborne geophysical data with special reference to radiometrics. Exploration Geophysics, 29, 284-289.

Buchanan, C., 1998. 30 arc second gridded bathymetry. GA - Geoscience Australia, CD-ROM.

Carroll, D., (ed), 1996. Geodata 9 second DEM user guide. Australian Surveying & Land Information Group, Canberra.

Daniell, J. J., 2008. Development of a bathymetric grid for the Gulf of Papua and adjacent areas: A note describing its development, J. Geophys. Res., 113, F01S15, doi:10.1029/2006JF000673.

Geographx, 2008. New Zealand 250m Digital Elevation Model, available from http://www.geographx.co.nz/downloads.html

Geoscience Australia, 2008. GEODATA 9 Second DEM and D8, Version 3 and Flow Direction Grid 2008, Data User Guide, Canberra, Australia, available from http://www.ga.gov.au/nmd/products/digidat/dem_9s.jsp

Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008. Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

Petkovic, P. and C. Buchanan, 2002. Australian bathymetry and topography grid (January 2002). [CDROM]. Canberra: Geoscience Australia.

Smith, W. H. F., and D. T. Sandwell, 1997. Global seafloor topography from satellite altimetry and ship depth soundings, Science, v. 277, p. 1957-1962, 26 Sept., 1997.

Webster, M.A., and P. Petkovic, 2005. Australian Bathymetry and Topography Grid, June 2005. Record 2005/12.

10. Other Data Sources

ETOPOv2g

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
National Geophysical Data Centre
http://www.ngdc.noaa.gov/mgg/fliers/06mgg01.html

ETOPO1

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service
National Geophysical Data Centre
http://www.ngdc.noaa.gov/mgg/global/global.html

NZ 250m DEM

Geographx
The Dominican Observatory
34 Slamanca Rd
Kelburn
Wellington
New Zealand
http://www.geographx.co.nz/downloads.html

SRTM 90m DEM

CGIAR Consortium for Spatial Information
http://srtm.csi.cgiar.org/

COCOS, CHRISTMAS AND LORD HOWE ISLAND BATHYMETRIC GRIDS

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Risk and Impact Analysis Group
Geoscience Australia
GPO Box 378, Canberra, ACT, 2601

GULF OF PAPUA AND ADJACENT AREAS GRID

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Seabed Mapping and Characterisation Group
Marine Geoscience and Environment Group
Geoscience Australia
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Appendix 1 – Multibeam Surveys

SURVEY CODE	SURVEY NAME	GA ID	VESSEL	DATA OWNER	SYSTEM
SST01/2008	Hobart-Sydney Transit	2467	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
SS05/2008	PULSE test, Tasmania	2466	R/V Southern Surveyor	CMAR	Simrad EM300 (30 kHz)
SS04/2008	Tsunami Detection Buoy	2465	R/V Southern Surveyor	BoM	Simrad EM300 (30 kHz)
SS03/2008	Eastern GAB	2464	R/V Southern Surveyor	CMAR	Simrad EM300 (30 kHz)
SS02/2008	Bonney Coast, Kangaroo Island	2463	R/V Southern Surveyor	SARDI	Simrad EM300 (30 kHz)
SS01/2008	SE Tasmania	2462	R/V Southern Surveyor	CMAR	Simrad EM300 (30 kHz)
SS06/2008	Lord Howe Island	2461	R/V Southern Surveyor	CSIRO/GA	Simrad EM300 (30 kHz)
SS07/2007	GBR Reefs	2447	R/V Southern Surveyor	JCU	Simrad EM300 (30 kHz)
SO189-2	Sumatra	2460	R/V Sonne	BGRH	Simrad EM120 (12 kHz)
SO189-1	Sumatra	2459	R/V Sonne	BGRH	Simrad EM120 (12 kHz)
SO186-1	SeaCause I	2458	R/V Sonne	BGR/IFM-GEOMAR	Simrad EM120 (12 kHz)
SO186-2	SeaCause II	2457	R/V Sonne	BGR	Simrad EM120 (12 kHz)
GA-2476	WA Margins reconnaissance (Legs 1-3)	2476	R/V Sonne	GA	Simrad EM120 (12 kHz)
NBP0408	NBP0408	2456	Nathaniel B. Palmer	NSF	Simrad EK500
	East Cay	2455	James Kirby	JCU	
	Sumatra subduction zone	2454	HMS Scott	NOCS/RAN/UKHO	
SS04/2007	WA Pelagic	2434	R/V Southern Surveyor	CMAR	Simrad EM300 (30 kHz)
SST03/2007	Hobart-Fremantle Transit	2433	R/V Southern Surveyor	CMAR	Simrad EM300 (30 kHz)
ANT-XXIII/9	ANT-XXIII/9	2432	R/V Polarstern	AWI	Atlas Hydrosweep DS2
SS03/2007	BoM tsunami buoy deployment	2431	R/V Southern Surveyor	BoM	Simrad EM300 (30 kHz)
SS02/2007	TASMOUNTS2	2430	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
Sea Trials SS02/2007	Hobart Seatrials 02/2007	2429	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)

SO-94	SO-94	2428	R/V Sonne	IFM GEOMAR	Atlas Hydrosweep DS
SO-113_2	SO-113 L2	2427	R/V Sonne	IFM GEOMAR	Atlas Hydrosweep DS
KR9813	KR9813	2426	R/V Kairei	JAMSTEC	
SST02/2007	Lacepede Shelf	2425	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS01/2007	Bight Basin	2424	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SST01/2007	SSTransit 01/2007	2423	R/V Southern Surveyor	GA/CSIRO	Simrad EM300 (30 kHz)
YK01-15	YK01-15	2422	S/V Yokosuka	JAMSTEC	Seabeam 2112 (12 kHz)
YK01-14	YK01-14	2421	S/V Yokosuka	JAMSTEC	Seabeam 2112 (12 kHz)
YK02-07	YK02-07	2420	S/V Yokosuka	JAMSTEC	Seabeam 2112 (12 kHz)
SO-190Transit	SO-190T	2418	R/V Sonne	IFM GEOMAR	Simrad EM-120 (12 kHz)
SS09/2006	LHRIDGE	2416	R/V Southern Surveyor	UNSW	Simrad EM300 (30 kHz)
SS11/2006	Tasmounts1	2415	R/V Southern Surveyor	CMAR/DEH	Simrad EM300 (30 kHz)
SST03/2006	SSTransit03/2006	2414	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS10/2006	NSW Slopes	2413	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
MR04-01	MR04-01	2412	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
SST02/2006	SSTransit 02/2006	2411	R/V Southern Surveyor	UNSW	Simrad EM300 (30 kHz)
SST01/2006	SSTransit 01/2006	2409	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS06/2006	Rowley Shoals	2408	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS05/2006	Meso_Eddies	2406	R/V Southern Surveyor	UWA	Simrad EM300 (30 kHz)
MR03K04L5	MR03K04_Leg5	2405	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
NBP0501	NBP0501	2404	R/V Nathaniel B Palmer	NSF	Simrad EM-120 (12 kHz)
SS03/2006	TRULL06	2402	R/V Southern Surveyor	UTAS	Simrad EM300 (30 kHz)
	Hobart Trials	2401	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
SS04/2006	Leeuwin Currents	2400	R/V Southern Surveyor	UWA	Simrad EM300 (30 kHz)
	J.K_11/04	2399	James Kirby	JCU	Reson Seabat 8101
	MOGAM06	2398	R/V OGS Explora	OGS	Reson Seabat 8150 (12 kHz)
SS02/2006	Palaeo Murrays	2397	R/V Southern Surveyor	ANU	Simrad EM300 (30 kHz)
VT82 (MD153L2?)	AUSFAIR_GAB Transit	2396	R/V Marion Dufresne	IPEV	Thompson Marconi TSM 5265
MD153	AUSFAIR_ZoNeco12	2395	R/V Marion Dufresne	IPEV	Thompson Marconi TSM 5265
MD152	TAS-NZ Transit	2394	R/V Marion Dufresne	IPEV	Thompson Marconi TSM 5265
MR04K03L2	MR04K03_Leg2	2393	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)

EW9510	EW9510	2392	R/V Maurice Ewing	LDEO	Thompson Marconi TSM 5265
EW0002	EW0002	2391	R/V Maurice Ewing	LDEO	Thompson Marconi TSM 5265
SS10/2005	Wabio_2	2390	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
NBP0406	NBP0406	2389	R/V Nathaniel B Palmer	US Antarctic Program	Simrad EM-120 (12 kHz)
MR00K07L2	MR00K07_Leg2	2388	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
MR01K05L2	MR01K05_Leg2	2387	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
MR02K04L2	MR02K04_Leg2	2386	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
MR03K03L2	MR03K03_Leg2	2385	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
MR03K04L1	MR03K04_Leg1	2384	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
SS09/2005	Naturaliste Rocks	2383	R/V Southern Surveyor	UWA	Simrad EM300 (30 kHz)
MD148	PECTEN	2382	R/V Marion Dufresne	SydneyUni/IPEV	Thompson Marconi TSM 5265
	SWS2003	2381	Conference Dataset		Various
SS06/2005	Cornea-Cartier	2375	R/V Southern Surveyor	AIMS/ANU	Simrad EM300 (30 kHz)
MANAUTE	MANAUTE	2374	N.O. L'Atalante	IFREMER	Simrad EM-12D (12 kHz)
	Sydney Woolongong Transit	2373	HMAS Melville	RAN	Atlas-Fansweep (20 -100)
VANC29MV	VANC29	2372	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC25MV	VANC25	2371	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC22MV	VANC22	2370	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC21MV	VANC21	2369	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC15MV	VANC15	2368	R/V Melville	SIO	Seabeam 2000 (12 kHz)
EW0112	EW0112	2367	R/V Ewing	LDEO	Atlas Hydrosweep
EW9910	EW9910	2364	R/V Ewing	LDEO	Atlas Hydrosweep
SS09/2004	SS200409	2363	R/V Southern Surveyor	Uni of Sydney	Simrad EM300 (30 kHz)
	Topas Trials	2361	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS11/2004	Notove	2360	R/V Southern Surveyor	ANU	Simrad EM300 (30 kHz)
SS10/2004	N_Fiji_1	2359	R/V Southern Surveyor	UTAS	Simrad EM300 (30 kHz)
SS07/2004	WinterEnv	2358	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
SS06/2004	Cotrove	2357	R/V Southern Surveyor	ANU	Simrad EM300 (30 kHz)
	Sydney Hobart Transit	2356	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
SS04/2004	S E Ecosystems	2355	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)

	EM300 Trials	2354	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)
	BHP_HIRES	2353		BHPP	
	Rottnest	2352	HMAS Cook	RAN-JCU	Seabeam (12 kHz)
	Albany	2351	HMAS Cook	RAN-JCU	Seabeam (12 kHz)
	Adelaide	2350	HMAS Cook	RAN-JCU	Seabeam (12 kHz)
	Eaxa	2349	HMAS Cook	RAN-JCU	Seabeam (12 kHz)
	GBR	2348	HMAS Cook	RAN-JCU	Seabeam (12 kHz)
	ASHMORE	2347	HMAS Leeuwin	RAN	Atlas-Fansweep (20 -100)
AUSTREA3	AUSTREA3	2346	N.O. L'Atalante	LINZ/IFREMER	Simrad EM-12D (12 kHz)
VANC30MV	VANC30	2343	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC28MV	VANC28	2342	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC27MV	VANC27	2341	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC26MV	VANC26	2340	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC24MV	VANC24	2339	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC23MV	VANC23	2338	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC20MV	VANC20	2337	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC19MV	VANC19	2336	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC16MV	VANC16	2333	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC14MV	VANC14	2332	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC12MV	VANC12	2331	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC11MV	VANC11	2330	R/V Melville	SIO	Seabeam 2000 (12 kHz)
VANC10MV	VANC10	2329	R/V Melville	SIO	Seabeam 2000 (12 kHz)
NBP0209	NBP0209	2328	R/V Nathaniel B Palmer	NSF	Simrad EM-120 (12 kHz)
NBP0008	NBP0008	2327	R/V Nathaniel B Palmer	NSF	Seabeam 2112 (12kHz)
NBP9603a	NBP9603a	2326	R/V Nathaniel B Palmer	NSF	Seabeam 2112 (12kHz)
EW0003	EW0003	2325	R/V Ewing	LDEO	Atlas Hydrosweep
EW9914	EW9914	2324	R/V Ewing	LDEO	Atlas Hydrosweep
EW9912	EW9912	2323	R/V Ewing	LDEO	Atlas Hydrosweep
EW9911	EW9911	2322	R/V Ewing	LDEO	Atlas Hydrosweep
EW9512	EW9512	2321	R/V Ewing	LDEO	Atlas Hydrosweep
EW9511	EW9511	2320	R/V Ewing	LDEO	Atlas Hydrosweep

TAN0308	NORFANZ	2312	R/V R/V Tangaroa	NIWA	Simrad EM-300 (30 kHz)
MR03K04L6	MR03K04_Leg6	2309	R/V Mirai	JAMSTEC	Seabeam 2112 (12 kHz)
SO 168	ZEALANDIA	2308	R/V Sonne	IFM GEOMAR	Simrad EM-120 (12 kHz)
EW0201	EW0201	2306	R/V Ewing	LDEO	Atlas Hydrosweep
EW0114	EW0114	2305	R/V Ewing	LDEO	Atlas Hydrosweep
KIWI10RR	KIWI10RR	2304	R/V Roger Revelle	SIO	Seabeam 2112 (12 kHz)
NBP9801	NBP9801	2101	R/V Nathaniel B Palmer	NSF	Seabeam 2112 (12kHz)
BMRG08MV	BMRG08MV	2007	R/V Melville	SIO	Seabeam 2000 (12 kHz)
MW9304	MW9304	1969	R/V Moana Wave	SOEST	MR1
NBP9702	NBP9702	1824	R/V Nathaniel B Palmer	NSF	Seabeam 2112 (12kHz)
EW9513	EW9513	1705	R/V Ewing	LDEO	Atlas Hydrosweep
SOJN06MV	SOJN06MV	1435	R/V Melville	SIO	Seabeam 2000 (12 kHz)
SOJN04MV	SOJN04MV	1431	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST10MV	WEST10MV	1274	R/V Melville	SIO	Seabeam 2000 (12 kHz)
BMRG07MV	BMRG07MV	1273	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST12MV	WEST12MV	1266	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST11MV	WEST11MV	1265	R/V Melville	SIO	Seabeam 2000 (12 kHz)
EW9203	EW9203	1212	R/V Ewing	LDEO	Atlas Hydrosweep
EW9202	EW9202	1211	R/V Ewing	LDEO	Atlas Hydrosweep
KN145L12	Wombat Plateau	1180	R/V Knorr	WHOI	Seabeam 2112 (12 kHz)
KN145L4	Perth Canyon	1179	R/V Knorr	WHOI	Seabeam 2112 (12 kHz)
SOJN08MV	SOJN08MV	1178	R/V Melville	SIO	Seabeam 2000 (12 kHz)
SOJN05MV	SOJN05MV	1175	R/V Melville	SIO	Seabeam 2000 (12 kHz)
BMRG05MV	BMRG05MV	1173	R/V Melville	SIO	Seabeam 2000 (12 kHz)
BMRG04MV	BMRG04MV	1172	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST09MV	WEST09MV	1166	R/V Melville	SIO	Seabeam 2000 (12 kHz)
BMRG06MV	BMRG06MV	1154	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST08MV	WEST08MV	1153	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST06MV	WEST06MV	1152	R/V Melville	SIO	Seabeam 2000 (12 kHz)
WEST05MV	WEST05MV	1149	R/V Melville	SIO	Seabeam 2000 (12 kHz)
SS07/2005	Wabio	296	R/V Southern Surveyor	CSIRO	Simrad EM300 (30 kHz)

SS01/2005	Fraser2	295	R/V Southern Surveyor	Uni of Newcastle	Simrad EM300 (30 kHz)
SS08/2005	Mentelle	293	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS03/2005	Carpbio	283	R/V Southern Surveyor	CSIRO/GA	Simrad EM300 (30 kHz)
SS05/2005	Arafura	282	R/V Southern Surveyor	GA/NOO	Simrad EM300 (30 kHz)
SS04/2005	Carpreefs2	276	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS02/2005	Mellish	274	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS05/2004	Kenn Plateau	270	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
SS03/2004	Bremer	265	R/V Southern Surveyor	GA	Simrad EM300 (30 kHz)
VANC13MV	VANC13	247	R/V Melville	SIO	Seabeam 2000 (12 kHz)
MD131	AUSCAN2	245	R/V Marion Dufresne	AGSO	Thompson Marconi TSM 5265
SS04/2003	Carpreefs1	238	R/V Southern Surveyor	GA	Reson 8101 (240 kHz)
MD130	AUSCAN1	236	R/V Marion Dufresne	AGSO	Thompson Marconi TSM 5265
EW0113	EW0113	235	R/V Ewing	LDEO	Atlas Hydrosweep
FR01/02	Torres Strait	234	R/V Franklin	GA	Reson 8101 (240 kHz)
HI339G	New Zealand Star Banks	233	HMAS Melville	RAN	Atlas Fansweep 20 (100kHz)
SS01/2000	Bioview	224	R/V Southern Surveyor	CSIRO	Simrad EM1002 (100kHz)
AUSTREA2	AUSTREA2	223	N.O. L'Atalante	GA/NOO	Simrad EM-12D (12 kHz)
AUSTREA1	AUSTREA1	222	N.O. L'Atalante	AGSO	Simrad EM-12D (12 kHz)
FAUST2	FAUST2	221	N.O. L'Atalante	GA/Uni of Paris VI	Simrad EM-12D (12 kHz)
ZoNeco5	ZoNeco5	220	N.O. L'Atalante	AGSO	Simrad EM-12D (12 kHz)
SO 136	TASQWA	212	R/V Sonne	AGSO	Atlas Hydrosweep (15.5 kHz)
SOJN07MV	SOJN07MV	210	R/V Melville	SIO	Seabeam 2000 (12 kHz)
MD110	Margau	208	R/V Marion Dufresne	IPEV/GA	Thompson Marconi TSM 5265
ADEDAV	ADEDAV	157	N.O. L'Atalante	GA/IFREMER	Simrad EM-12D (12 kHz)
TASMANTE	TASMANTE	125	N.O. L'Atalante	GA/IFREMER	Simrad EM-12D (12 kHz)
RS9401	Macquarie Ridge	124	R/V Rig Seismic	AGSO	MR1
TRANSNOR	TRANSNOR	123	N.O. L'Atalante	IFREMER	Simrad EM-12D (12 kHz)

Appendix 2 – SRTM DEM Metadata

PROCESSED SRTM DATA VERSION 4

The data distributed here are in ARC GRID, ARC ASCII and Geotiff format, in decimal degrees and datum WGS84. They are derived from the USGS/NASA SRTM data. CIAT have processed this data to provide seamless continuous topography surfaces. Areas with regions of no data in the original SRTM data have been filled using interpolation methods described by Reuter et al. (2007).

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Citations should be made as follows:

Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

REFERENCES

Reuter H.I, A. Nelson, A. Jarvis, 2007, An evaluation of void filling interpolation methods for SRTM data, International Journal of Geographic Information Science, 21:9, 983-1008.