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Digital Terrain Model for the Tasmanian Region: a pilot study into combining disparate datasets

by

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Executive Summary

The surface of the earth can be represented as a mesh of topographic values termed a grid. The grid is stored in a computer and is known as a digital model of terrain. This arrangement allows for the grid to be presented in many visual forms and to be both analysed and manipulated for various terrain specific parameters. The generation of the terrain grid is based on two fundamental requirements:

1. a set of geographically located topographic observations; and

2. an algorithm to fit a continuous and bounded surface to this spread of observations.

The diversity of dataset coverage in the Tasmanian region enables a test of the validity of using various gridding and grid conditioning techniques to produce a realistic model of terrain.

A generalised methodology is presented for the overall construction of a digital terrain model using disparate datasets. This procedure is also shown to result in some surface artefacts.

Introduction

For many years now bathymetry observations have been acquired across the world's oceans. Acquisition of the data has spanned the traditional methods of continuous depth profiling along ship tracks using echosounders, through to the more modern techniques of multi-beam swath mapping. In addition, gravity-to-depth inversion via satellite-to-ocean-surface altimeter measurements [36,40] have been used recently. The current databases, though, are dominated by detailed depth sampling along irregularly spaced ship tracks. The value of these datasets is limited by their positional and depth accuracies.

Bathymetry is a primary geophysical dataset and is useful to geoscientists in representing the morphology of the seafloor. The aim is to view the earth surface as if the oceans were drained of their waters. This surface is best visualised as a continuously varying feature, from land to seafloor, where any feature is readily referenced to its neighbours. Previous methods at achieving this have included contour map production as exemplified by the early efforts in the Offshore Resource Map Series (ORMS) project [19] of the Bureau of Mineral Resources (now AGSO). Modern-day computation, however, requires that this continuous surface be somehow represented discretely[1]. A grid[2] is able to store this surface as a set of equidistant topographic values. Each value is confined to a cell, whose dimensions represent a piece of the surface and is known as the grid's resolution. This finite representation is then able to satisfy digital requirements. The grid can then be viewed as an image in two or three dimensions, converted to a contour map or subsequently analysed for terrain related

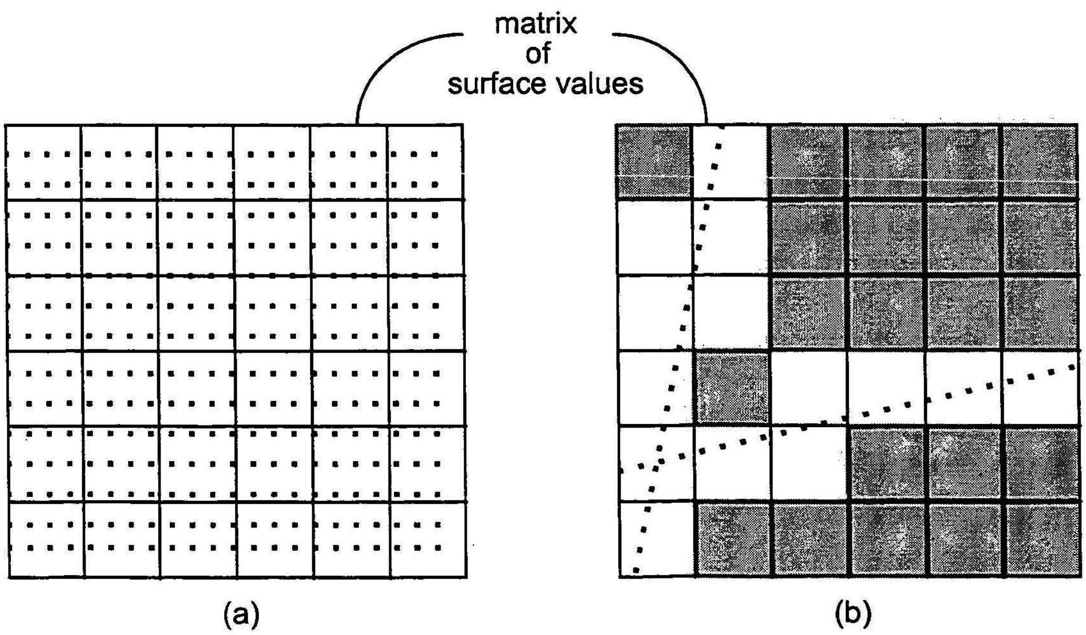


Figure1. In the surface matrix of (a), each cell value is determined in some way by the underlying source points. In (b), however, the shaded cell values would need to be inferred by some extrapolation/interpolation of the source point values.

[1] Discretisation refers to the representation of a continuously varying feature by a finite set of values.
[2] The terms grid and lattice are often used interchangeably, though the latter has a less strict definition (see ARC/INFO's on-line help topic "What is a lattice?").

parameters. Note that a triangulated irregular network (TIN), which is a triangulation on the set of sparse observation points, is also able to store the surface in the digital domain. However, this set of adjoining triangles forms sharp edges and fails to present terrain as naturally smooth.

Generally, fully processed and interpolated swath and satellite-altimeter-derived bathymetric datasets are supplied as a regularised spread of depths. These require little modelling effort for representation as a grid provided the grid interval is well chosen. For example, the overlying grid cell value may be the arithmetic mean or median of the underlying observations. This situation is depicted in Figure 1(a). Areas dominated by depths from sparse ship tracks, however, are not easily represented as a completely filled matrix. In fact, Figure 1(b) shows the biased sampling of the subsurface that results along tracks that are irregularly spaced and oriented. The outcome is a grid whose cells faithfully represent the seafloor profile along those tracks, but would have to assume some terrain form for the intervening cells.

In any large area covered by various bathymetric datasets, there is generally found a disparity in both the quality of the depth observations and the coverage density of the data acquired. The determination of a unique surface generation technique is non-trivial. An integrated procedure to construct one single seamless representation is needed. Therefore, this report outlines the basis for a pilot study into such a procedure for land and seafloor terrain centred on the Tasmanian region of south-east Australia.

The pilot study area is bounded by longitudes 140° E and 152° E and by latitudes 37° S and 51° S. Morphologically, it is dominated by the Australian landmass of Victoria and Tasmania, as well as a complex continental margin that includes Bass Strait and both the South Tasman Rise and East Tasman Plateau. The outline of the area is depicted in Figure 2. The area was chosen because of the diversity of bathymetry - from pre-GPS, sparse ship tracks to more recent spatially-extensive swath-mapping programs.

By way of introduction, the pilot study area is presented as a series of images in Figures 3, 5 and 6. Figure 3 depicts the best compromise model of the available datasets in the area, at the time of production, and is the outcome of this report. Its presentation of terrain is more intuitive than an equivalent contour representation - see Figure 4. By comparison, Figures 5 and 6 are models based on the freely available ETOPO5 [7] and satellite-predicted bathymetry [43] datasets, respectively.

Objectives

The utility of representing terrain as a digital grid is gaining increasing recognition and is reflected in much recent work [1,8,12,24]. Therefore, the pilot study area and terrain datasets therein provide the basis for a study having the following broad objectives:

- the production of a regional Digital Terrain Model (DTM) grid for the Tasmanian region at an appropriate resolution;

- a discussion of the datasets used - their source and limitations; and

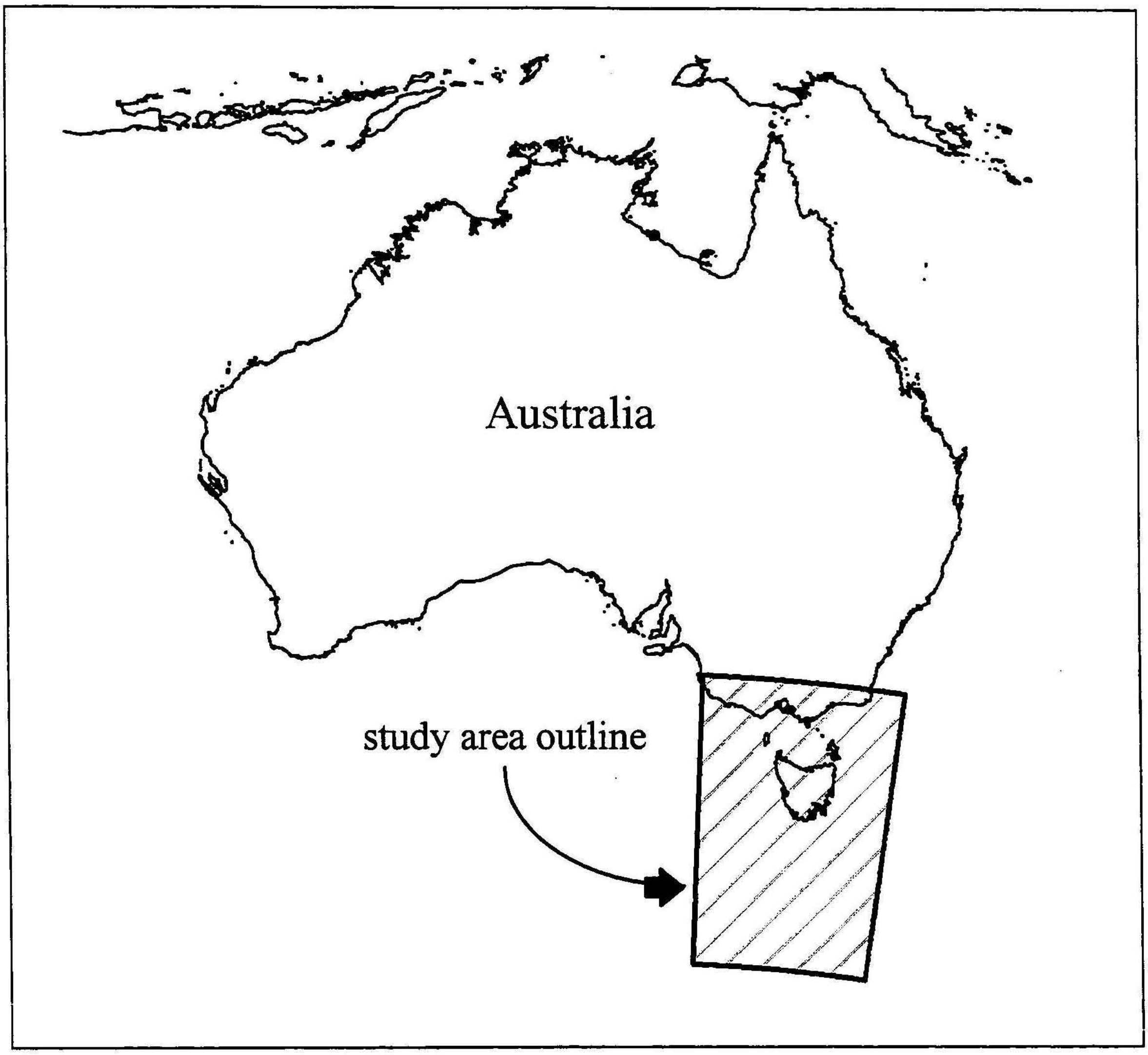


Figure 2. Outline of the study area.

- an analysis of the best available gridding techniques for the datasets given.

Accepting that a regional digital grid is the best means to model bathymetry and elevation, it follows that a methodology for its construction and analysis needs to be considered and implemented. This report presents such a methodology. Discussion, though, will focus on modelling bathymetry as the land component was included as a pre-gridded dataset [3]. The theoretical and practical aspects of modelling land elevation, though, can be found in [12,16,17]. In addition, ideas on incorporating improvements as bathymetric coverages and interpolation techniques improve are considered.

Note that this record is the output of a pilot study with limited scope. Time and resources were not available to exhaustively examine all corporate and external bathymetric databases for all ship track depth soundings in the study area. Company exploration data, for example, falls into this category and would need to be considered in a more rigorous approach.

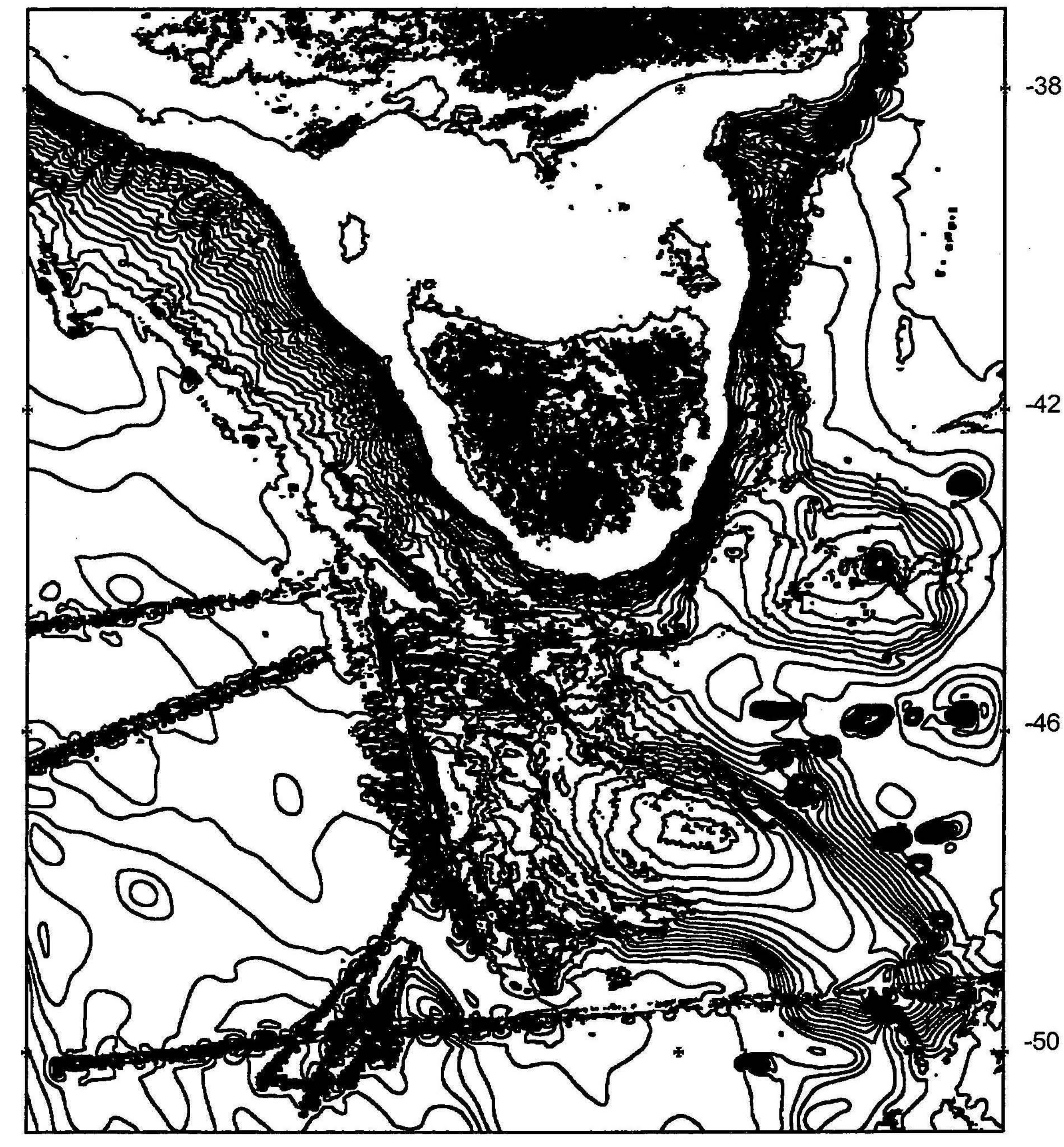


Figure 4. Contour map representation of the terrain model for the pilot study area given in Figure 3. Contour interval is 200 metres and was generated off the equivalent ARC grid data structure.

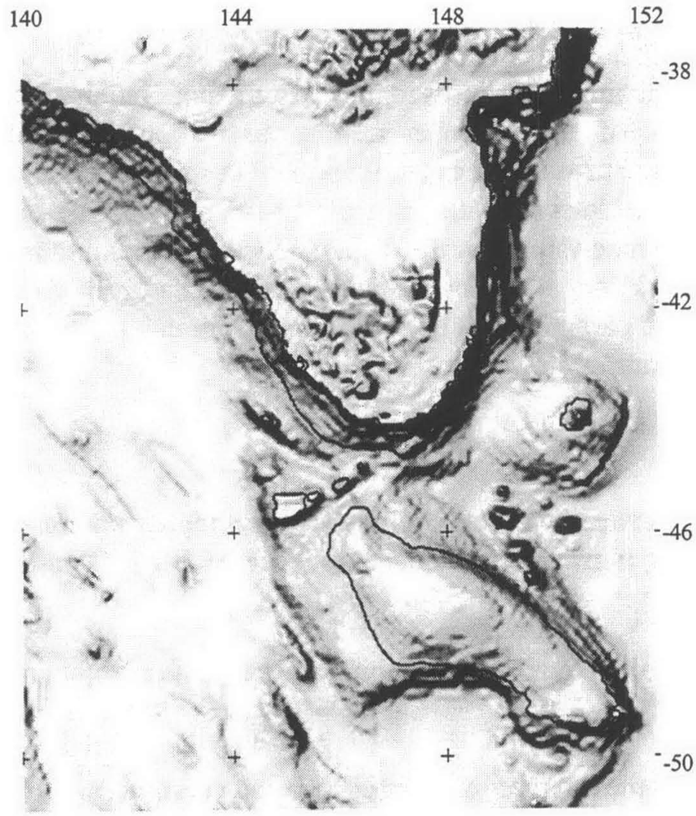


Figure 5. ETOPO5 for the study area. Imaged as an intensity layer with north-west sun illumination. Derived 200 m and 2500 m isobaths shown.

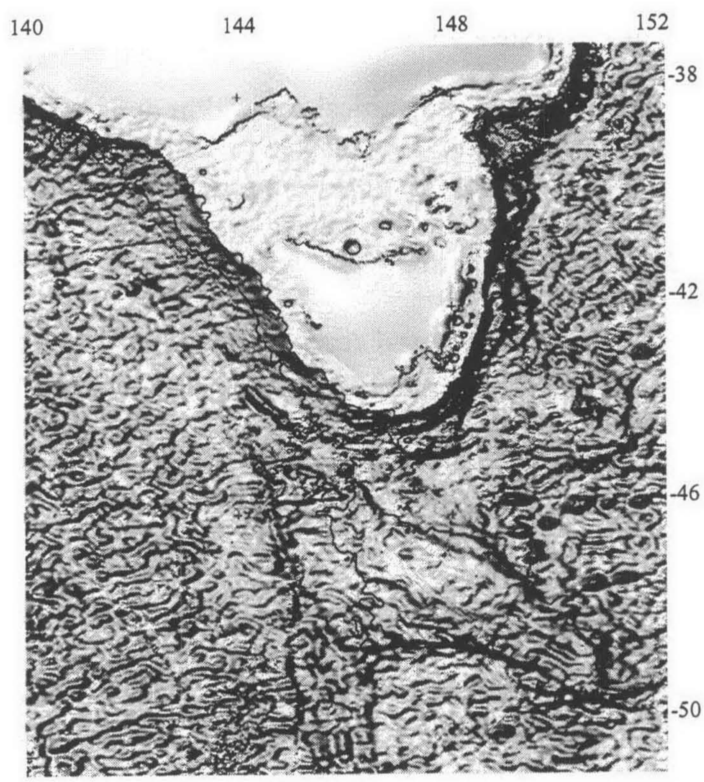


Figure 6. Satellite-derived predicted bathymetry for the study area. Imaged as an intensity layer with north-west sun illumination. Derived 200 m and 2500 m isobaths shown.

Grid Representation Theory

Various numerical and imaging procedures in the earth sciences require data to be organised as a regularly-spaced mesh of values. However, most observations acquired in the field are irregularly spaced. They are taken from either individual sparse measurements or along random and sometimes pseudo-systematic traverses. In order to produce the required regular grid it is necessary to estimate values for the data in between these arbitrary measurements in the x, y plane. In this section, a brief overview is given of the "grid" data structure, its mathematical background, parameters to be considered given the source data, and problems that may arise in its generation.

Grid Data Structure

Generally, a grid can be understood as a regularly sampled representation of a physical quantity. This partitioning in two-dimensional space (see ARC/INFO on-line help facility) is sufficiently described by:

- a rectilinear mesh of equally-spaced rows and columns at right angles to each other;
- a cell defined by the intersection of each row and column;
- a value representing the modelled parameter for each cell[3]; and
- a form of transformation relating the mesh coordinates of row and column pair to some reference frame.

Specifically, for a terrain grid, the rows and vertical cell widths define the north-south extents of the data whilst the columns and horizontal cell widths define those for the east-west direction. Furthermore, row and column dimensions are generally equal so that the cell size, or represented terrain area, defines the smallest geographical feature able to be reproduced. This dimension represents the resolving power, or resolution, of the grid.

The equivalence of a grid to a two-dimensional array allows for easy digital storage and manipulation by appropriate software. For example, once a corner of the grid is known in real-world coordinate space it is only a matter of row and column multiplication by the cell widths to determine where any other cell in the grid is geographically located.

From Source Data to a Grid

Observed data are generally sparse or irregularly spaced and biased in certain directions. The surface is under-sampled in the intervening regions and the problem of defining its 'true' character is ill-posed. Nevertheless, various techniques exist in which the measured values are interpolated and extrapolated to fill all the cells making up a grid with fixed boundaries. The numerical methods for the generation of a surface from sparse data fall into two broad categories: integral and statistical interpolation [42].

[3] Image grid, or raster, datasets can hold many values per cell, each being referred to as a "band".

Integral interpolation methods

Integral interpolation methods are wholly mathematical and rely on specifying grid cell values by fitting a global function, usually a polynomial, to the spread of underlying observations. Parameters allow this function (ie. surface) to be tuned for desired properties.

The methods generally incorporate the notion of minimum curvature smoothing, where the squared curvature over the entire fitted surface is minimised [2]. Splining techniques[4] are a popular application of this and may include a tension parameter to control the amount of fitted-surface oscillations between source data points [18,42].

These methods are the most widely used in the earth sciences with variations being offered in the search strategies for contributing observations [33,35], the form of the fitted polynomial [18] and the degree of smoothing, or tension applied [18,42], to the resulting surface.

Statistical interpolation methods

Statistical interpolation methods, on the other hand, estimate grid values by selecting weights based on the data auto-correlation [42]. Confidence limits are given and can be used to quantify how well the modelled surface actually fits the source data. Kriging procedures (see below) exemplify this class.

All gridding techniques generally indicate how they honour the source data points and are usually specified by how a cell treats the underlying source point value(s). As outlined above though, the greatest variations are to be found in the estimation of those cells lying in between source points.

Gridding Issues

Once the boundary of the area to be modelled has been chosen, two further gridding decisions are required: the grid resolution and the chosen technique's surface-fitting parameters.

Grid resolution

As mentioned, resolution refers to the grid's cell size and should be chosen as a compromise between digital storage requirements and representation of the smallest sampled feature of interest. No additional information is gleaned from the source data by choosing a cell size significantly smaller than the smallest observation interval. On the other hand, too large a cell size will produce a surface with less detail that causes heavy averaging of a tightly sampled feature. The balance between the two may be a

[4] Analogous to a cartographer's use of a long flexible strip to draw a smooth curve through a series of non-colinear points. For surface-fitting, however, the view is of a series of observations acting as springs to deform a thin elastic plate.

case of trial-and-error. For example, the Airborne Geophysics Group of AGSO routinely grid their flight-line datasets at one-fifth the line spacing. This is a trade-off between maximising resolution along the line and allowing the curvature of the fitted surface a degree of freedom in delineating trends across the lines.

Surface-fitting parameters

The gridding algorithm's interpolation parameters are designed to fit and tune the shape of the fitted surface. These can be summarised as:

- the amount of stiffness, or curvature, to the surface between data constraints;
- the contributing influence of surrounding source points to an interpolated cell; and
- the number of iterations, if offered, of the above to achieve the desired result.

In terms of surface extrapolation, algorithms like ANUDEM [11], regardless of distance from source points, automatically fill in grid cell values out to the bounds of the area of interest. However, others such as Intrepid's [9] suite of gridding routines, allow the user to define the number of cells from observations at which values are to be calculated.

Gridding Problems

The pilot study area provides a clear example of the problems faced when attempting to fit a realistic-looking surface to an area covered by many disparate data sources. These can be summarised as:

- areas of high data density calling for a smaller cell size than those adjoining, where the data density is lower;
- areas covered by dense parallel ship tracks where systematic data shifts along alternate lines are encountered;
- inconsistent depth measurements between ship tracks where they intersect (ie. Cross-over Errors); and
- inconsistent depth measurements between datasets of different origin.

These problems are addressed below.

Datasets Used

Figure 7 depicts the various sources of land and bathymetric data used to compile the DTM for the pilot study area. The details of these datasets are discussed below.

GEODATA 9-arc second Digital Elevation Model

The cells of the final DTM that define the land component are derived directly from the pre-gridded GEODATA 9 SECOND DEM [3]. It is an Australia-wide land-based model of terrain created using an extensive dataset of both sparse point and AGSO airborne elevation data, as well as a vast array of stream lines and water bodies. ANUDEM (version 4.2) was then applied to these data to generate a hydrologically-consistent surface model. This dataset currently resides on AGSO's corporate database server.

Melville fully-processed swath mapping

The R/V *Melville* is an oceanographic research vessel of the Scripps Oceanographic Institution. It is fitted with a SeaBeam 2000 multi-beam (the reader is referred to [4] for the physics and trade-offs in swath sampling the subsurface) system. In April 1997 it was contracted by AGSO as a vessel of opportunity, on its transit from Hobart to Melbourne, to map part of the Gippsland Basin and east Bass Strait canyon. The continental slope and rise along the east Tasmanian continental margin were also included.

The data were supplied as a mesh of depth, longitude and latitude points referenced to the WGS84 datum. It has a resolution of approximately 0.001° (ie. approximately 100 metres).

Melville partly-processed swath tracks

From 1994 to 1996 the R/V *Melville* spent some time in the pilot study area whilst on transit between the United States and Antarctic waters. Swath data were acquired on these passes.

The supplied data of depth, longitude and latitude points are processed for vessel roll, yaw and pitch but have no beam steering corrections applied. Furthermore, information was not readily available regarding datum parameters, so the WGS84 datum was assumed.

Maurice Ewing partly-processed swath tracks

The R/V *Maurice Ewing* is an oceanographic research vessel of the Lamont Doherty Earth Observatory. It is fitted with a Krupp Atlas HydroSweep DS multi-beam system, which is optimised for water depths greater than 500 metres. In 1995, the vessel was involved in a mapping effort over the Macquarie Ridge, but also recorded some widely spaced swath-tracks over the southern extremity of the South Tasman Rise.

The supplied data of depth, longitude and latitude points are partly processed for ship navigation and were assumed to be referenced to the WGS84 datum.

L'Atalante fully-processed swath mapping

The N/O *l'Atalante* is a marine research vessel owned and operated by IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer). It is fitted with two multi-beam systems: a Simrad EM12D for deep water and a Simrad EM950/1000 for shallow water. It took part in a joint French, Australian and USA marine ship scientific exchange program and from February to April 1994 was used to map in detail a large tract of the South Tasman

Rise as well as a portion of the deeper west Tasmanian continental margin - the Tasmante Survey [10]. Entry and exit swath tracks to the survey area were also acquired.

The data were supplied as a mesh of depth, longitude and latitude points referenced to the WGS84 datum. It has a geodetic resolution of approximately 0.0031° (ie. approximately 310 metres) in the east-west direction and 0.0025° (ie. approximately 250 metres) for north-south.

Satellite-derived predicted bathymetry and some ship track depths

The predicted bathymetry dataset imaged in Figure 6 reflects the work of Sandwell and Smith [37,40,43] in processing the ocean surface radar-altimeter data recently acquired by both the European Space Agency's ERS-1/2 [6] and Topex/Poseidon as well as the United States Navy's Geosat radar altimeter satellites [27]. They present a method that uses sparse ship track soundings to "ground truth" sea surface gravity calculations for the 15 - 200 kilometre wavelength component. It is in this band that they expect to find strong correlations between ocean floor topography and marine gravity anomalies. However, this correlation is highly variable as it is predicated on a low sediment cover.

The predicted bathymetry dataset is obtained as a mesh of depth, longitude and latitude points at about a 0.04° (ie. approximately 4000 metres) spacing [43]. Figure 6 shows that although it is very successful in identifying large-scale seafloor morphology, it is dominated by a "wormy" character. Its real power though, comes in the identification of uncharted seamounts - compare with the ETOPO5 image in Figure 5, which reflects contour interpretation off original ship track data (ie. General Bathymetric Charts of the Oceans, or GEBCO, maps).

Hydrographic Office surveys

The supplied data of depth, longitude and latitude points represent the early systematic efforts of the National Mapping program in surveying[5] the continental shelf out to the 300 metre isobath and occasionally to deeper waters. These data are now in the custody of the Royal Australian Navy (RAN) Hydrographic Office. The planned nature of the surveying means that much of the supplied data is made up of parallel ship track depth soundings at an average spacing of three kilometres.

The dataset supplied was un-attributed for navigation details so the datum is again assumed to be WGS84, although the survey era indicates another datum.

ETOPO5 depths

Earth TOPOgraphy-5 (ETOPO5) is a gridded dataset of earth topography at 5 arc minute (ie. approximately 9000 metres) resolution [7]. Prior to the work of Sandwell and Smith on predicted bathymetry, outlined above, it represented the best available global view of the ocean floor. Its merits have been severely questioned, though, because of its reliance on human-generated contours and the overshoot nature of the minimum-curvature model fitted

[5] Through mostly the *Cape Pillar* and *Cape Moreton* vessels from the mid-1970s through to 1990.

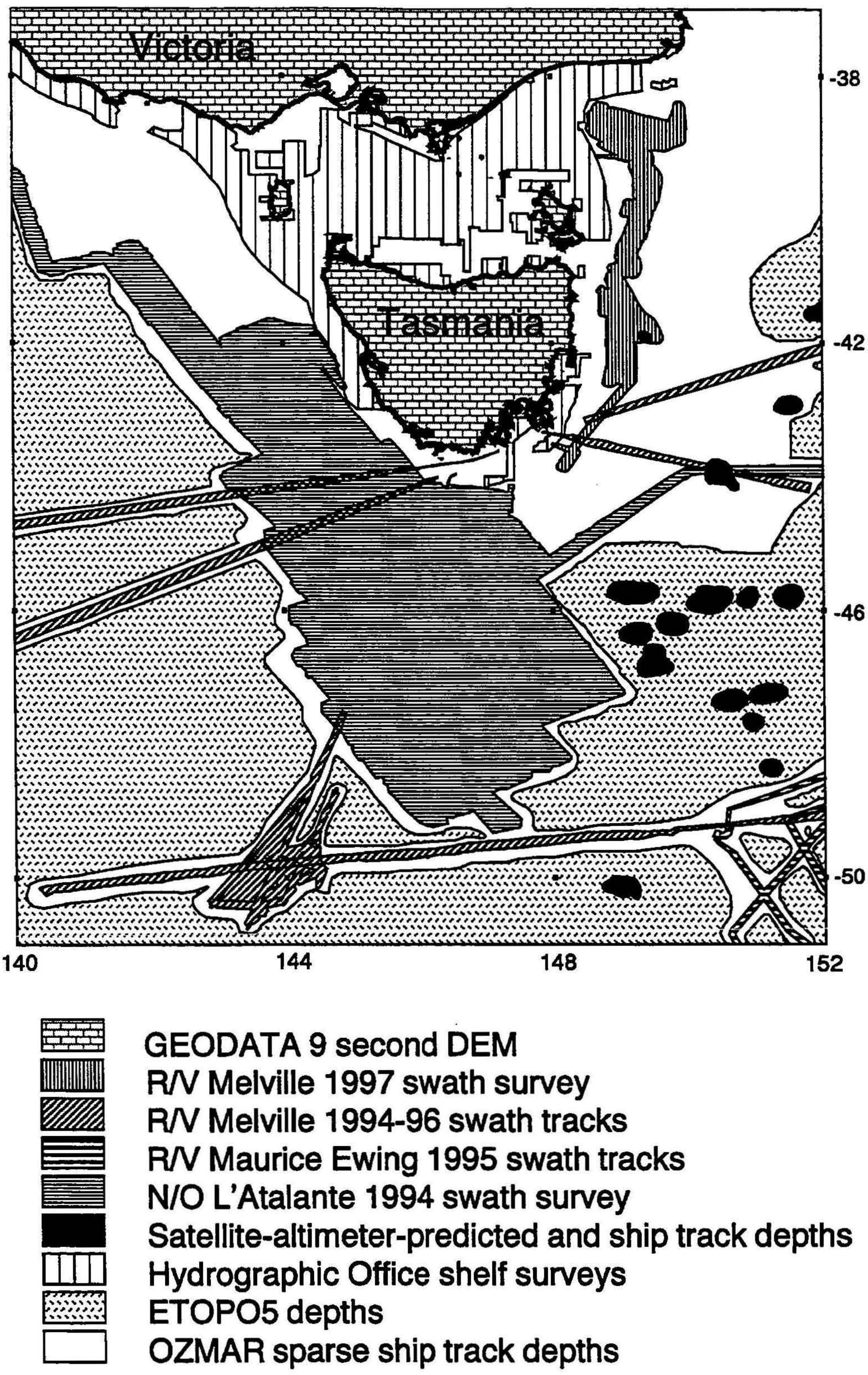


Figure 7. Bounding polygons showing the extents of the datasets used in the pilot study area.

[41]. Figure 5 shows the dataset for the pilot study area - bathymetry and elevation. It depicts broad features, as does predicted bathymetry, but since it is a contour interpolation of sparse ship track soundings, can only model those seamounts that have been crossed.

To be incorporated with the other bathymetric point datasets the extracted grid was clipped for the appropriate polygon shown in Figure 7, and simplified to a mesh of depth, latitude and longitude points.

OZMAR database depths

Depth soundings of sparse ship tracks across Australian waters are compiled in AGSO's own OZMAR digital database (see Appendix 1). These currently number some 470,000 for the study area, although only 180,000 were used (ie. refer to bounding polygon in Figure 7), and vary greatly in spatial density - from a few hundred metres where ship tracks radiate out of a port to hundreds of kilometres in the south-west of the study area. Furthermore, because of their diverse heritage, individual depth errors are common with many navigation details unknown so that there is ambiguity in both datum and depth accuracy. The lack of a coordinated survey effort amongst these vessels has led over time to both large gaps and redundant coverage of the subsurface, as vessels will tend to follow the same route as they take the shortest path from point to point.

The supplied data were extracted from the database as depth, longitude and latitude points.

Interpolated fill-in depths

This is a small, sparse dataset and as such is not represented in Figure 7. It comprises the 100, 150, 200 and 300 metre isobaths circling the Tasmanian landmass and several small areas of interpreted depth measurements in the Bass Strait, which were not covered by Hydrographic Office data. The isobaths are digitised off 1:250,000 bathymetric maps, which are based on the above Hydrographic Office data and other Australian Navy surveys.

Tools Used

In this section an overview is given of the software tools used to analyse the source bathymetric datasets, construct the final grid and view the resulting image representations. The relevant product documentation provides more detail.

Geographic Information System Software

ARC/INFO (of Environmental Systems Research Institute) was the GIS tool employed. It is able to store, manage and spatially analyse large domains of geographic information. All the bathymetric datasets were supplied as, or converted to, ASCII files of depth, longitude and latitude and then imported into ARC as separate coverages. This was seen to be the best compromise between the volume of digital storage and the requirements for quick viewing and editing of the data in the spatial domain. ARC/ARCEDIT was used to edit spurious depth values while the ARC/GRID cell-based modelling environment was used to spatially manipulate, filter and combine the grids.

Edited bathymetric point coverages were converted to ASCII files of depth and coordinate value columns by unloading appropriate relational table fields in the ARC/TABLES environment. The constructed ARC grid data structures were converted to ASCII files using the ARC gridascii routine. These files can then be imported to ER Mapper, Petrosys and Intrepid for image rendering or further manipulation. For the most part, a basic knowledge of relational databases and ARC commands sufficed to manage this large quantity of data.

Gridding Software

The gridding programs evaluated were:

ANUDEM

ANUDEM[6] [11] is essentially an iterative multi-gridding procedure that fits a discretised smooth surface to a large irregular spread of point and contour elevation data. Its ability to honour the down-slope movement of water, through a connected drainage network, has given it strong appeal in the modelling of land-based terrain [15,16,17]. This feature of the tool, though used on the pre-gridded GEODATA 9 second DEM dataset, was not used for the bathymetry in the area. Water-shaping processes on subsea topography would appear to be due more to the lateral motion of currents rather than to water-flow under the influence of gravity. However, consideration could be given to the down-slope, high-density mixtures of water and sediment as turbidity currents in continental slope canyon systems.

ANUDEM is run via a batch file that is able to accept data from a variety of files and formats. It outputs both a grid and a series of associated diagnostic files in several formats. These associated files are useful in localising likely problem areas in the source data, such as remaining sinks and source points having large residual values to the fitted surface.

Intrepid gridding tool

Intrepid [9] is a fully integrated geophysical processing and visualisation system. Although designed for the types of data acquired by airborne surveys, it also offers a suite of algorithms for both the interpolation of sparse data and subsequent conditioning of the resultant grid. The nearest-neighbour and box-filter gridding algorithms were examined as they could handle point data without any supporting survey information. Other tools used included the decorrugation tool for removing unwanted elongate anomalies in a grid, spectral filtering in the fourier domain to examine the apparent "wormy" noise in the predicted bathymetry dataset, and the grid stitching tool to smoothly join adjoining grids.

[6] ARC/INFO has utilised a version in its routine TOPOGRID.

Petrosys gridding algorithms

Petrosys [32] is a software package that provides many mapping and analysis tools for interpreted seismic and well log data. As such, it offers a suite of algorithms for the interpolation of data points positioned along lines to form a two-dimensional surface. It does, however, require several intervening steps for the conversion of these data to its own format and the setting up of a projected map base before a grid can be generated.

ARC/GRID IDW and spline algorithms

ARC/GRID provides two sophisticated interpolation routines. The first, Inverse-Distance Weighting (IDW), performs a weighting on surrounding observations to the interpolated cell as an inverse-distance function. The generated surface may also be influenced by sampled linear features without a topographic component. The second function, spline, aims to fit a 2-dimensional thin-plate spline of minimum curvature to a point dataset, with the surface honoured at the point samples. Both interpolation routines allow tuning of the surface smoothness through the setting of quantitative and categorical parameters.

ARC/INFO kriging algorithm

Kriging has been widely used in both economic resource estimation and soil modeling [30,31]. It has also been suggested as a possible alternative to minimum curvature techniques for the rendition of bathymetric maps [42]. In response, ARC/INFO offers the kriging program to interpolate a grid from a set of sparse data points. Options are provided for both the forms of statistical sampling of observations and the type of semi-variogram model to be used. Kriging, however, is not immediately intuitive and requires a clear understanding of the statistical nature of the variable to be modelled.

ARC/INFO TIN generation routine

A Triangulated Irregular Network (TIN) is a set of contiguous, non-overlapping triangles whose common vertices are the observations with (x,y) coordinates of value z. It is a digital abstraction of a surface and so complementary to a grid. However, it is much simpler to generate as it requires no statistical or mathematical computation to infer values for a rigorous mesh-style model. ARC/INFO provides the TIN environment for this need. It allows for the generation and analysis of TINs with conversion to and from ARC's grid data structure.

Imaging Software

Although algorithms to image raster data are available in ARC/INFO, Intrepid, and Petrosys, ER Mapper [5] version 5.2 was used to view all image-rendered gridded datasets and produce the images contained in the figures of this record. It is an advanced image processing package that can display, enhance and analyse both raster and vector data in real-time. Links to ARC/INFO coverages, for example, allow for quick vector overlays and so correlation between imaged features and geographic data. Whereas Intrepid grids are directly compatible with ER Mapper's image file format, all other grid formats require several steps of importation and geocoding before they can be viewed.

Digital Terrain Model Construction Methodology

The construction of the digital terrain model (DTM) for the pilot study area involved a procedural approach. The following discussion presents the methodology in building this model. Scope for improvement is addressed in a later section.

Choosing Dataset Bounds and Recognising Limitations

As stated previously, the primary objective of the study is to use those source datasets that could be converted to a surface to best represent the continuous nature of terrain. No single dataset was of sufficient extent, resolution and accuracy for this task. In fact, Figure 7 shows the boundaries of the datasets chosen to compile the final model. The reasons for their choice are as follows:

Multi-beam swath mapping - apart from uncorrected noisy samples and some processing artefacts, swath sampling is the best available representation of the sub-surface. As either a fully-processed mesh of points or raw spread of original depth soundings along track it suffices in the definition of a high resolution surface. Overlying individual ship track data were not included because of cross-over errors (see below).

Satellite-altimeter-predicted bathymetry - although resulting in topography dominated by noise in the 20 - 25 km wavelength range (see 'wormy' character in Figure 6) this method is seen to be superior to both ship track soundings and ETOPO5 in the identification of seamounts [21]. Therefore, all predicted depths over seamount features were extracted from the original dataset and incorporated.

Hydrographic Office Surveys - the data were of sufficient density to justify a surface fit without additional soundings. Although a large subset of OZMAR ship track depths overlie this dataset, it was excluded because of the widespread cross-over error adjustments required. Furthermore, the benefits in applying Intrepid's decorrugation tool to the resulting grid were realised.

ETOPO5 - this was employed in the deeper abyssal terrains and across the southerly nose of the South Tasman Rise. Although there was a reluctance to use the data because of its derivation from human-generated contours and surface-overshoot problems (see above), the areas in question were covered too sparsely by ship tracks. This would have resulted in a surface with a "bulls-eye" character for the observations along those tracks. Nevertheless, ETOPO5 is taken as a compromise in the presentation of a more appealing and continuously smooth surface across the study area.

OZMAR ship track depths - these data were used to fill in those areas not covered by the above and where their density was sufficient to define a realistic-looking surface without the aid of ETOPO5. Furthermore, where a ship track was found to traverse a seamount the relevant soundings were extracted and included with those points from satellite-altimeter-predicted bathymetry to better control its depth.

Dataset Cleaning

A generated surface should be constrained, within some criteria, by the underlying data. Large-scale errors, or noise, will be reflected in localised anomalies in this surface. In terms of depth soundings, these are of three obvious types and are now presented:

Spurious bad depths

Spurious bad depths are characterised by positive and negative spikes, as shown in Figure 8. Identifying such features in the source data is difficult because of the quantity of soundings to be examined - some 180,000 from the OZMAR database to be used in the study (Appendix 1). However, these features are easier to recognise in images, particularly with sun-illumination applied. As such, an initial gridding run of the data and conversion to an image was often adequate to identify the problem. Programs, such as ANUDEM for example, aid in this identification by outputting a suite of diagnostic files that localise anomalous source points. Alternatively, the grid could be converted to a contour file and examined for "bulls-eye" features that could be due to anomalous points. Nevertheless, large data spikes without a gravity signature or with unrealistic gradients were flagged and not used. Flagging was done by marking a field in the feature's attribute table (ie. ARC coverage's INFO file) so that its anomalous nature could be verified later.

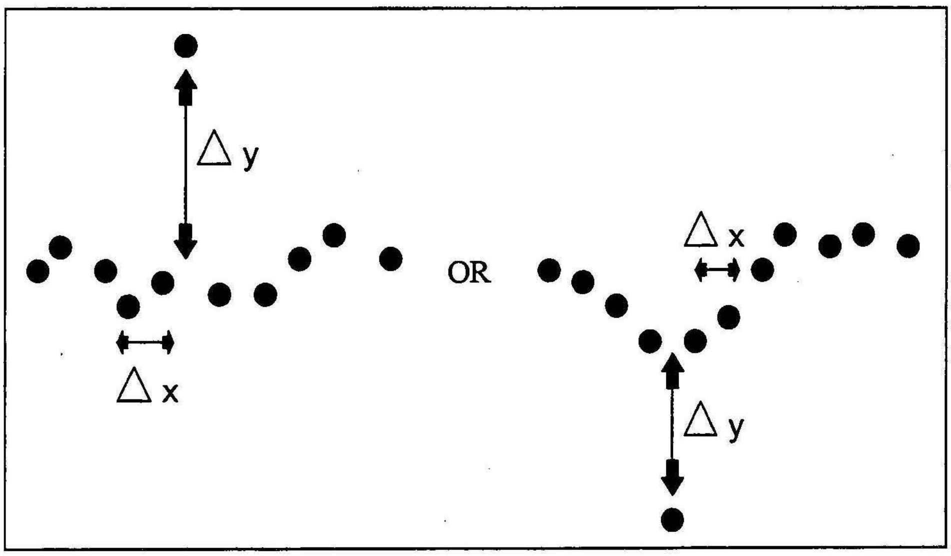


Figure 8. Idealised profile of how depth-sounding spikes would appear along a ship track. A Δy considerably greater then Δx indicates a potential anomalous value.

Cross-over errors

Overlapping ship track soundings of differing vintages are bound to produce non-correlative sampling of the subsurface and is obvious at the cross over. The reasons for this are many and include the accuracies of different echo sounders, errors in human-digitising, complex sub-surface geometry and navigational errors. To exhaustively retrieve, re-examine and readjust for these was considered too prohibitive for the purposes of this pilot study. Generally though, the heavy averaging of the initial 0.01° cell-size gridding pass (see below) was successful in smoothing out small-scale mismatches between lines (ie. generally less than 30 metres). In those cases of large discrepancies, one line was adjusted relative to the other using ARCEDIT. There, depths were reset in decreasing steps away from the cross-over until differences with other tracks were considered insignificant (of the order of 10 metres and less). These adjustments were biased to those lines paralleling dipping topography. Clearly, this method is not satisfactory and depth mismatches likely remain to produce local pits and bumps in the final grid where OZMAR ship track data was the dominant source. A more rigorous network adjustment algorithm is to be sought with the most reliable survey depths set as the levelling benchmarks.

Swath mapping beam noise

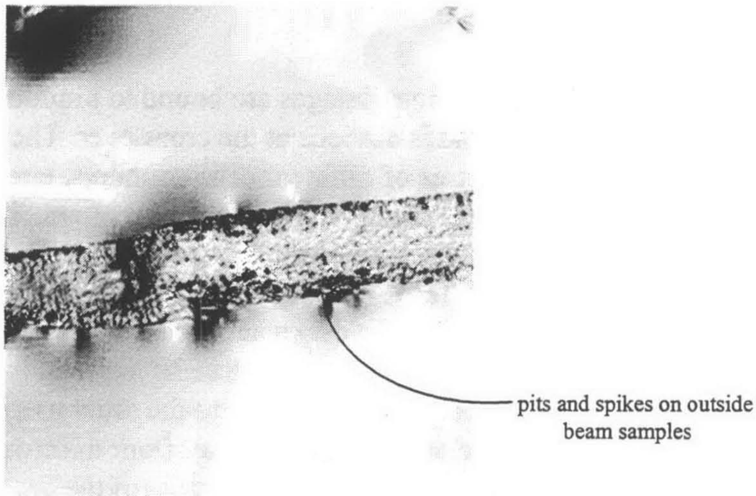
Swath beam steering noise is present in unprocessed swath data as spurious pits and spikes within a track and widespread anomalous values along the outer edges (see Figure 9(a)). The former were left in the final grid whilst a good deal of the latter were clipped out of the associated depth coverages prior to gridding. In contrast, noise in processed swath data is present as either rotating crenulations on outer swath edges (see Figure 9(b)), due to an inability to correctly compensate for ship turns, and as ridging along swath track overlaps (see Figure 9(c)). These remain in the final grid and may account for topographic shifts, for example, of up to 50 metres within the *l'Atalante* dataset.

Note that the number of depth points edited in the OZMAR dataset does not exceed half of one percent and they were predominantly carried out along tracks in the continental slope and rise regions of the western Bass Strait, as well as over the East Tasman Plateau.

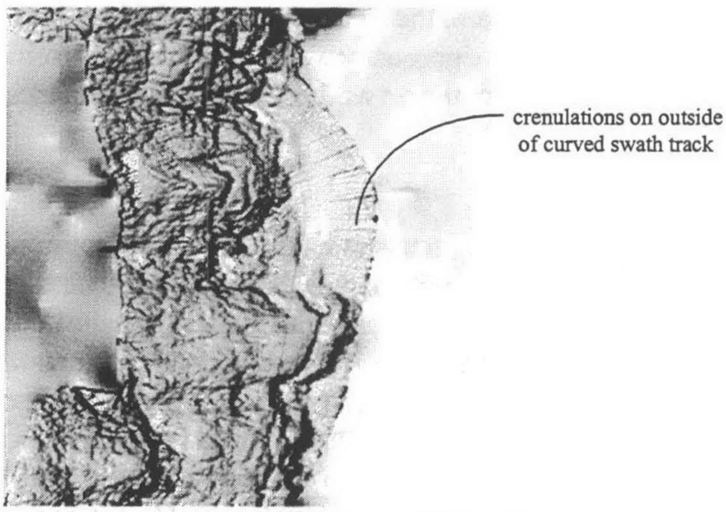
Choosing the Resolution

The pilot study area is covered by seafloor depth measurements of different spatial densities. These range from a mesh of depth points at 5 arc minutes for ETOPO5 to one of approximately 4 arc seconds for the swath data off north-eastern Tasmania (ie. 1997 R/V *Melville* survey). As previously discussed, the data structure defined by a grid requires a consistent sampling interval meaning that a compromise must be sought between data storage and representation of the final surface at the best possible detail.

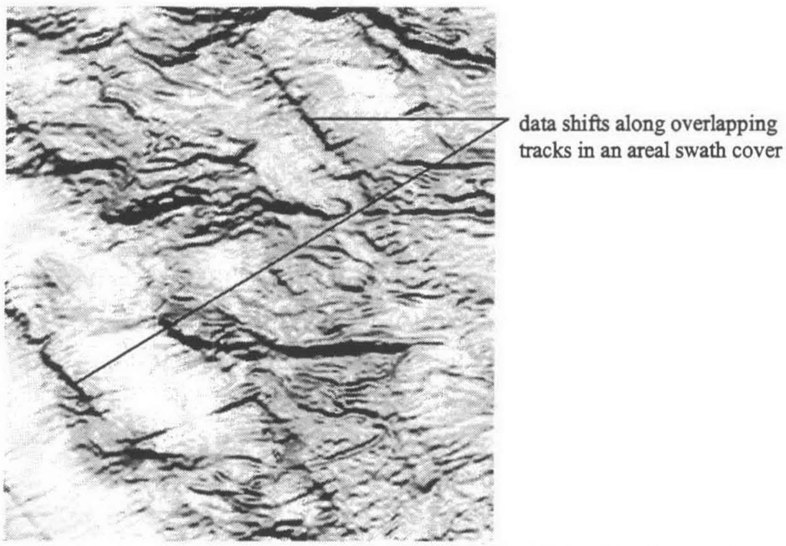
The complete DTM for the study area (see Figure 3) has a cell spacing of 0.0025°. This was chosen since it is the resolution of the pre-gridded land-based GEODATA DEM as well as being close to the resolution of the *l'Atalante* swath data acquired over much of the South Tasman Rise. This entails two trade-offs: the swath data off north-eastern Tasmania is



(a) Noisy values on partly-processed swath tracks. Data from 1994-96 *Melville* passage.

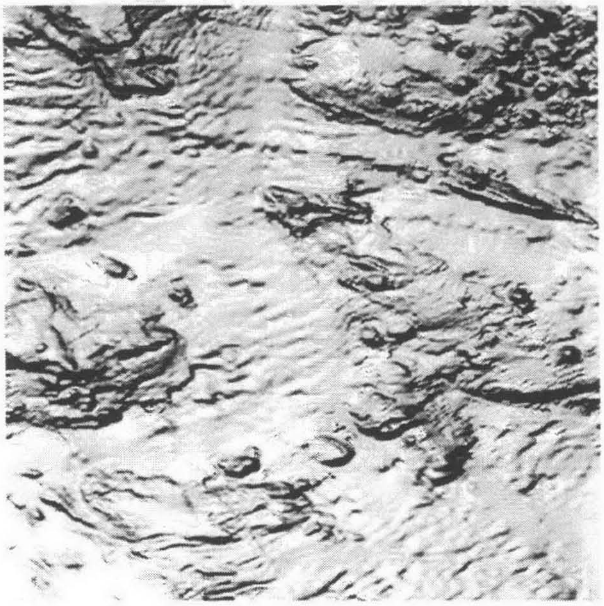


(b) Noise in fully-processed swath data due to vessel steer. Data from 1997 *Melville* program.

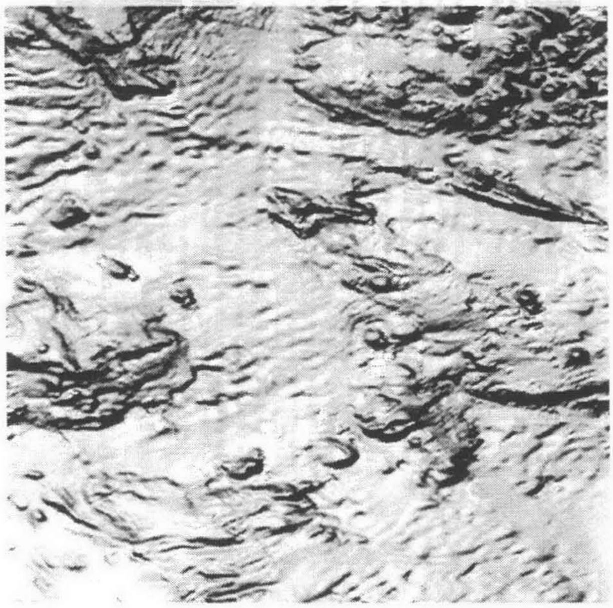


(c) Overlapping track noise in fully-processed swath data. Data from 1994 *l'Atalante* program.

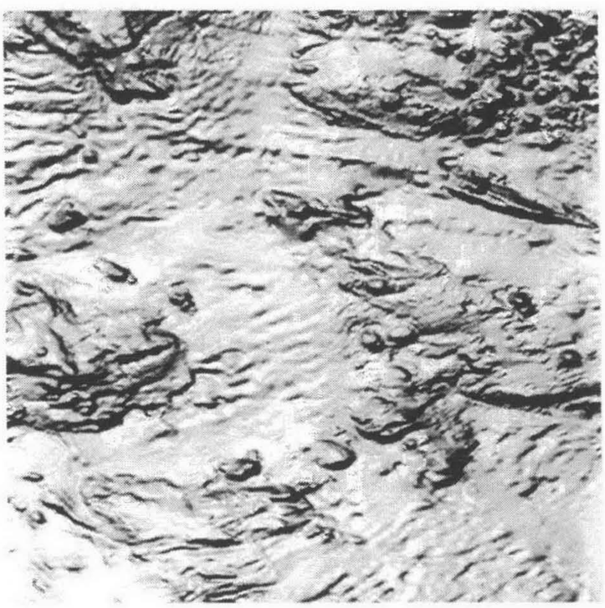
Figure 9. Examples of noise in the gridded swath data on the final DTM. ANUDEM is the gridding tool used. All images are intensity layers with north-west sun illumination.



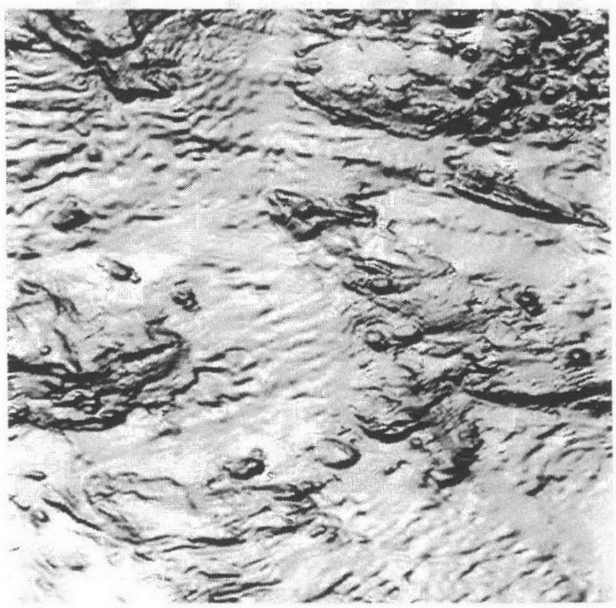
(a) ARC/GRID spline function.



(b) ARC kriging routine.

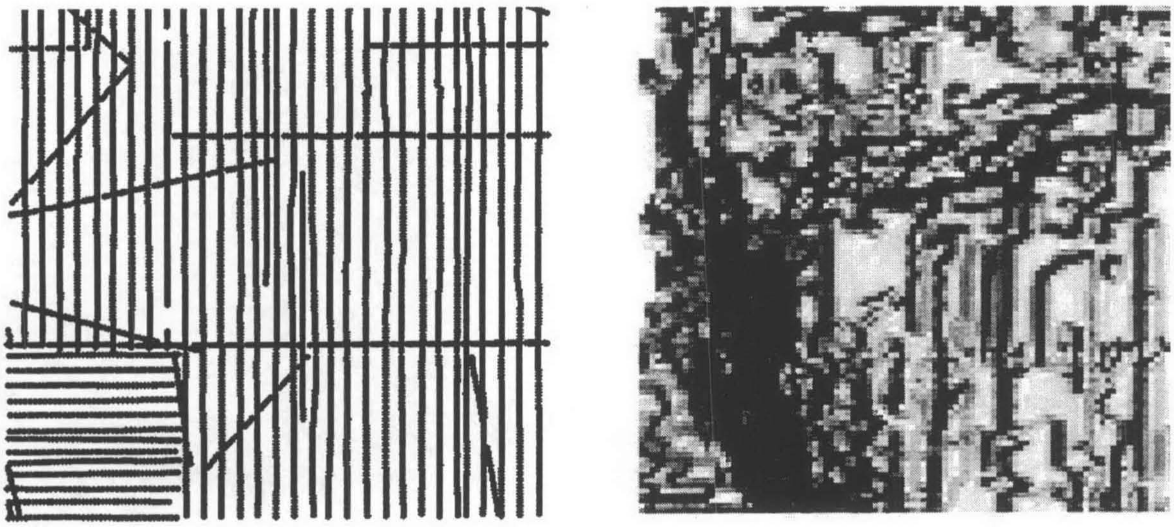


(c) Intrepid's nearest neighbour routine.



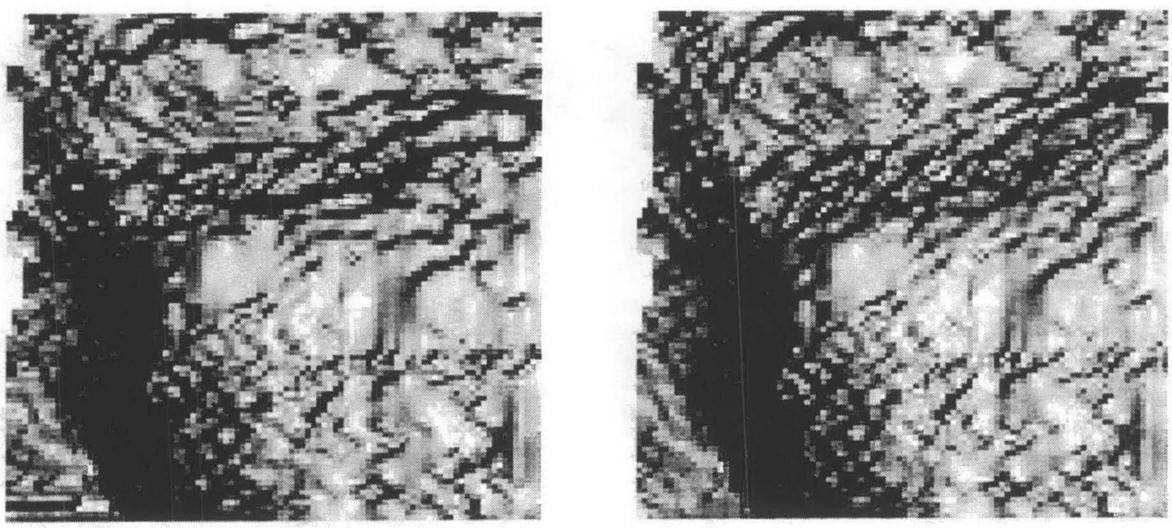
(d) ARC/TIN TIN with quintic lattice conversion.

Figure 10. Sample of several gridding routines on a subset of the *l'Atalante* swath data. The area is from longitude 146.35° E to 147.35° E and from latitude 44.25° S to 45.25° S. All images are intensity layers with north-west sun illumination.



(a) Original ship tracks.

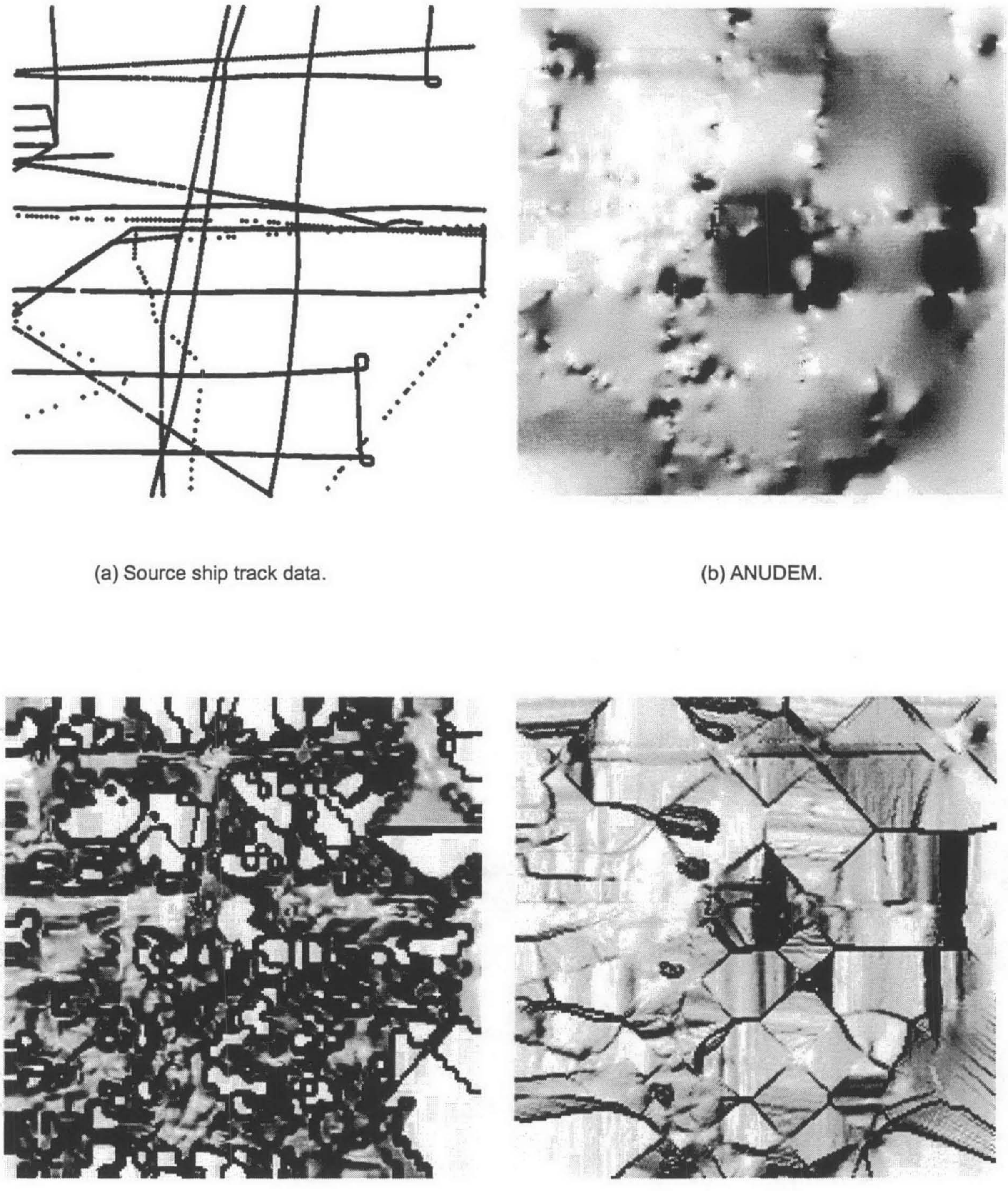
(b) Initial grid.



(c) Decorrugation along columns.

(d) Additional decorrugation along rows.

Figure 11. Use of Intrepid's gridding and decorrugation tools for constructing a grid and removing unwanted elongate anomalies. Area is a sample of Hydrographic Office shelf survey bathymetry from longitude 145.2° E to 146.2° E and from latitude 39.3° S to 40.3° S. Images are intensity layers with north-west sun illumination.



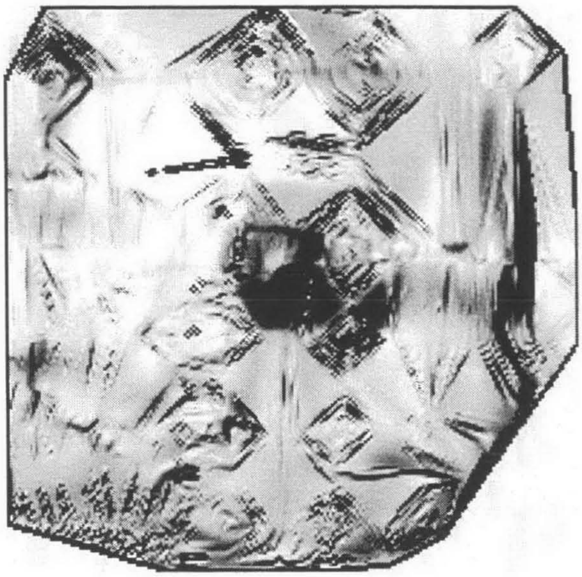
(a) Source ship track data.

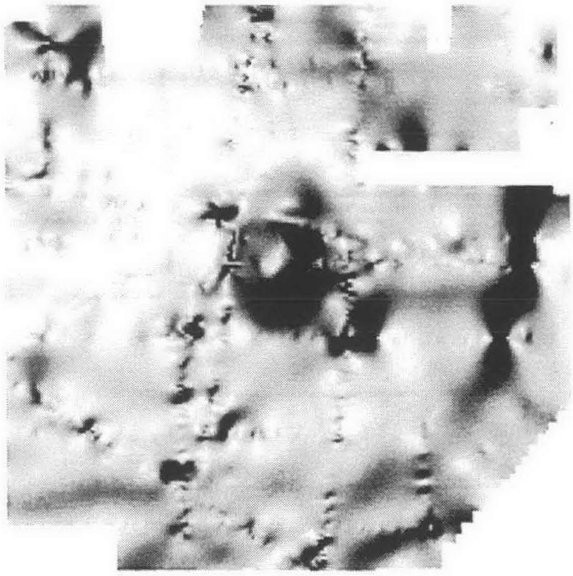
(b) ANUDEM.

(c) ARC/GRID spline function.

(d) ARC/GRID kriging function.

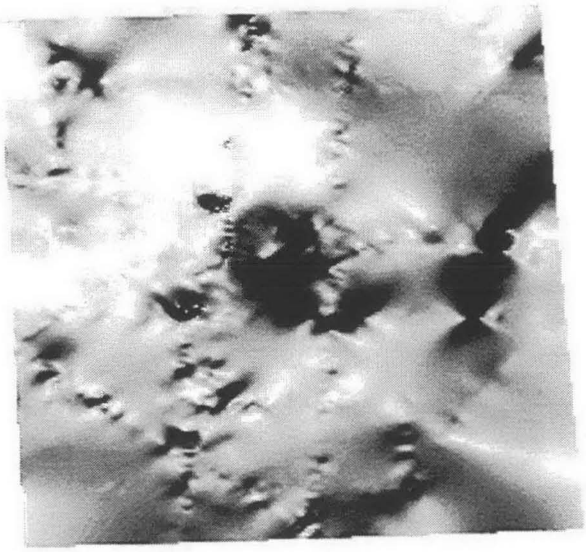
Figure 12. Sample of several gridding routines on a subset of sparse ship track depth soundings. Area is from longitude 149.5° E to 151.5° E and from latitude 43° S to 45° S. All images are intensity layers with north-west sun illumination.

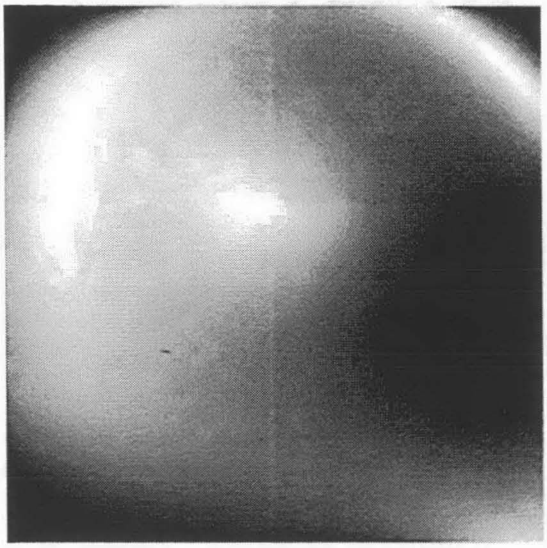




(e) ARC TIN with quintic interpolation.

(f) Intrepid's nearest-neighbour grid tool.





(g) Petroseis minimum-curvature gridding.

(h) ARC/GRID trend function.

Figure 12 (continued).

under-sampled (ie. from an approximate 0.001° spacing) whilst the OZMAR ship track and ETOPO5 bathymetric data is over-sampled in respect to the average spacing of the source points.

Gridding Tests

In this section, the rationale behind the choice of gridding software is discussed. Test regions were chosen in the study area where each was a sample of the four spatially extensive datasets: swath mapping, Hydrographic Office surveys, ETOPO5 and OZMAR sparse ship track data.

Gridding swath data

Fully-processed swath data are generally supplied as a regularised spread of depth values. Converting this mesh to a surface of equivalent or coarser spacing involves no interpolation. In this case, the choice of an appropriate gridding tool is irrelevant as each should honour the original data underlying each cell - the form of averaging will vary - and produce equivalent surface representations. That is, there is no space available between source points for grid cell values to be determined. Figures 10(a) - (d) provide four examples of gridding a sample of the *l'Atalante* swath data at a cell dimension of 0.0025°. As expected, there is little variation in the gridded surface form. Differences, though, are found in the associated computational effort with ARC/INFO's GRID spline and kriging functions taking the most time and ARC/INFO's TIN-generating routine the least. The produced TIN requires a further conversion step for representation as a grid (ie. via the tinlattice routine). Although not depicted in the figures, ARC/INFO's pointgrid routine will also directly map sparse point data to a specified grid, though there is no averaging and cells with no observations are left blank. Note that equivalent arguments hold for gridding partly-processed swath tracks. In summary though, ANUDEM is favoured because of its associated diagnostic files that identify spurious observations.

Gridding Hydrographic Office parallel ship track data

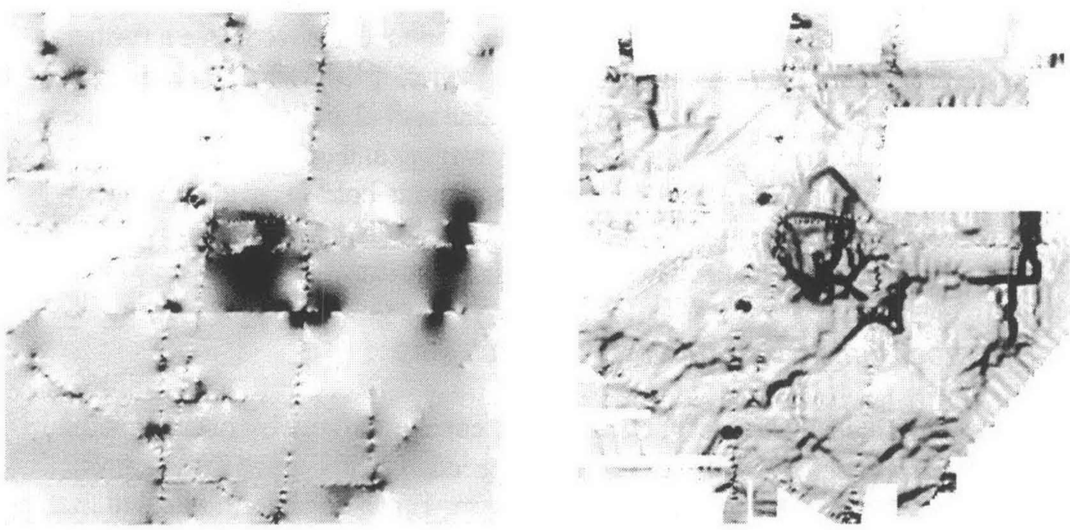
Figure 11(a) highlights a portion of the Bass Strait covered largely by north-south ship tracks of the Hydrographic Office. These data are gridded in Figure 11(b) at a 0.01° cell size using Intrepid's nearest-neighbour algorithm. Tests, however, indicated that all the considered gridding routines produced an equivalent surface. The sun-illuminated image clearly shows a series of elongate anomalies that correlate with the underlying trend of the acquisition lines. These are of the order of 1 - 2 metres in amplitude and both mask fine detail and detract from the broad outline of the Bass Basin.

Figures 11(c) and (d) show the results of successive applications of Intrepid's decorrugation tool acting on wavelengths of about 6000 metres (ie. about twice the line spacing) in both the east-west and north-south directions, respectively. The removal of most of the corrugations is to be noted, and resulted in the use of this procedure on the grid derived from the Hydrographic Office data outlined in Figure 7.

Gridding OZMAR sparse ship track data

Figure 12 shows the results of various gridding routines for a sample of sparse ship track data over the East Tasman Plateau feature. Clearly, the generation of a smooth, realistic surface is difficult to achieve. Least squares methods (eg. ARC/GRID trend function), though, attempt to apply such a surface but the global solution applied results in the loss of high frequency content along the actual data lines - see Figure 12(h).

All the examples show major variability when interpolating data in between source tracks. Nevertheless, ANUDEM, Petrosys and Intrepid are best able to produce a realistic model for the resolution depicted. Although ANUDEM's thin-plate spline fit shows too much rigidity across the lines of source data, this can be mitigated by both a judicious use of an RMS smoothing value and the adjustment of the surface roughness parameter. This results in a more biased minimum curvature fit away from minimum potential. In any case, ANUDEM is to be favoured not only because of its generation of supporting diagnostic files, but also because its surface is better behaved at finer resolutions. This is exemplified in Figure 13, where the ANUDEM model matches more closely its equivalent coarser representation (ie. Figure 12(b)) than is the case with the Intrepid-generated surface (ie. Figure 12(f)).



(a) Using ANUDEM. (b) Using Intrepid's nearest-neighbour gridding tool.

Figure 13. Comparison of surface-fitting results when resolution is increased relative to spacing of ship tracks. Area and imaging parameters are the same as those for Figure 12.

Gridding widely-spaced ETOPO5 mesh data

As previously noted, ETOPO5 was extracted as a gridded dataset at a 0.083°, or 5 arc minute, cell spacing [7]. To incorporate these data into the base model, as defined in

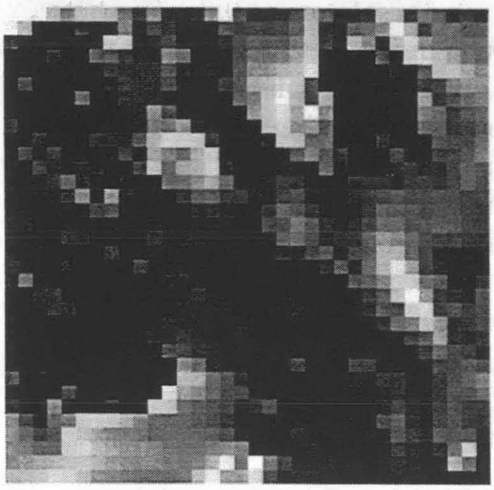
Figure 7, it was necessary to re-grid them at an initial resolution of 0.01° (see below). Figure 14 shows the problems and solution taken in trying to achieve a smooth surface. In fact, all the sampled gridding routines produced similar speckled surfaces to that of Figure 14(b). This indicates the difficulty in attempting to fit a smooth surface with a cell size considerably smaller than the source data spacing. Even specific combinations of resampling and smoothing routines such as Intrepid's Newton 4th-order smoothing algorithm was unable to produce a substantially more appealing representation. A solution was found, however, by generating detailed contours (ie. at 10 metres) off a low-pass filtered version of the raw grid and then gridding these in ANUDEM with full minimum curvature applied. As depicted in Figure 14(d), the resulting surface is a smoother representation of (a), but remains strongly correlated (ie. a correlation coefficient of 0.993 using the ARC/GRID correlation command).

Final Grid Compilation

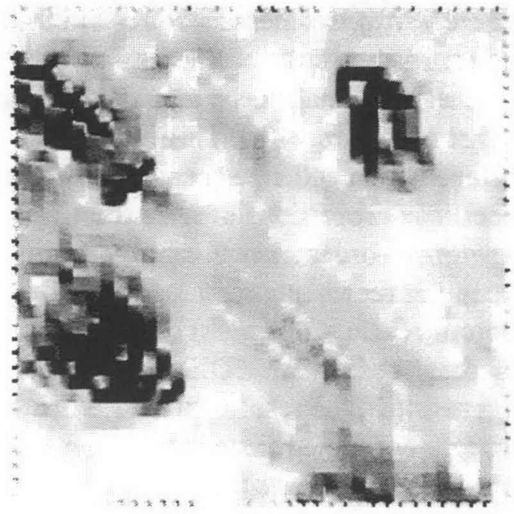
The DTM for the pilot study area imaged in Figure 3 is the result of building a complete surface by incorporating smaller and perhaps more detailed grids into a larger and more general one. The aim is to produce as continuous and realistic a surface as possible without leaving dataset transitions that are too abrupt. This involves a series of procedures to integrate separately gridded datasets into an overall grid and mitigate these transitions. The sequence of grid production is as follows:

Grid-1: All bathymetric datasets were edited to the required extents (see Figure 7) and gridded using ANUDEM for a cell size of 0.01°. A normalised RMS value of 1.5 was used to promote a greater degree of smoothing to the fitted surface.

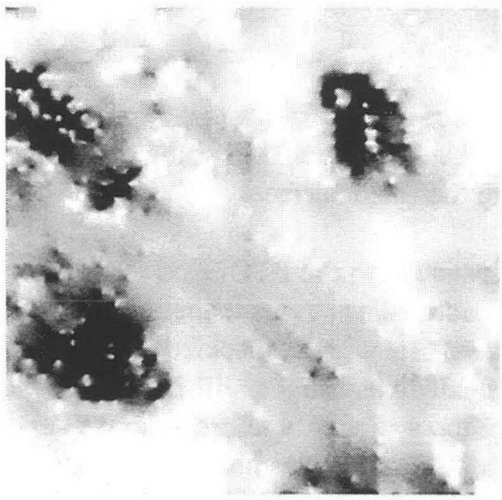
Grid-2: Grid-1 did not satisfactorily fit a smooth surface to the ETOPO5 points (see Figure 14). The wide spacing of the regularised source data versus the required surface spacing (ie. 0.083° to 0.01°) resulted in a surface with a 'speckled' appearance. Given the nature of ETOPO5, the decision was made to utilise it as fill-in data for the abyssal regions, as OZMAR ship tracks there are too sparse. Therefore, heavy filtering of the data to produce as smooth a representation as possible was not considered detrimental. This filtering, however, could not be performed on Grid-1, because of the loss of detail that would result from smoothing the remaining areas in the grid. An option considered, as discussed previously, was the treatment of ETOPO5 data as contours instead of point depths. This was performed in ARC using the latticecontour program on a low-pass filtered version of the gridded dataset for a 10-metre contour interval. Additional smoothing of the contours was achieved by the spline command in ARCEDIT. This data was then clipped according to the appropriate polygon of Figure 7 - note the spacing between the ETOPO5 and swath polygons to lessen the effect of large depth discrepancies and so allow for a smoother transition in the fitted surface fabric. However, the incorporation of both contour and widespread spot depth data into a single ANUDEM gridding run revealed a tendency of the algorithm to fit a terraced surface to the contour data. In contrast, a run solely with contours produces a more appealing smooth fit (see Figure 14(d)). This is due to the global smoothing



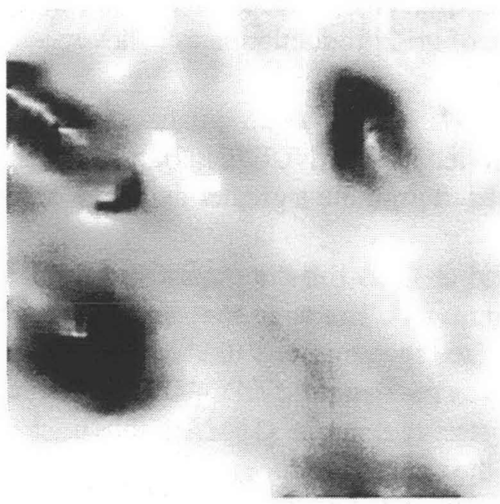
(a) Original mesh dataset at 0.083°.



(b) Bilinear resample of (a) to 0.01° using ARC/GRID resample function.



(c) ANUDEM grid at 0.01° on (a) converted to a point dataset using ARC's gridpoint function.



(d) ANUDEM lattice at 0.01° on contours generated off low-pass filtered version of (a).

Figure 14. Treatment of a subset of ETOPO5 bathymetric data using both derived depth points and derived contours to test for the generation of a smooth and continuous surface. Area is from longitude 141° E to 144° E and from latitude 46° S to 49° S. Images are intensity layers with north-west sun illumination.

nature of the current (ie. 4.4) version which has been addressed in a modification[7]. As a solution then, the Grid-2 surface was produced separately with only ETOPO5 contours and seamount point depths.

Grid-3: Grid-2 was clipped and combined with Grid-1. The functions mosaic and merge of ARC/GRID resulted in a seam with too large a step along the joins and was clearly evident in a sun-illumined image. In response, Intrepid's grid-stitching tool was trialed and found to produce a smoother transition.

Grid-4: As discussed, the nature of Hydrographic Office data meant that they could be successfully treated by separate gridding and subsequent removal of along-line anomalies wholly within the Intrepid package.

Grid-5: Grid-4 was joined with the base grid Grid-3 using Intrepid's grid stitching tool.

Grid-6: The new base grid Grid-5 is at a resolution of 0.01° while all the swath data was separately gridded at the final desired DTM resolution of 0.0025°. To equate the cell sizes for further merging, Grid-5 was re-sampled using the resample function with bilinear interpolation in ARC/GRID.

Grid-7: Both swath track data and the 1997 *Melville* swath survey were gridded at a cell-size of 0.0025° using ANUDEM with a normalised-RMS of 0. The *l'Atalante* swath survey data were gridded at the same resolution using Intrepid's box-filtering routine with reduced minimum curvature smoothing. These settings promoted the generation of a tight fitting surface to the underlying observations (ie. no smoothing).

Note that all swath data were also included in the lower resolution Grid-1. This meant that the grid edge along swath data junctions was already tuned for the added detail in the swath data. Thus, the more simplistic merge function in ARC/GRID was used to combine the grids. That is, edge feathering and grid-cell value shifts were not required. In the order of decreasing importance (ie. fully-processed swath surveys being more accurate than partly-processed swath tracks) then, the following grids were summed - refer to Figure 7 - to produce the final DTM grid Grid-7:

- GEODATA 9 second DEM;
- R/V *Melville* 1997 swath survey;
- N/O *l'Atalante* 1994 swath survey;
- R/V *Maurice Ewing* 1995 swath tracks;
- R/V *Melville* 1994-96 swath tracks; and
- Grid-6.

This study-specific DTM construction procedure can be more generally specified in the methodology presented in Figure 15.

[7] The main adaptation in ANUDEM v4.6 is that it accounts for the spatially varying discretisation error that occurs in representations of surfaces by regular grids. This error depends on the width of the grid cell, which is static across the surface, and surface slope, which varies across the surface (pers. comm. Michael Hutchinson and see [14]).

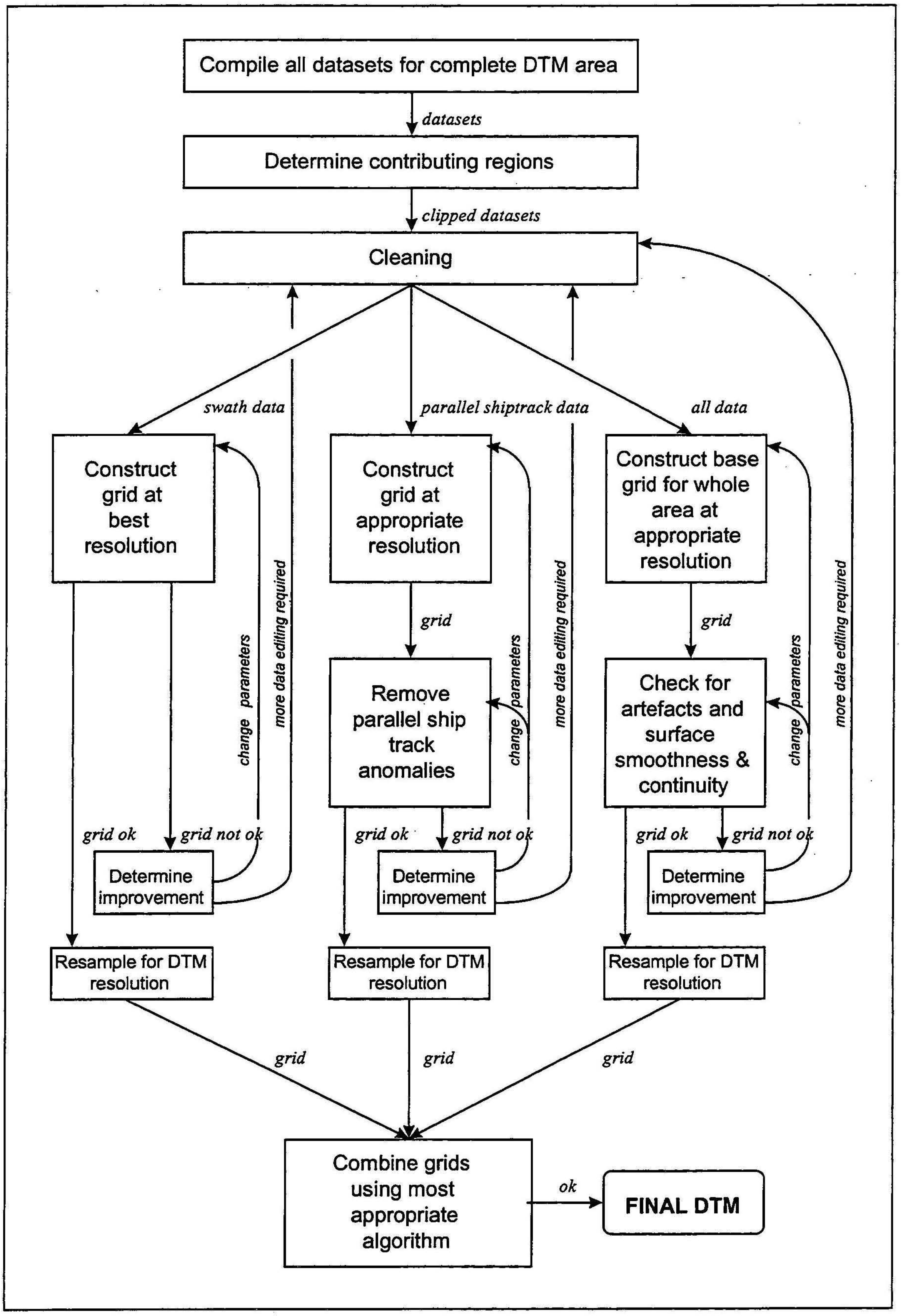


Figure 15. Flow-chart depicting a general methodology for the construction of a digital terrain model.

Resulting Artefacts

Gridded artefacts can be considered as unwanted features that have resulted from the production method. They can be readily discerned in a sun-illuminated image representation. For the study area DTM these are:

- lineations where Intrepid's grid stitching has not been wholly successful in rendering a smooth join (eg. along the eastern edge of the *l'Atalante* data);
- some sharp edge transitions with merged swath datasets due to the different gridding techniques used;
- an unrealistic look of surface fabric 'stretching' across the data gaps between ETOPO5 bathymetry and interposed swath tracks;
- moat-like structures about some of the seamounts due to possible poor fitting between the spot depths and surrounding ETOPO5-generated contours;
- the previously discussed depth spikes and pits in the partly processed swath tracks; and
- low-amplitude north-west to south-east lineations out over the Gippsland coastline and basin, which are parallel to Hydrographic Office survey tracks and were not decorrugated.

Improvements and Iterations

The DTM resulting from this study can be understood as a 'snapshot' surface-fit to the known bathymetric and elevation coverage at the time of construction. The continuing acquisition of more data and improvements in gridding techniques indicates that the representation of terrain should be an iterative process. Furthermore, the number of resulting artefacts detailed above could be lessened by a more exhaustive treatment of the data and application of the tools used. For example, the large depth discrepancies between ETOPO5 and the more accurate swath-sampled depths could be handled by some form of least-squares warping of the former to the general trend implied by the margins of the latter. A more rigorous method, however, could consider the re-definition of GEBCO contours - from which the bathymetric component of ETOPO5 is derived . This would involve the consideration of all additional sparse ship track and swath data since its initial production.

The regeneration of the DTM can be justified by:

- Increased resolution sought - this needs to be a compromise between additional detail sought and both storage and processing requirements. For example, the DTM includes a sub-sampled version of the 1997 *Melville* swath program - to include its full resolution (approximately 110 metres) requires resampling all the other grids with the consequent increase in storage capacity. An alternative solution exists in maintaining a separate full resolution grid of the relevant dataset and analysing it separately for the detail sought;

- More source data - for example, the passage of a new swath track, the acquisition of another swath survey, or a substantial increase in the coverage of individual ship tracks such as the inclusion of company exploration data, would justify the redefinition of the surface in those areas. In this case, the procedures in building the DTM as outlined above, would be followed again;

- Improved gridding techniques - for example, the discovery of new and improved surface-fitting techniques could act as a catalyst for the regeneration of the DTM. Consideration would need to be given to the likely benefits. Examples could be better statistical measures on the fitting of the surface [22], better localised treatment of smoothing (as mentioned, ANUDEM version 4.6) or even techniques such as post-generation surface adaptations [23]. However, time and cost trade-offs need to be considered; and

- the availability of cross-over error correction methods for sparse ship track data (see the XOVER algorithm presented in [44]).

Digital Terrain Model Applications

The hardcopy image of the DTM shown in Figure 3 is useful in so far as it presents a static view of the terrain. Topography is inferred from broad histogram colour-mapping and contour overlays whilst artificial sun-illumination aids the eye in discerning perspective. It is, however, limited by the fixed imaging parameters used and an inability to be analysed and manipulated down to discrete topographic values.

The real expressive power of the DTM is to be realised in its digital grid form. This comes about by application of appropriate software both for real-time, multi-perspective feature recognition and for algorithmic treatment of related parameters.

A broad overview of how the grid may be used in a wider scientific and engineering context is now given. This discussion does not aim to be exhaustive, but hopes to synthesize what is currently under consideration in the literature and so stimulate some further potential uses of this product. It will limit itself mostly to that part of the terrain below sea-level - examples of uses for the above sea-level component can be found in [12,17].

Visual Analysis

Analysis of the model in a real-time, 2D-3D visualisation system such as ER Mapper allows for quick changes to be made to the display parameters. Thus, an area of interest can be localised and highlighted for the feature of interest and thus reveal more subtle spatial patterns.

Geomorphology

Geomorphological features are immediately apparent in the image and a discussion of those to be seen in the *l'Atalante* dataset can be found in [10]. The continental shelf and slope, abyssal plain, seamounts and submarine ridges are readily identified and spatially referenced. More detailed depth analysis can be performed by various techniques such as altering the image-algorithm transform limits and constructing profiles or overlaying vector files of model-derived isodepths.

Profiles can be used to examine the gradient of continental rise and slope as well as the form of various tectonic elements such as the Tasman Fracture Zone that defines the western margin of the South Tasman Rise.

Geology

The visual expression of terrain can aid in the identification and delineation of inter-related crustal elements. For example, close examination of the southerly bending component to the east-west oriented spreading fabric abutting the Tasman Fracture Zone at approximately 144.6° E and 46.25° S indicates right-lateral wrenching motion along the oceanic transform fault to the west of it. This motion has probably resulted in the formation of large basement blocks making up the northwestern part of the South Tasman Rise [10].

The submarine canyons incised into the western margin of Tasmania clearly indicate the continental source for the sediment wedges developed at the continental rise and out onto the abyssal plain. These are probably stacked turbidite fans formed as a result of the focused energy of turbidity currents down the canyons. In fact, the single swath track out to the west shows the extent of sedimentation masking the spreading fabric and indicates that the Tasman Fracture Zone no longer acts as a barrier to sediment supply.

Analysis of the data can raise issues such as those on whether intra-plate tectonic mechanisms have influenced the terrain elements in a north-westerly sense? This would be based, for example, on the general strike of such features as the continental block centred at 144.6° E and 44° S, the Derwent River valley, the Tamar Graben and the broad Bass Basin outline. Furthermore, from a magnetostratigraphic viewpoint, can a detailed correlation be made between ship track magnetic signatures and the crenulations of the seafloor spreading fabric at the foot of the Tasman Fracture Zone?

Fishing

Fishing stocks can be sustainably managed through the regulation of both species' habitats and their breeding grounds. The current DTM is an invaluable macro-level tool for the identification of not only local habitats, but also for seafloor features, such as seamounts, that may attract fish and benthic life-forms.

Geographic Analysis

In its digital form the DTM may be brought into a GIS environment and both examined and enhanced for the detail of its modelled parameter - topography. The following presents some possibilities.

Navigation

Contour maps at various detail are able to be generated rapidly from a grid. These may serve as general bathymetric indicators once an appropriate projection is chosen. Consideration would obviously need to be directed not only to the grid resolution, but also to the accuracy of the underlying source data, which could be handled by the overlaying of polygons identifying some reliability factor. For example, high-resolution swath-mapped obstacles would be given greater weight than extrapolated features derived from the surface fit over a single ship track. Furthermore, those features whose depths are acoustically sampled are of greater reliance than those determined from the downward-continuation of the regional satellite-gravity field.

Line-of-sight calculations are possible and could be of use in such things as sighting of bottom-positioned transponder locations. Again, attention has to be directed to the accuracy of the underlying data - for example, the overshoot curvature-highs characteristic of ETOPO5 [41].

Law of the Sea

All of the Law of the Sea work requires a good knowledge of bathymetry. As mentioned, contours are readily generated from a grid so that critical isobaths, such as the 2500 metre, can be shown on the DTM (eg. as in Figure 3) and examined in relation to other boundaries and features such as the maximum claimable area of seafloor. Other features such as the foot-of-slope and related Hedberg Line could be modelled using some sophisticated slope-determination algorithm.

Related Modelling

Topography can be understood as a membrane between two distinct media: the crust below and either the water above, for its bathymetric component, or the atmosphere and associated hydrologic cycle for its elevation component. These two media are able to be investigated through the techniques of numerical modelling for many physical processes. Topography allows for the control of parameters in these models. A brief discussion with some examples follow.

Oceanography and coastal processes

Heavily sampled ocean-bottom highs may indicate moat-like structures about their base. Their form could be used to indicate the nature of ocean-bottom currents.

The bathymetric component of the DTM allows for volumetric determination whilst the elevation component aids in delineating drainage networks and related watersheds. Finite-element methods[8] are often employed to model the interaction between the two in the littoral environment.

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[8] The finite element method allows for a continuous quantity to be approximated by a discrete model composed of a set of piecewise continuous functions defining a finite number of sub-domains. These sub-domains can then be examined by computers [39].

In many areas, the shelf morphology is of use in understanding the current, wave and tidal processes at work in the water column. Work in this field is again reflected by widespread application of the finite element technique [28].

Seafloor engineering

That part of the surface defined by high-resolution swath data can, in conjunction with back scatter signals, be of use in the study of seafloor stability and hazards. Furthermore, knowledge of water depth and seafloor slope can be used with tide and current data to model the likely forces on submerged man-made structures.

Crustal dynamics

The use of topography to model crustal dynamics is widespread, where parameters such as stress and strain fields are examined. For example, the bending of the seafloor spreading-fabric sampled by the *l'Atalante* swath data at the base of the Tasman Fracture Zone could be mapped to a finite element mesh and examined for intra-plate forces.

Product Outputs

Apart from this record the two major outputs of the study are:

- a digital grid of surface terrain for the Tasmanian region; and
- an imaged raster map reproduction of the digital grid.

The digital grid is the most valuable outcome and is to reside in AGSO's corporate database. The server and path is unknown at the time of printing.

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Appendices

Appendix 1

Structure and History of OZMAR

The Offshore Zone Mapping And Resources (OZMAR) database is an in-house digital database designed and maintained by AGSO. It contains a large amount of data on individual ship tracks in an area bounded by Madagascar to the west and New Zealand to the east as well as the Equator to the north and the Antarctic coastline to the south.

OZMAR began as a series of survey files maintained on a VAX/VMS system in an AGSO format until it was decided to transfer these files to the Oracle environment. The data currently stored is mainly that of research vessels and company exploration data more than ten years old.

The database comprises 19 relational tables currently loaded in the Oracle Database Management System residing on a corporate server. These tables include, for example, information on the survey, ship, organisation, instruments and navigation methods employed. Links are currently in place to allow ready access and query of information by Microsoft Access on the organisation's PC network.

The positional accuracy of the contained data is variable. Generally, 1 metre accuracy is given for radio navigation positioning, whilst 5 metres and up to 1500 metres are quoted for Differential Global Positioning System and ship data of the 1960s-70s vintage, respectively.

A system is currently in place to update OZMAR with new survey information as required. Further information on this and other details can be found in [34].

The following listing is a sample of the information that may be extracted from OZMAR. It lists the survey name, organisation, vessel, year of survey, navigation method employed and associated number of depth soundings for all the sparse ship tracks used in the pilot study area polygon (see Figure 7).

Survey Name	Organisation	Vessel Name	Year	Nav Method	Soundings
MONS05AR	SIO	ARGO	1961		227
V1812	LDGO	VEMA	1962		257
UM6402-A	UTOKYO	UMITAKA MARU	1964		213
C0907	LDGO	R.D. CONRAD	1965		53
C0906	LDGO	R.D. CONRAD	1965		267
ELT27	LDGO	ELTANIN	1967		130
ELTANIN 68	LDGO	ELTANIN	1968		282
UM67	UTOKYO	UMITAKA MARU	1968		199
ELTANIN 69-70	LDGO	ELTANIN	1969		282
ELT38	LDGO	ELTANIN	1969		686
S TASMANIA	BMR/AGSO	HAMME	1971	E	6779

TASMAN SEA 1	BMR/AGSO	HAMME	1971	E	3465
CENTRAL CORAL SEA	BMR/AGSO	LADY CHRISTINE	1971	E	1379
EASTERN COAST	BMR/AGSO	LADY CHRISTINE	1971	E	8685
ELTANIN 71-72	LDGO	ELTANIN	1971		1187
EL47A	LDGO	ELTANIN	1971		223
S COAST	BMR/AGSO	LADY CHRISTINE	1972	E	12620
DSDP29GC	SIO	GLOMAR CHALLENGER	1973		187
VEMA 3301	LDGO	VEMA	1975		815
V3215	LDGO	VEMA	1975		308
V3303	LDGO	VEMA	1976		1311
VEMA 4	LDGO	VEMA	1976		728
V3304	LDGO	VEMA	1976		195
S OCEAN 2	BMR/AGSO	NELLA DAN	1980	E	842
S OCEAN 3	BMR/AGSO	NELLA DAN	1981	E	2108
BASS BASIN	BMR/AGSO	LADY VILMA	1982		4425
KERGUELEN 1	BMR/AGSO	RIG SEISMIC	1985	E	1881
OTWAY BASIN 1	BMR/AGSO	RIG SEISMIC	1985	C	13990
SONNE 36 B	BGR	SONNE	1985		3962
OTWAY BASIN 2	BMR/AGSO	RIG SEISMIC	1987	C	14816
GIPPSLAND BASIN 1	BMR/AGSO	RIG SEISMIC	1987	C	12736
TASMAN SEA 3	BMR/AGSO	RIG SEISMIC	1988	C	2062
W TASMANIA BASIN	BMR/AGSO	RIG SEISMIC	1988	C	9368
OTWAY BASIN 3	BMR/AGSO	RIG SEISMIC	1988	C	8634
GIPPSLAND BASIN 2	BMR/AGSO	RIG SEISMIC	1988	D	6362
MW8801	SOEST	MOANA WAVE	1988		223
GIPPS-BASS BASIN 1	BMR/AGSO	RIG SEISMIC	1989	C	5989
GIPPS-BASS BASIN 2	BMR/AGSO	RIG SEISMIC	1989	D	1460
JARE30G6	IPR	SHIRASE	1989		1901
SE AUSTRALIA	BMR/AGSO	RIG SEISMIC	1991	A	7215
JARE32L6	IPR	SHIRASE	1991		1818
JARE33L3	IPR	SHIRASE	1992		1831
TASMANTE	IFREMER	L'ATALANTE	1994	F	207
BASS GEOCH-MALABAR	BMR/AGSO	RIG SEISMIC	1994	A	2567
OTWAY 94	BMR/AGSO	RIG SEISMIC	1994	A	7398
TASMANIA GEOLOGY	BMR/AGSO	RIG SEISMIC	1995	A	2403
TASMAN DEEP SEISMIC	BMR/AGSO	RIG SEISMIC	1995	A	5384
OTWAY 95	BMR/AGSO	RIG SEISMIC	1995	A	1145
SOUTH TASMAN	BMR/AGSO	RIG SEISMIC	1995	A	859

RISE					
GLOBEX BASS BASIN	GLOBEX	RIG SEISMIC	1996	A	487
HOWICK OFFSHORE	CULTUS	RIG SEISMIC	1996	A	9832
OTWAY, KANGAROO IS	VICM,MESA	RIG SEISMIC	1996	A	6126

Navigation codes are:

A - differential GPS
B - as E plus differential GPS
C - as E plus stand-alone GPS
D - radio navigation
E - dead reckoning tied to Transit satellite fixes
F - stand-alone GPS (subject to Selective Availability)

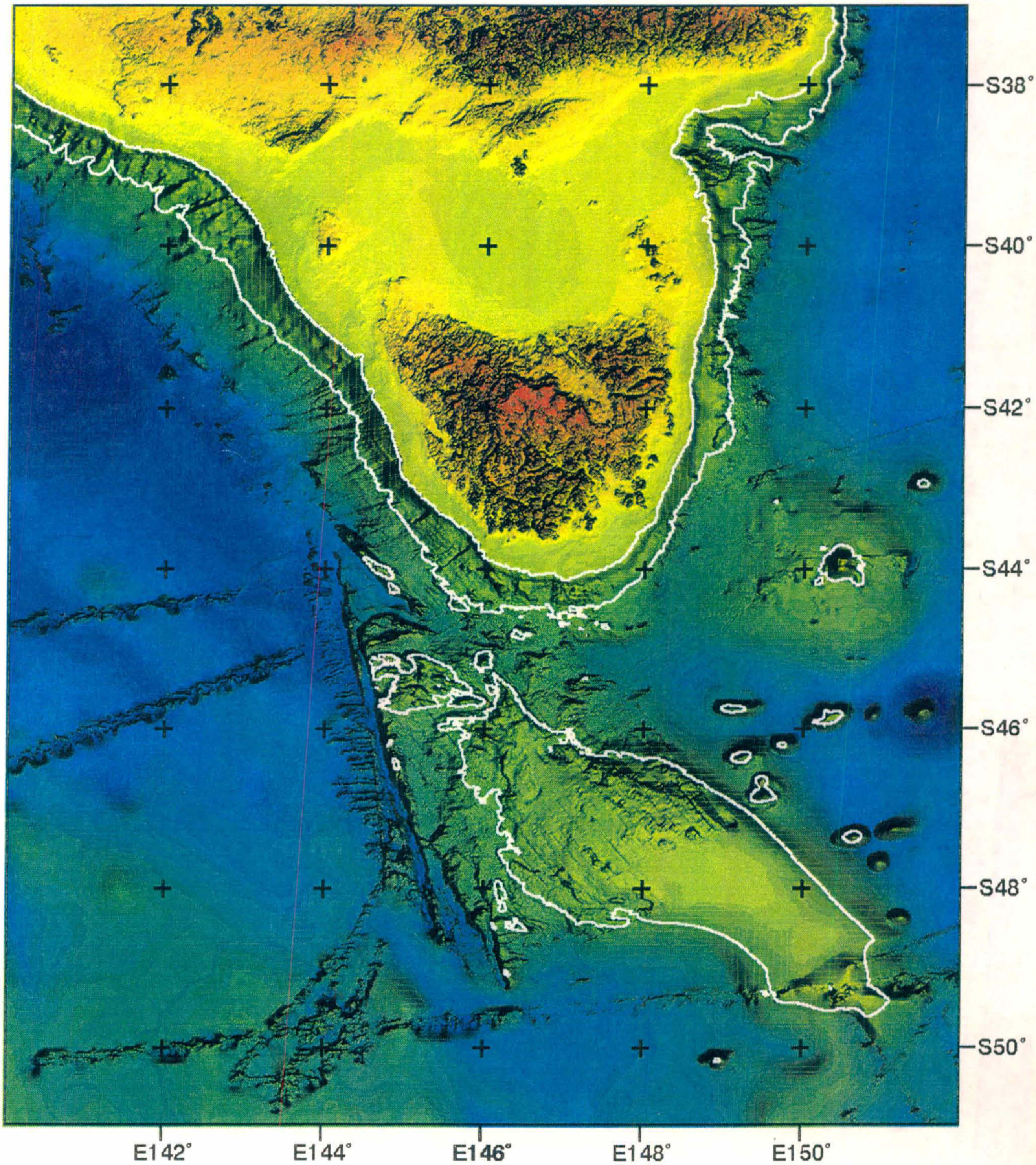

Figure 3. DTM of study area as an ER Mapper image. Combined pseudo-colour layer with guassian equalisation and intensity layer with south-east illumination. Derived 200 m and 2500 m isobaths shown. Projection is geodetic.