

Concepts behind the GEBCO global bathymetric grid

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The purpose of these notes is to provide a qualitative background for the concepts and limitations related to the gridding process that was used to construct the GEBCO global bathymetric grid. These notes are not intended to be rigorous mathematical explanations. Many pictorial examples are given, as are links to more detailed descriptions. [Click on each image for an enlarged view.](#)

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Definition of bathymetry: (a) The measurement of ocean depths, (b) the depth values thus derived, (c) maps, contours, or data sets referring to sea floor depth.

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1) What is a grid? [return to top](#)

A grid is a computer-based representation of a 3-dimensional (x,y,z) data set. In a gridded database, the z values are given at equidistantly-spaced intervals of x and y . In the GEBCO bathymetric grid, z is the depth to the sea floor or is the height of land above sea-level and is given at evenly-spaced increments of 1 minute of arc in both longitude (x) and latitude (y). In picture form, viewed from above, a grid outline looks like a lattice or matrix.

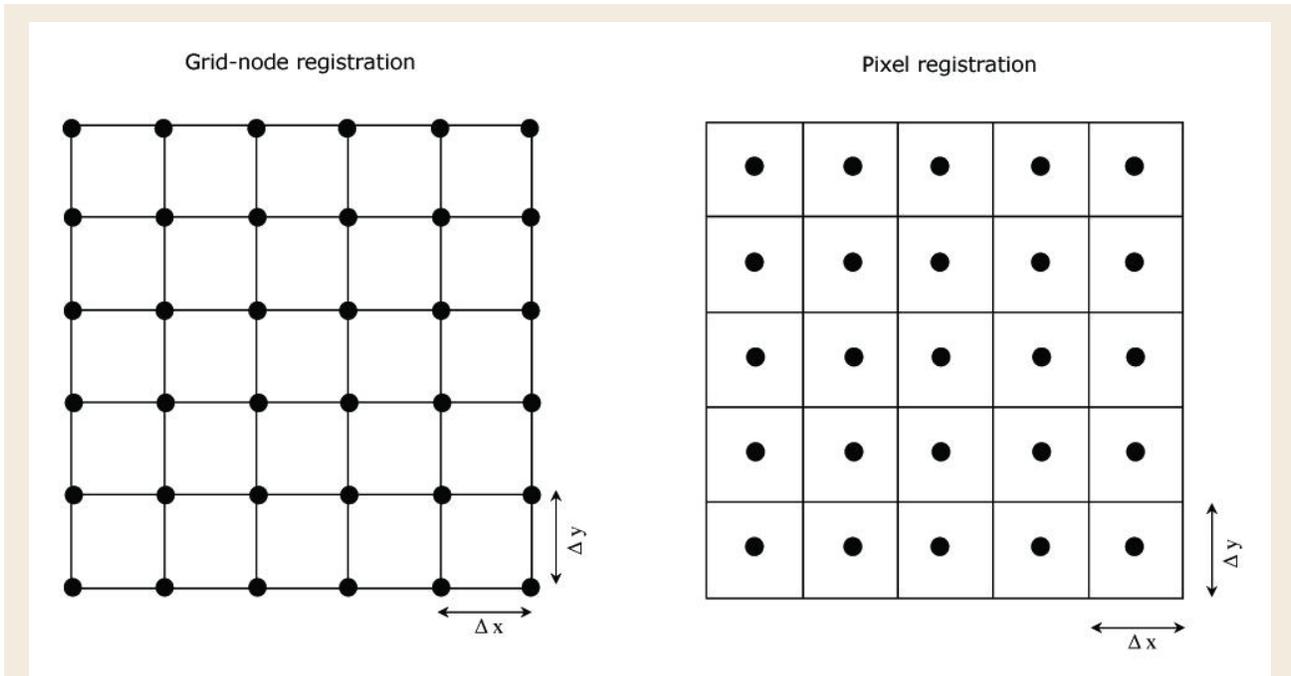


Figure 1: A grid with bin (cell) dimensions $\Delta x \times \Delta y$ is defined as having grid-node (grid-line) registration when the gridded values are specified at the intersections of the grid lines, and pixel registration when the gridded values lie at the centre of each bin. Note that a grid registered in grid-node format contains one more row of elements in both the x and y directions than in pixel format. The GEBCO bathymetric grid is grid-node-registered.

2) Advantages of a grid [return to top](#)

Gridded databases are ideally suited for computer-based calculations. In binary form, they are compact and permit sub-sets of the data to be easily extracted and manipulated. They allow comparison with other gridded databases, and facilitate the plotting, visualisation and ready analysis of the grid values.

3) What is a surface? [return to top](#)

In 2-dimensions we can fit a polynomial through input (x,y) data. In 3-dimensions we can fit a continuous 3-D surface through an uneven distribution of input (x,y,z)

data. In general, these input (x,y,z) values will be unevenly or randomly distributed.

A surface can be thought of in terms of a mathematical rubber sheet that is manipulated to pass closely through each of the input z values. The gridded values are then computed by interpolating z at equal intervals of x and y .

In geographical space, in the GEBCO bathymetric grid, each input (x,y,z) bathymetric data point comprises a depth (z) given at longitude, x , and latitude, y (Over land areas, the z value is height above sea-level). A surface-fitting algorithm was used to interpolate depth (and height) values at evenly-spaced longitude and latitude increments. In effect, we drape a mathematically-constrained surface over the input z values.

Using a colour palette to depict different levels of z , and using artificial surface illumination, the 3-dimensional nature of a gridded data set can be readily seen:

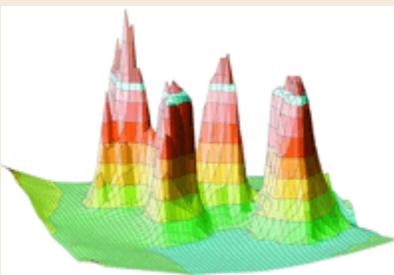
Figures 3A-C: A 4-minute bathymetric surface depicting the Comoros Islands viewed from the southwest at an elevation of 45 degrees above the base plane and with a vertical scale of 1000m to an inch. The surface is artificially illuminated from the west. Orange and pink colours represent shallow regions, greens and blues define deeper ocean. [Click on images to enlarge.](#) [return to top](#)



[\(Figure 3A\)](#) A basic view of the gridded surface.



[\(Figure 3B\)](#) With bathymetric contours overlain.

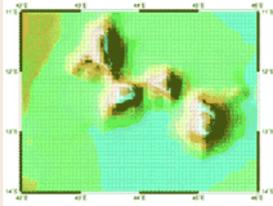


[\(Figure 3C\)](#) With 4-minute grid mesh overlain.

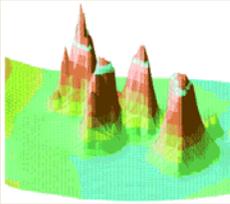
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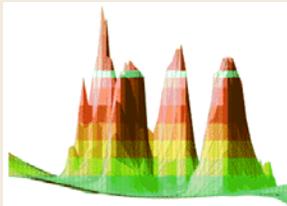
Changes in the viewing angle can be used to enhance certain aspects of the 3-dimensional gridded surface:



[Figure 3D](#): With vertical scaling, colours and illumination of the Comoros Islands surface the same as in Figures 3a-c, a plan view (looking down from vertically above) results in the 3-D surface looking like a standard bathymetric map in which the geographical location is well defined. [Click on image to enlarge.](#)



[\(Figure 3E\)](#) Viewed from the south at an elevation of 45 degrees above the base plane, the island group rises up from the seafloor and its 3-D vertical structure is readily seen. [Click on image to enlarge.](#)



[\(Figure 3F\)](#) Viewed edge-on, from the south, the horizontal aspect of the surface is virtually eliminated whilst the vertical structure is strongly displayed. [Click on image to enlarge.](#)

4) Construction of the GEBCO global bathymetric grid [return to top](#)

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4.1 Discussion [return to top](#)

The GEBCO bathymetric grid is a mathematical model. It is a 3-D mathematical representation derived from the unevenly-distributed input bathymetric information. A mathematical surface was fitted to the input data and the gridded z (depth) values were interpolated onto an evenly-spaced x (longitude) and y (latitude) lattice. The bin size of the GEBCO global bathymetric grid is 1×1 arc minutes. At the equator, this corresponds to bins having dimensions of 1.85×1.85 km.

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The GEBCO grid is [grid-node registered](#) and has a longitude range of 0-360° (0-180° E/W) and a latitude range of 90° N - 90° S. Thus, at a bin spacing of 1-minute the number of gridded data values (grid nodes) that cover the earth is 10801 x 21601 = 233,312,401. This comes from there being (180x60)+1 grid nodes in the N-S direction and (360x60)+1 nodes E-W. Since about 70% of the surface of the earth is ocean, this equates to a colossal 163 million interpolated depths values in the world's oceans.

As a result of the tremendous amount of work necessary to construct, check and quality control the GEBCO global bathymetric grid, [the world's oceans were divided into regions of responsibility for individual GEBCO gridders](#). Each gridded further sub-divided these large areas into more manageable sub-regions of 10x10 degrees which facilitated the task of error-checking and artefact reduction.

In basic terms, the following [flow diagram](#) depicts the steps involved in producing the component 10°x10° grids that make up the GEBCO global bathymetric grid. An iterative process was adopted. As described [here](#), the input bathymetric contours from the GEBCO Digital Atlas (GDA) were considered authoritative and so, when the gridded bathymetric surface was [compared](#) to these input contours, any mis-fits had to be corrected. To achieve this, additional (x,y,z) depth points were provided as extra input data and the grid was re-calculated. These additional points were derived from [echo-sounding sheets](#), and from other contour charts and data sources. The iteration process was repeated until all errors and artefacts in the resultant grid were eliminated or reduced to an acceptable level.

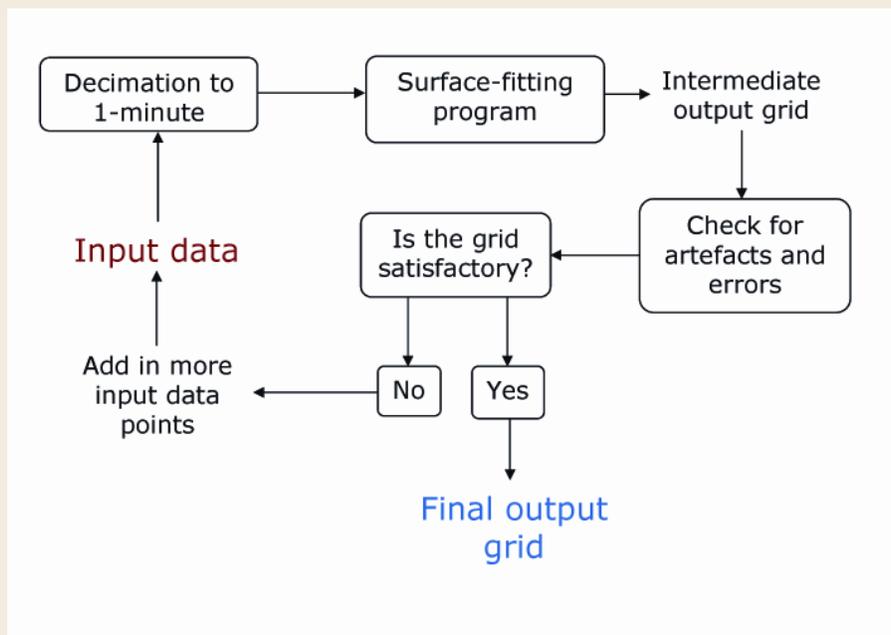


Figure 4A: Flow chart giving the overall scheme used in the construction of the GEBCO bathymetric grid.

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4.2 The input data [return to top](#)

For each $10^{\circ} \times 10^{\circ}$ sub-grid, one input data file, in (*longitude, latitude, depth*) format, was created. Depending upon the area, it contained one or more of the following:

[Digitised GEBCO Digital Atlas \(GDA\) bathymetric contours.](#)

Land elevations from the [GLOBE database](#)

Coastlines (0 meters) from the [WVS database](#)

Antarctic coastlines from the [SCAR database](#)

Additional shallow-water contours and soundings

Additional contours in [featureless areas](#)

Additional individual [echo-soundings](#)

4.3 Decimation of input data [return to top](#)

If the locations of the input data are plotted it is seen that some grid bins contain no data but that other bins may contain a number of depth points. The process of decimating (thinning) any depth data within each 1x1 arc minute bin and replacing these points by just one representative depth value is a technique used to enhance the gridding process. It has two major advantages. Firstly, the representative depth value is calculated by taking the median of the input depth values. This generally eliminates erratic or otherwise spurious input depths. Secondly, by reducing the number of points being passed into the surface-fitting program, the computation time is considerably shortened. For example, in parts of the Indian Ocean, the original input data were thinned by as much as 90% at the decimation step. Each new, single representative value is located at the average position of the input data within that particular bin. Note that, at this decimation stage, bins that contained no input data remain empty - it is the steps of surface-fitting and interpolation that fills them.

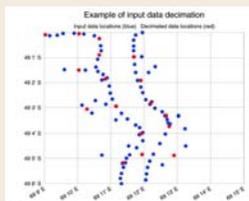


Figure 4B: For this small area near Kerguelen Island, the numerous input data (blue dots) are replaced in the decimation process by just a few representative values (red dots). Grid lines represent the 1-minute bins used in the gridding process. [Click on image to enlarge.](#)

4.4 Surface-fitting algorithm [return to top](#)

GEBCO gridders made much use of the Wessel and Smith GMT software (<http://gmt.soest.hawaii.edu>) for the construction, quality control and visualisation of the grids that make up the GEBCO global bathymetric grid.

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The 1x1 minute decimated data file is fed into a surface-fitting computer program (GMT: surface) which uses as its interpolation algorithm a 3-D bi-cubic spline under tension. This program fits a 3-D mathematical surface to the decimated input data. The surface was required to pass within 1m of the input z values and, after this condition was satisfied, an interpolation process was used to compute z values for every grid node on the surface. Thus, each 1x1 minute grid node within the $10^{\circ} \times 10^{\circ}$ sub-grid is now associated with an interpolated depth value. Starting from unevenly-distributed input data, the processes of decimation, surface-fitting and interpolation result in evenly-distributed z values defined at equidistantly-spaced intervals of x and y. These equidistant (x,y,z) values comprise the gridded data set.

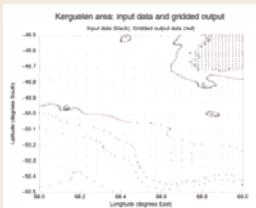


Figure 4C: For an area SW of Kerguelen Island, unevenly-distributed input data (black circles) are converted into equidistantly-spaced gridded values (red circles) through the gridding process. The gridded values are at a 1-minute spacing. [Click on image to enlarge.](#)

4.5 Border (overlap) size [return to top](#)

In constructing each $10^{\circ} \times 10^{\circ}$ sub-grid, a border of an additional 5° was added to each side of the sub-grid. Thus, each $10^{\circ} \times 10^{\circ}$ sub-grid was derived from a larger area of $20^{\circ} \times 20^{\circ}$. This 5° overlap was necessary to minimise discontinuities along common sub-grid boundaries by helping to preserve the continuity and smoothness of the gridded surface across these edges.

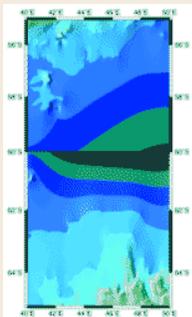
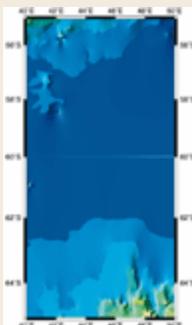


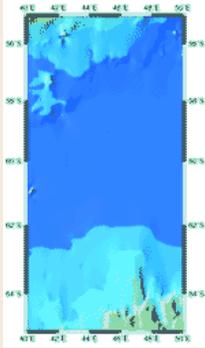
Figure 4D: The Enderby abyssal plain south of Africa shows an extreme example of the necessity of an overlap region when constructing the sub-grids. In this picture, no overlap was used to construct the grids and a striking E-W discontinuity of almost 2000m is revealed at $60^{\circ}S$ where two sub-grids were joined. The surface is artificially illuminated from the NW. [Click on image to enlarge.](#)



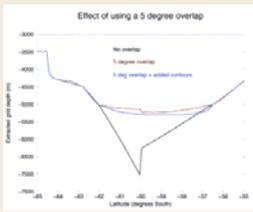
(Figure 4E) Re-making the two sub-grids each with a 5° overlap produces a more realistic surface. However, visible as the bright line across the centre of the image, a small E-W discontinuity of about 100m across the common boundary remains. [Click on image to enlarge.](#)

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(Figure 4F) The further inclusion of additional individual echo-soundings data and digitised 100m-level intermediate contours produces the final gridded surface. The refined detail afforded by these additional contours is evident in the upper part of the figure. *Click on image to enlarge.*



(Figure 4G) A profiles of depth extracted from the grid made without overlaps clearly shows the discontinuity in gridded depth (black line). The inclusion of a 5° overlap produced a more accurate surface though a small discontinuity, at 60°S, is still present (red line) due to the overall lack of surface constraints in the abyssal plain area. Including intermediate-level contours and additional soundings data resulted in a final surface that agrees most closely with the GEBCO GDA contours and with along-track ship data (blue line). All profiles were taken in the in the S-N direction along 45.75°E. *Click on image to enlarge.*

Main exceptions to the general gridding methodology outlined above are given [here](#). More detail of the steps in the gridding process is given [here](#).

5) Gridding errors and artefacts [return to top](#)

5.1 [Main types of gridding errors](#)

5.2 [Identification and minimisation of grid artifacts](#)

A gridded surface is a purely mathematical representation of the input (x,y,z) data. As such, when constructing a grid, care must be taken to ensure that the characteristics of the gridded data reflect the nature of the input dataset. The GDA contours were hand-drawn and were derived from a tremendous number of shipboard echo-soundings data by experienced researchers and hydrographers who have considerable geological knowledge. As a result, these contours are considered authoritative and were the main data input into the gridding procedure. The prime requirement of the gridded version of the GEBCO bathymetry was that it matched as closely as possible these input GDA contours. However, a mathematically-rigorous 3-D surface can never perfectly fit interpreted contours. Mis-matches between the gridded version of the depth data and the original input data, and other gridding artefacts, had to be reduced or eliminated before the grid was acceptable.

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5.1 Main types of gridding errors [return to top](#)

By adjusting the stiffness (tension) of the surface we can specify the closeness of fit of the surface to each input z value. A tension of 0 specifies a relatively stiff minimum-curvature surface which can miss passing through highly-variable z values. However, a very flexible surface (tension $\gg 0$) can oscillate wildly as it passes through all input points.

The most common grid artefacts were over-shoots. These occurred in two distinct areas of relatively steep topography: at the summits of seamounts, ridges, rises and plateaux and on continental shelves where there is an overall lack of shallow-water data; and, at the bases of many of these features, particularly at the base of continental slopes where the standard GEBCO contour interval of 500m was not enough to properly constrain the surface-fitting algorithm.

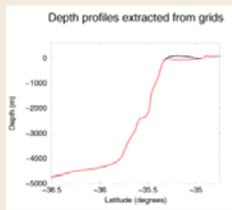


Figure 5A: A depth profile extracted from a preliminary version of the bathymetric grid for the southwestern Australian margin shows that a poorly-constrained surface-fitting algorithm produces an artificial flexural bulge on the continental shelf (black line). Additional echo-soundings and contour data must be included to help constrain the gridding process to better reflect observations (red line). [Click on image to enlarge.](#)

Relatively featureless areas such as abyssal plains, sediment fans, basins and wide continental shelves produced extensive areas of erroneous depths.

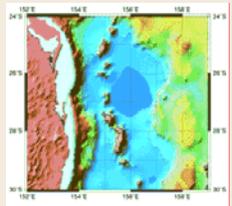


Figure 5B: On the eastern Australian margin, extensive gridding artefacts on the broad continental shelf (at $152.5^{\circ}\text{E}/24.5^{\circ}\text{S}$) and in the Tasman abyssal plain (at $156^{\circ}\text{E}/27^{\circ}\text{S}$) are due to a lack of constraining input data during the gridding process. [Click on image to enlarge.](#)

Minor gridding artefacts that were easier to fix included those due to mis-labelled input contours and due to isolated unreliable echo-sounding values.

5.2 Identification and minimisation of grid artefacts [return to top](#)

The most convenient way of comparing the gridded depths to the input depths was found to be by simple visual means, as follows. Gridded depths were plotted in plan view as a coloured surface. On to this base layer, the input digitised GDA contours were [overlain](#).

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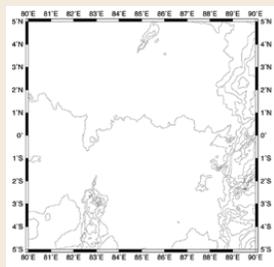
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The palette used to colour the gridded surface has colour change intervals that correspond to the GDA contour interval. If the match is perfect between the gridded bathymetric surface and the input GDA contours then all colour changes on the surface will be bounded by an overlain GDA contour line. Mis-matches show up as discrepancies in which colours on the gridded surface spill across the bounding GDA contours or are [unbounded](#) by GDA contours. Thus, any colour change not bounded by a GDA contour was considered to be an artefact. The use of artificial illumination on these plots reveals more subtle grid artefacts which may lie within one colour palette band.

In areas of widely-spaced contours such as abyssal plains and wide continental shelves, and in areas generally devoid of shallow-water contours such as the summits of rises, it was essential to further constrain the surface-fitting grid computations. This was done through the addition of [individual echo-soundings](#) and/or [intermediate-level contours](#). These additional data were derived, where possible, from the original data compilation sheets that had been created by the bathymetrists.



[Figure 5C](#): *Hand-written echo-soundings, in this case in uncorrected fathoms, are shown for a 1° square immediately south of Île Europe between Africa and Madagascar. These echo-soundings compilation sheets are plotted at a scale of 4 inches to one degree at the equator (about 1.1 million:1). [Click on image to enlarge.](#)*



[Figure 5D](#): *Standard 500m-level GEBCO contours (black lines) fringe the gentle slope of the Enderby abyssal plain between Africa and Antarctica. The lack of these contours on the relatively featureless plain produced a poorly constrained gridded surface. From the original echo-soundings compilation sheets, intermediate 100m-level contours (red lines) were drawn for the entire abyssal plain. These additional contours were input into the gridding procedure and provided the required control for the surface-fitting algorithm. [Click on image to enlarge.](#)*

It is important to note that sparsely-contoured areas do not necessarily reflect poor [ship track coverage](#).

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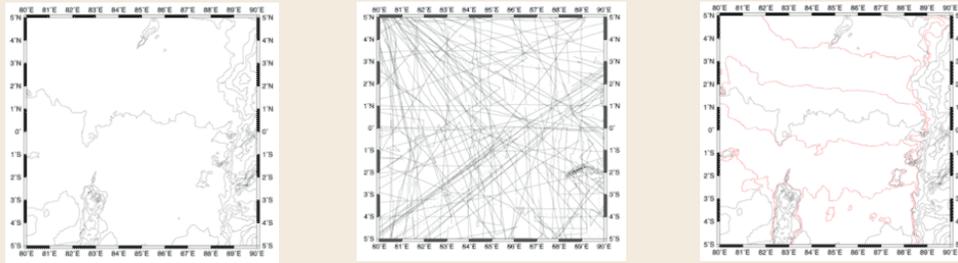
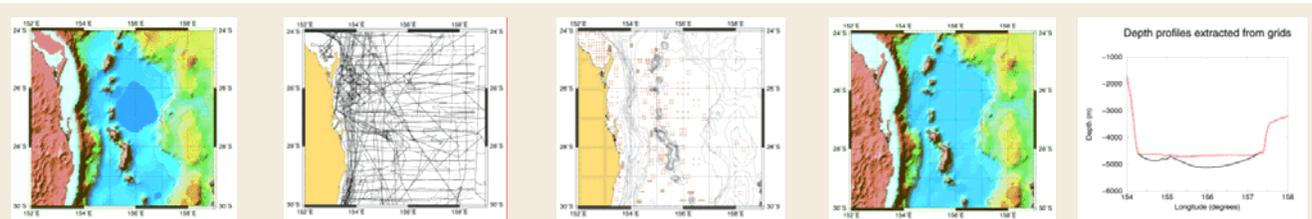


Figure 5E: In the Bay of Bengal, the Ganges sediment fan shows relatively few contours at the standard GEBCO 500m interval. Ship track coverage for this area is excellent ([Figure 5F](#)) and the very high density of ship tracks readily allowed intermediate 200m interval contours to be drawn ([Figure 5G](#)) to help constrain the gridding process. *Click on images to enlarge.*

With experience, GEBCO gridders were able to identify portions of each $10^{\circ} \times 10^{\circ}$ grid that had a high potential for otherwise producing grid artefacts. For these areas, extra depth values were pre-emptively added to the input data file and this resulted in a decreased number of gridding iterations required to produce each final $10^{\circ} \times 10^{\circ}$ grid.

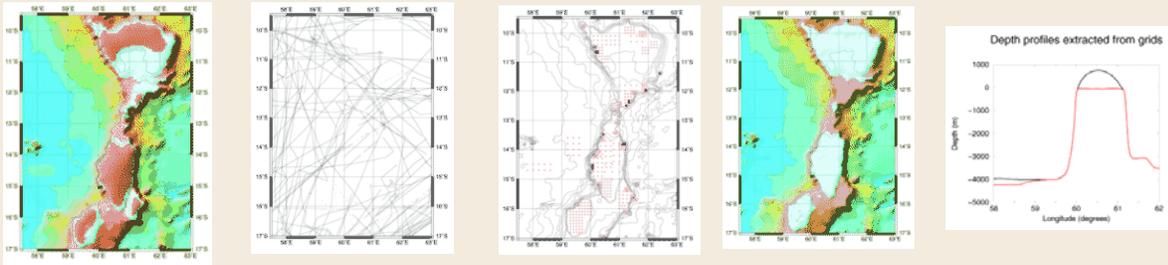
The following three series of plots illustrates the identification and reduction/elimination of gridding artefacts:



Figures 5H (1-5): ([Figure. 5H-1](#)) Off eastern Australia, colours not bounded by an input contour reveal extensive gridding artefacts in the upper left on the continental shelf and in the centre on the Tasman abyssal plain. Ship track coverage for this area is very good ([Figure 5H-2](#)) and many spot soundings exist on the shelf. From the original echo-soundings compilation sheets, many additional depth values ([Figure 5H-3](#)) were input into the gridding program. These additional input data provided the necessary constraints that result in a final grid that is free from artefacts ([Figure 5H-4](#)). Depth profiles ([Figure 5H-5](#)) extracted from the initial grid (black line) and the final grid (red line) show the elimination of the artefacts (depth profiles extracted W-E along 26.25° S). *Click on images to enlarge.*

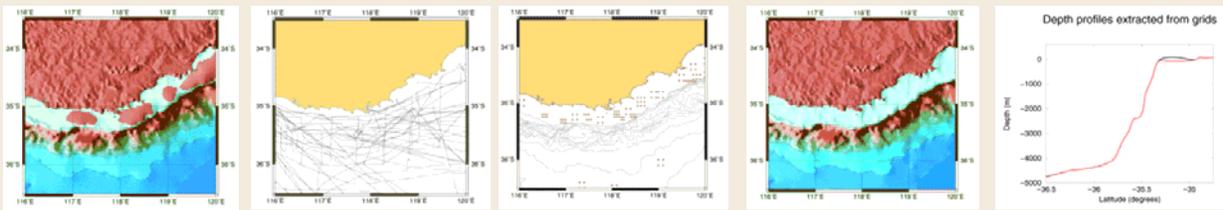
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Figures 5I (1-5): ([Figure 5I-1](#)) The Mascarene plateau in the western Indian Ocean proved very problematic to grid. Pronounced artefacts, shown as large amorphous blobs, occurred on the summits of each rise and at the foot of most. ([Figure 5I-2](#)) A high number of ship tracks, as well as numerous spot depths recorded on compilation sheets, allowed many additional depth values to be input ([Figure 5I-3 - red dots](#)). Their inclusion eliminated the grid artefacts ([Figure 5I-4](#)), and extracted depth profiles taken W-E along 14.5°S ([Figure 5I-5 - red line](#)) show that summits are no longer smoothly domed as they were in the less-constrained original grid ([Figure 5I-5 - black line](#)). *Click on images to enlarge.*

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Figures 5J (1-5): ([Figure 5J-1](#)) Along the southwestern Australian continental margin, the initial lack of shallow-water input data resulted in many artefacts on the shelf edge where the gridded surface could not flex far enough to match the actual geomorphology. Numerous ship soundings and spot depths exist for this area ([Figure 5J-2 - only ship tracks are shown](#)) from which additional input data were derived ([Figure 5J-3 - red dots](#)). The final grid ([Figure 5J-4](#)) more closely reflects observed depths, and extracted depth profiles ([Figure 5J-5 - red line](#)) no longer overshoots the shelf break ([Figure 5J-5 - black line](#)). (Profiles extracted S-N along 118.35°E). *Click on images to enlarge.*

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6) Limitations of the GEBCO grid [return to top](#)

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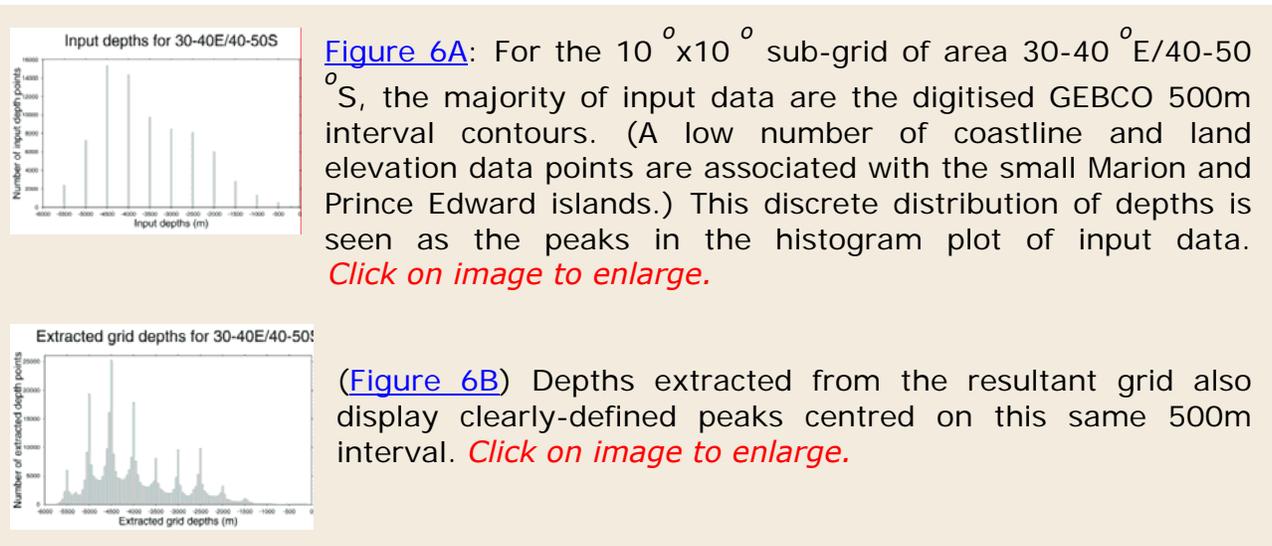
A more complete list of limitations can be found [here](#).

6.1 Navigational accuracy [return to top](#)

The grid is not intended to be used for navigational purposes.

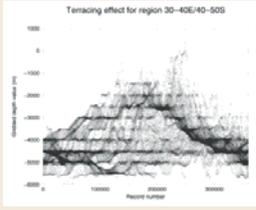
6.2 Terracing [return to top](#)

GEBCO, traditionally, has concentrated upon the derivation and interpretation of bathymetry in deep water, and, for decades, the GEBCO standard contours have been fixed at intervals of 500m (500m, 1000m, 1500m, 2000m, and so on). In shallow regions, a 200m and a 100m contour were drawn only where justified. The bulk of the [current GEBCO GDA contour data set](#) comprises these standard 500m contours and it is these data that form the main [input](#) to the gridding process. With most of the input data being at discrete 500m intervals the surface-fitting algorithm is biased towards these depths and the resultant gridded depths are similarly concentrated around these 500m intervals. This *terracing* effect is clearly seen by plotting extracted grid depths as a [histogram](#). These peaks correspond to the 500m contour interval of the input digitised GDA contour data and this terracing effect, due to the distribution bias of the input values, is a well-known problem of constructing grids from contours. Plotting the extracted grid depth against grid record number is another way to reveal the terracing effect.



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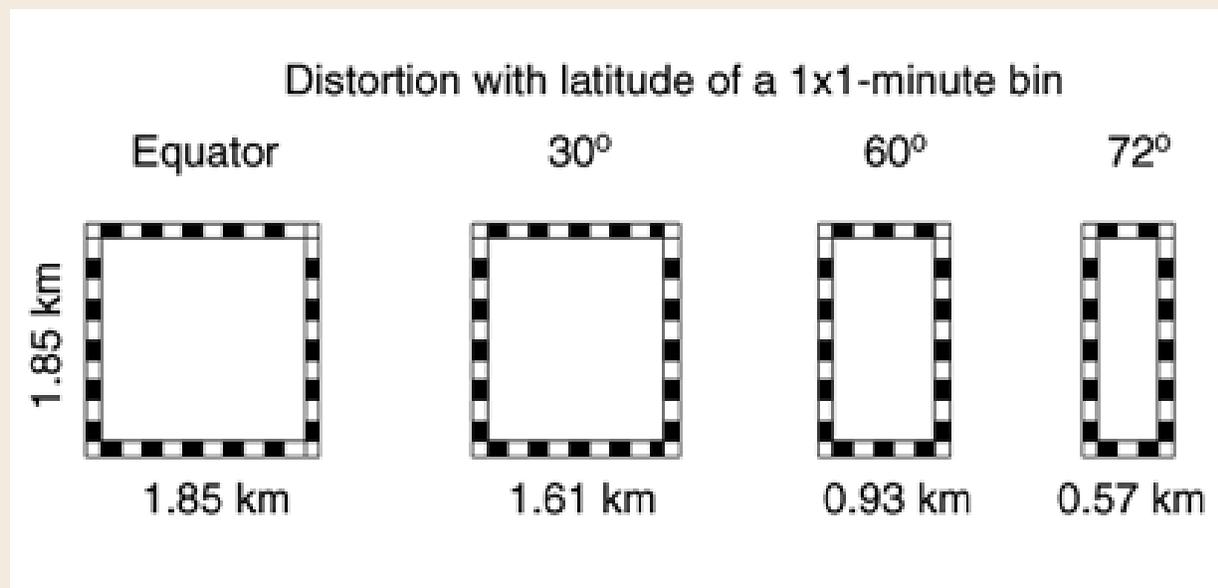
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(Figure 6C) A plot of depth against grid record number serves to display these peaks as horizontal concentrations at the input depth intervals. *Click on image to enlarge.*

6.3 Aspect ratio of grid bins [return to top](#)

The distance subtended by an arc length of 1-minute in the E-W direction decreases away from the equator. Thus, 1x1-minute bins become narrower in the E-W direction towards the poles. This narrowing effect results in non-uniform spatial interpolation during the gridding process. The latitude-dependent distortion of the bin geometry required that the Arctic Ocean grid be constructed using a more involved, specialized [gridding method](#) but, for all other oceanic regions, this distortion was considered acceptable. Assuming a spherical earth, the 1x1-minute bin dimensions vary with latitude as follows:

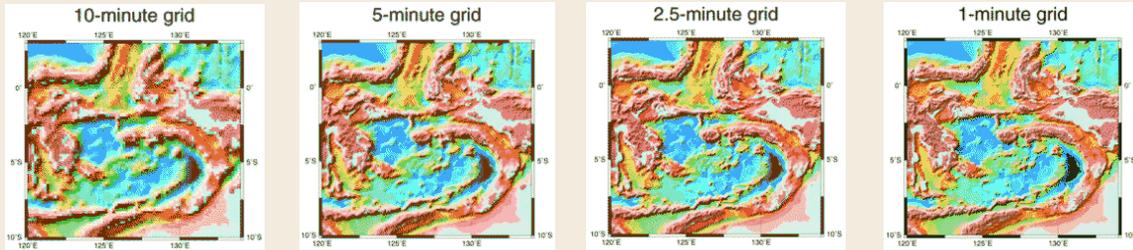


[Figure 6D](#): The change in the length of E-W arcs with latitude.

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7) GEBCO grid resolution, precision and accuracy [return to top](#)

In a grid, the *apparent* detail increases as the size of the grid cells decreases.



Figures 7A-D: As exemplified in the Weber deep area north of Australia, the amount of visible detail increases dramatically as the grid spacing decreases from a coarse 10 minutes to a finer 1 minute interval. *Click on images to enlarge.*

If, following the [decimation process](#), each grid bin is occupied by a decimated value, the area can be considered to have a horizontal grid resolution of about twice the grid spacing. This situation can arise, for instance, where the input data comprise very dense, closely-spaced (x,y,z) values, such as in a dataset from a multi-beam swath-mapping system.

The decimation process, however, eliminates input data that could provide finer detail and no smaller-scale features can be extracted from the resultant grid. Thus, attempting to artificially boost the horizontal resolution by sampling the grid at a cell size smaller than its native spacing provides no additional information since any closely-spaced data have already been eliminated by decimation.

For a 1-minute bathymetric grid in which all decimated bins are occupied by a representative depth value, the horizontal grid resolution is about 2 minutes (about 3.7 x 3.7km at the equator) so seafloor features of this size should be represented within the grid. Due to the very uneven distribution of input data in the GEBCO global grid, the horizontal grid resolution is no better than 2 x 2 minutes.

The vertical accuracy of the gridded bathymetry values depends upon the accuracy of the input data. A rule of thumb for present-day multi-beam echo-sounders is that the vertical depth is accurate to about 0.5% of water depth. In 4000m of water this equates to a vertical depth accuracy of about ± 20 m. Single-beam echo-sounders under the supervision of a skilled operator can reveal depth measurements that are considered accurate to within about ± 5 m in the deep ocean. Thus, it is important to note that the accuracy of the resultant gridded depths is on the order of meters even though computer programs can access the gridded data with unprecedented precision (many decimal places). Depths in the GEBCO global bathymetric grid are given to the nearest whole meter.

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8) Format of the GEBCO grid [return to top](#)

The GEBCO grid is in netCDF format to ensure compatibility with the GMT software package (<http://gmt.soest.hawaii.edu>). Bathymetry is given as negative integer depths in corrected meters. Land areas contain heights above sea-level in positive integer meters. Click here for more information on the [grid format](#).

9) Useful web sites [return to top](#)

GLOBE land elevations - originally sampled at 30 arc seconds, this database was used in the GEBCO gridding process to define elevations over land areas. <http://www.ngdc.noaa.gov/seg/topo/globe.shtml>

GMT software - Used in the construction, quality control and visualisation of the GEBCO global bathymetric grid. <http://gmt.soest.hawaii.edu>

SCAR coastline - Around Antarctica, the permanent features contained in the SCAR database were used as the location of the zero-meter contour. Temporal features such as edges of ice shelves were ignored. http://www.add.scar.org/add_main.html

WVS coastline – In the construction of the GEBCO global bathymetric grid, the World Vector Shoreline coastline was used as the zero-meter contour line. <http://rimmer.ngdc.noaa.gov/mgg/coast/wvs.html>

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End of document.

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