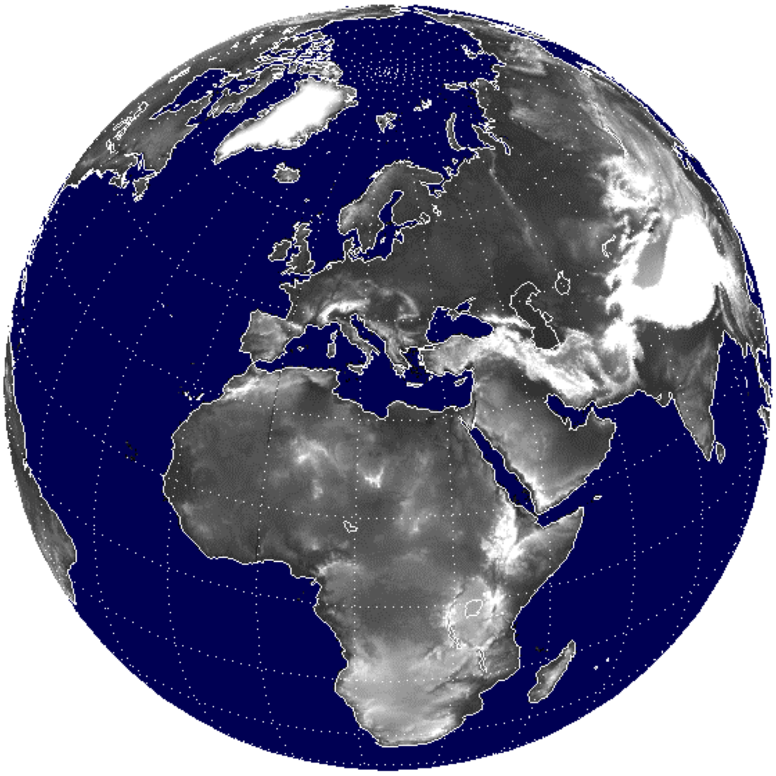
Report on ACE Version1 Generation



Johnson, C.P.D., Berry, P.A.M., Hilton, R.D.,
Geomatics Unit
De Montfort University
The Gateway
Leicester
LE1 9BH
U.K.

1. Introduction

This report outlines the procedures used to generate the first full release of the new ACE Version 1 GDEM. It illustrates the various kinds of errors detected in existing topographic models, and demonstrates the decision protocols used in merging existing ground truth with the altimeter based height dataset. Illustrative examples are given.

1.1 Health Warning

In this first full release of ACE Version 1, there are several known error sources, summarised below.

a) In every million altimeter points used in the ACE Version 1 creation, a few (typically 2 to 50) points have wildly erroneous values not screened out in the pre-filtering process. Accordingly, in each 15-degree segment of ACE, a small number of pixels may have values in error by thousands of metres. Because these errors are so large, they are very easy to identify and remove. Accordingly, rather than delaying the release of ACE and remaking the whole global dataset (a lengthy procedure) these values have been left in, and this health warning attached to notify users of the problem.

b) For a small percentage of the 1-degree tiles used for ACE Version 1 generation, a 'mixed pixel' designation was returned by the decision protocols. This means that over part of the area, the optimal result would be obtained by using the altimeter based dataset, whilst over the remainder of the tile there is insufficient altimeter data to form a DEM, and existing ground truth must be used. In this first full release of ACE Version 1, these tiles have been left with the best existing ground truth; they will be remade using multiple sources in the next release.

c) Whilst the vertical offsets at the 1-degree tile boundaries have been greatly improved in ACE Version 1, some offsets remain, particularly in areas where altimeter arcs cannot be used as controls. These offsets have not been smoothed out to create a continuous (though erroneous) surface, but have been deliberately left so that users have clear visibility of the error characteristics.

2. Assessment of Characteristic GDEM Error Signatures

The first step of the detailed assessment of the error signatures was the creation of a dataset containing the altimeter derived heights and their corresponding latitude, longitude and orbit number. The new dataset also contained heights from three GDEMS in the public domain sampled at the resolution of the altimeter (i.e. for each altimeter height there is a height from each of the three GDEMS matched to it). By creating this new data structure it was possible to plot profiles along the tracks of the altimeter and examine the surfaces described by each of the four datasets. With the use of the new dataset and profile analyses it was then possible to clearly define and describe unknown error signatures existing in the GDEMS. The analysis was also capable of showing what characteristic error patterns exist in the different types of source data used to create the GDEMS.

2.1. Characteristic GDEM Error Signatures

The detailed along track profile analysis using the altimeter dataset and three GDEM dataset was able to identify seven characteristic error signatures all of which were used to identify the quality of the different source data used in each of the GDEMS.

2.1.1. Vertical offsets due to Changes of Data sources on Degree Boundaries

This type of error exists at the boundaries between one-degree squares, where the source data from which the GDEM is compiled changes. This source data change results in the typical tile effects seen in the difference bitmaps created in previous work. At the degree boundary where the source data changes in the GDEM there is usually an abrupt change in form of a vertical offset. The change of data source on the degree boundary usually resulted in a change of data quality therefore, the quality of the representation of the surface sometimes changed on a degree boundary. Looking at profiles across regions where data sources change can identify changes in data quality and vertical offsets. These vertical offsets on degree boundaries are also easily seen in shadow mapping a region where the data source changes.

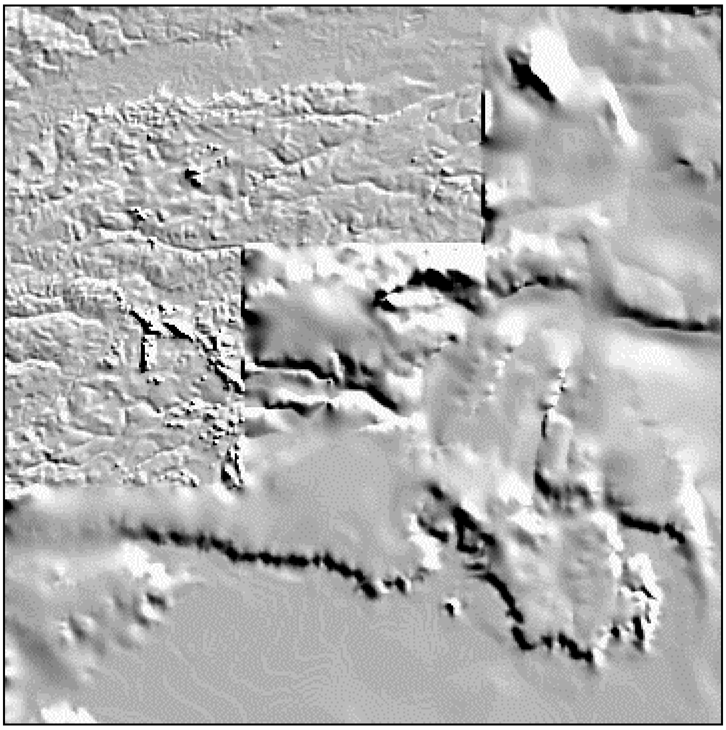


Figure 1

The above figure (fig.1) is a shadow map of a 3-degree by 3-degree (67-70W, 1-4N) area in South America. This nine square degree region represents parts of Colombia and Brazil. The three one-degree squares in the upper left corner of the image are Digital Terrain Elevation Data (DTED) for over Colombia while the remaining six one-degree squares are Digital Chart of the World (DCW) data for over Brazil. The shadow map therefore clearly shows an offset occurring on the degree boundaries between the different datasets. Coincidentally these one-degree boundaries very nearly coincide with the Colombian-Brazilian boarder.

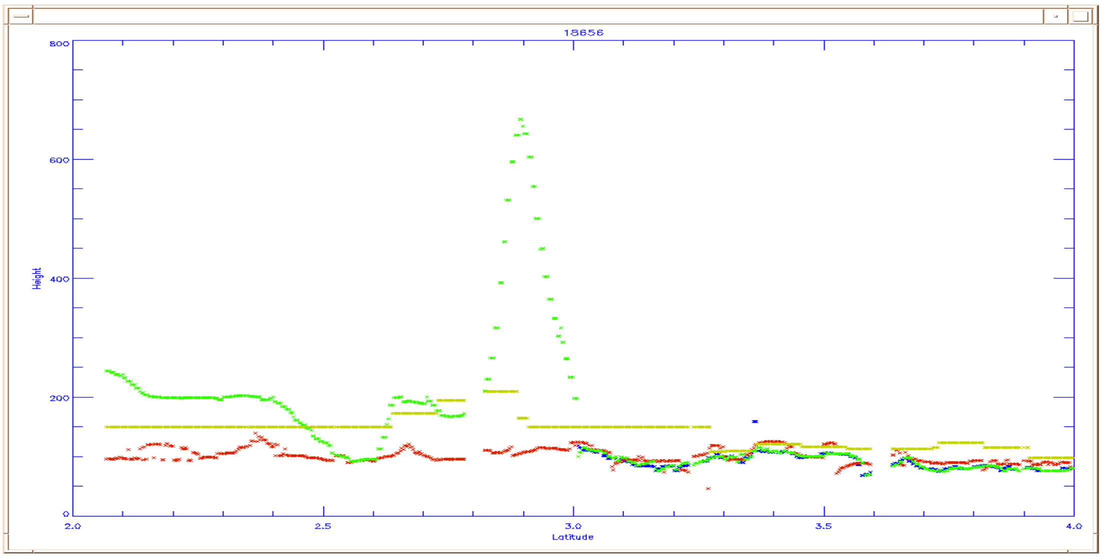


Figure 2

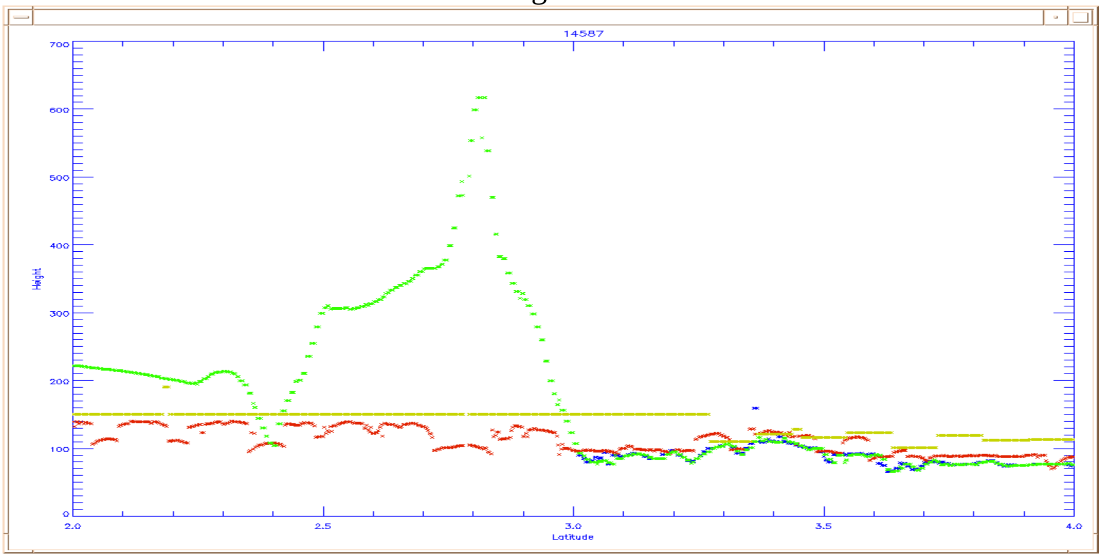


Figure 3

The two figures above (fig. 2 & fig. 3) are two along track profiles going across the area shown in figure 1 above. The profiles show the height (y-axis) vs. longitude (x-axis) for each of the datasets where red is the altimeter, blue is GLOBE_v1, green is GTOPO30 and yellow is JGP95E. From both profiles you can see that at the three-degree longitude boundary there is an abrupt change in the height values in the GLOBE_v1 and GTOPO30 datasets. At the three-degree longitude boundary a change in data source occurs. Both profiles show that from two to three degrees longitude DCW data is used in both GLOBE_v1 and GTOPO30 (GLOBE_v1 and GTOPO30 are both identical and since the GTOPO30 is plotted over the GLOBE_v1 this part of the profile appears green). Both profiles also show that from three to four degrees longitude GLOBE_v1 and GTOPO30 have used very similar but slightly differently processed DTED data. Throughout both profiles the JGP95E appear to be very generalised and a poor representation of the terrain in this area. The inaccuracies of JGP95E are partly due to its five-minute resolution. From this profile it is easy to assess that the DCW data used in GLOBE_v1 and GTOPO30 is grossly unrealistic, and the DTED in GLOBE_v1 and GTOPO30 is good since it is in agreement with the altimeter.

2.1.2. Vertical offsets and Distortions

This error signature is typical mainly to DTED data where by the GDEM and the altimeter both describe very similar surfaces. The error in this case is when the GDEM's surface appears to contain some sort of bias (vertical shift) or tilt (distortion).

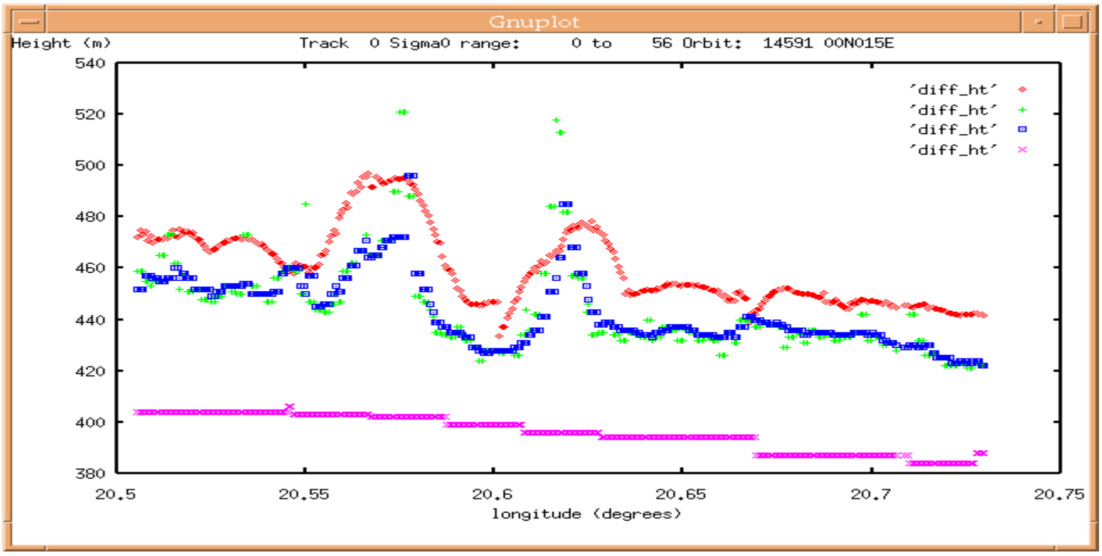


Figure 4

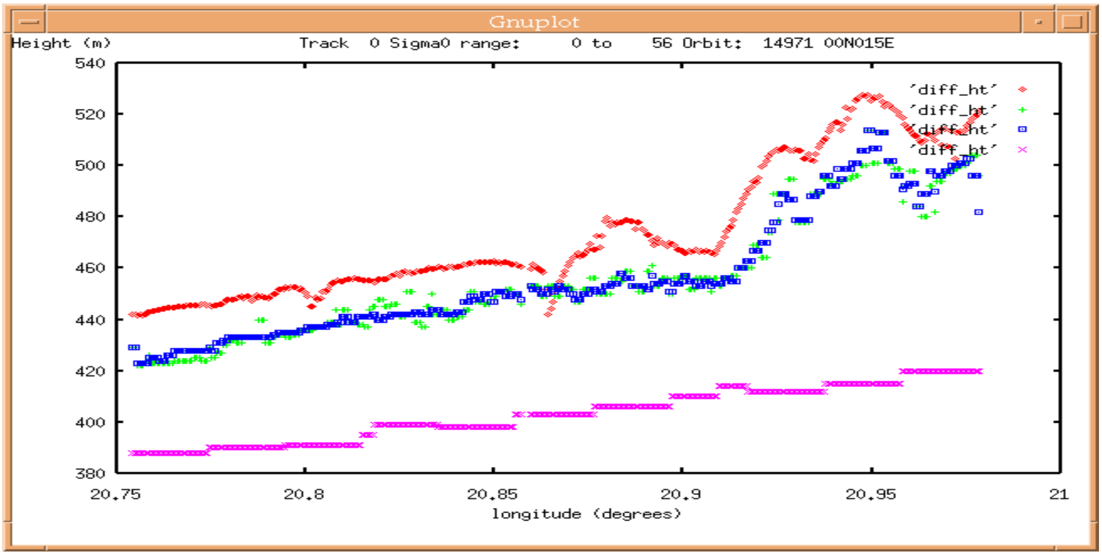


Figure 5

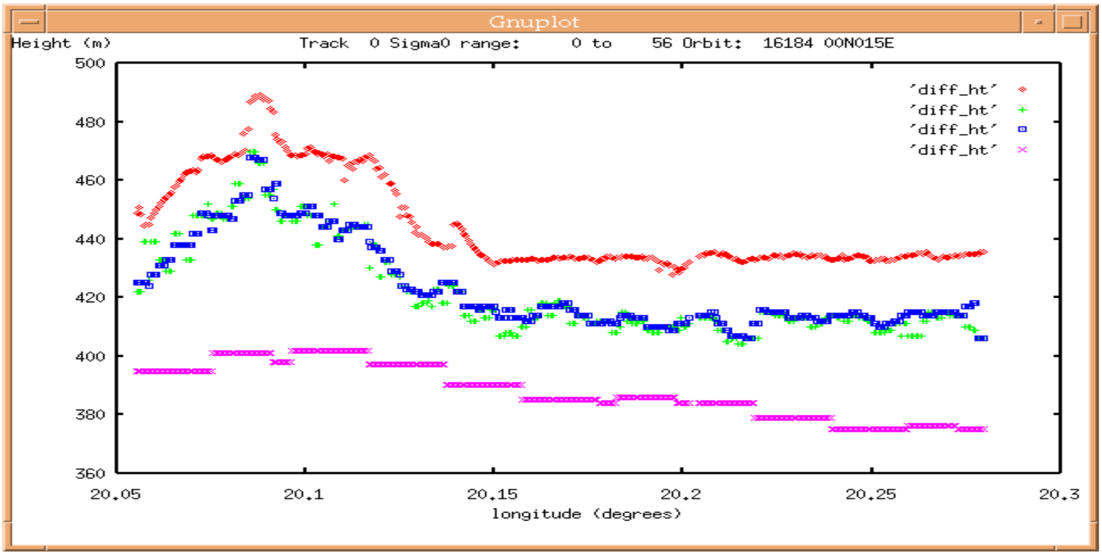


Figure 6

Figures 4,5 and 6 are along track profiles going across a one degree DTED square in Chad (19-20E, 11-12N). The red profile shows the altimeter's surface, the blue is the GLOBE_v1 surface, the green is the GTOPO30 surface and the purple is the JGP95E surface. In the three figures the altimeter, GLOBE_v1 and GTOPO30 surfaces are very closely correlated. Each of these figures also shows a twenty-metre offset between the altimeter and the GLOBE_v1 and GTOPO30 surfaces. JGP95E is slightly correlated to the altimeter but the coarse resolution of JGP95E limits the amount of detail contained in the DEM. The height offsets seen in these profiles suggest that different reference surfaces may have been used between the different datasets. This error signature was found to be common to a lot of the DTED in South America and Africa.

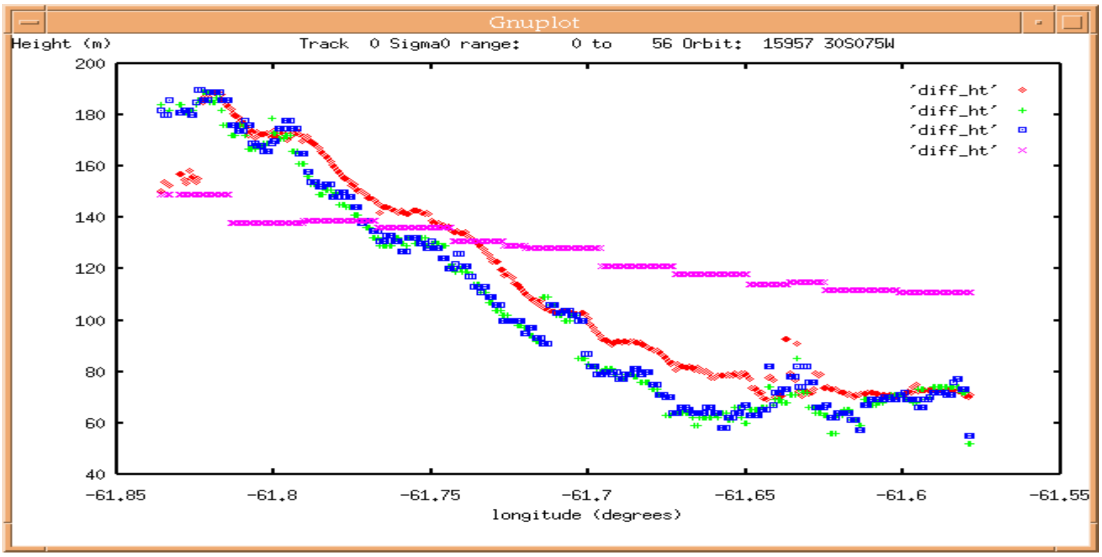


Figure 7

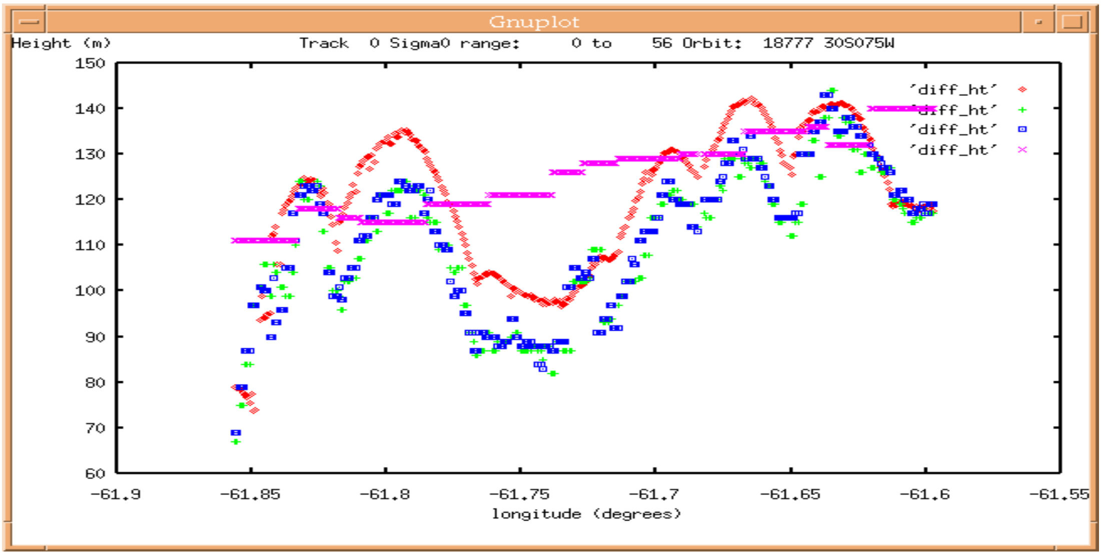


Figure 8

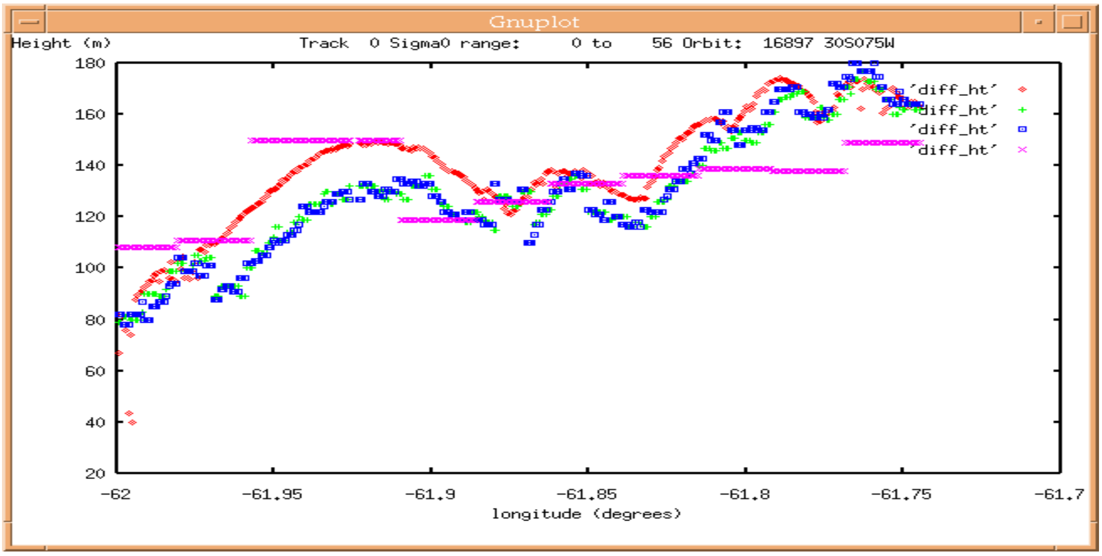


Figure 9

The above figures (figs. 7,8 & 9) are profiles across a one-degree DTED square in Argentina (61-62W, 27-28S). The profiles show varying agreement between the altimeter (red) and GLOBE_v1 (blue) and GTOPO30 (green) hence, there is no clear offset between the different surfaces. Even though there is no clear offset there is still a correlation between the three surfaces suggesting that they're some distortions in the DTED datasets. The JGP95E (purple) surface is certainly very generalised very inaccurate.

2.1.3. Gross Errors

Gross errors are best described as regions where the GDEM's representation of the land surface is totally uncorrelated to that of the altimeter. Gross errors are non-existent or missing features defined by the GDEM.

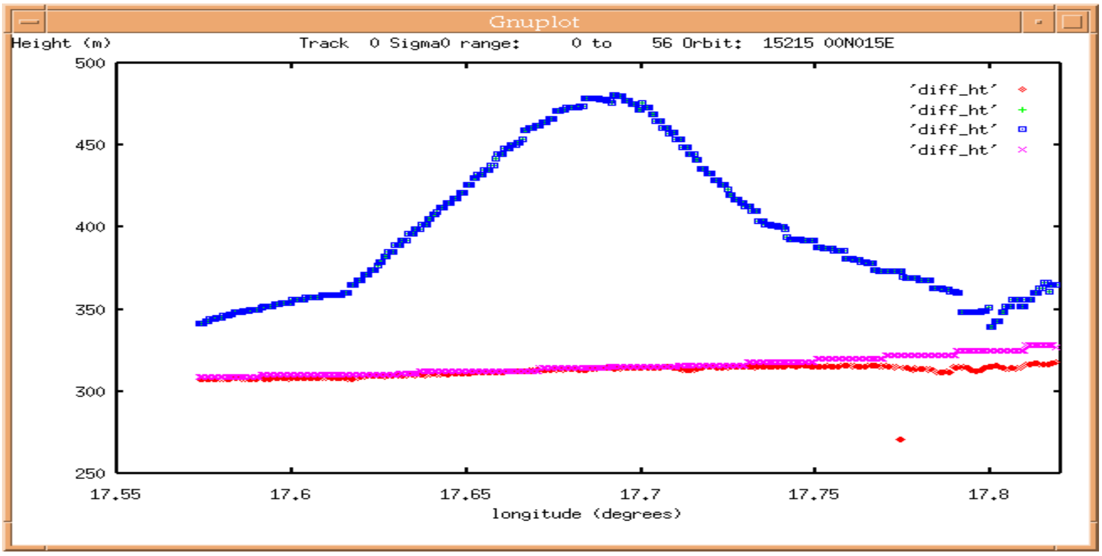


Figure 10

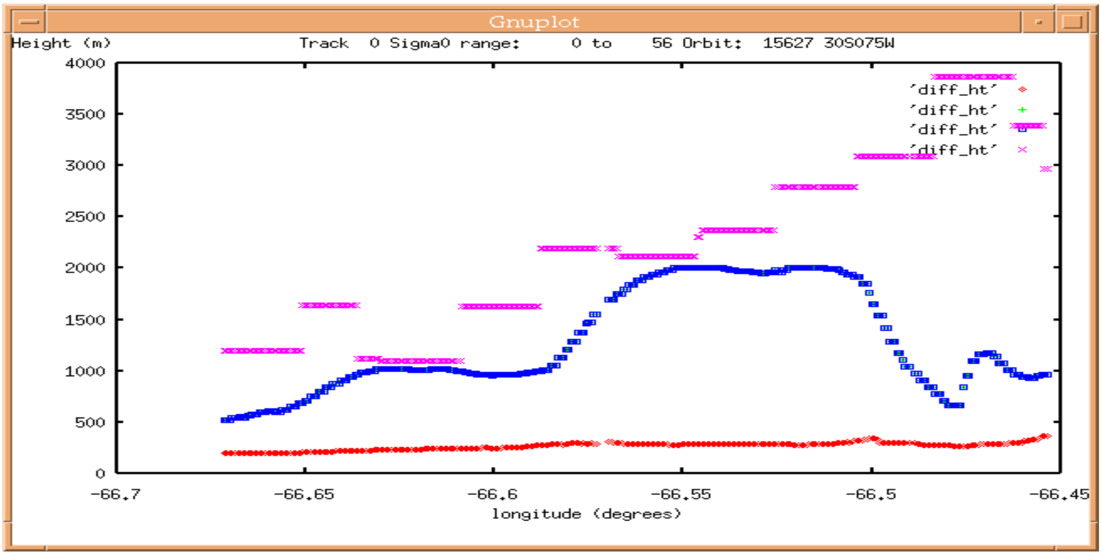


Figure 11

Figure 10 shows profiles across a one-degree DCW square in Congo (17-18E, 0-1N). In this profile altimeter (red) maintains good lock and is describing a totally flat surface. The profile in Congo shows an approximately one hundred and fifty metre gross error feature in the GLOBE_v1 (blue) and GTOPO30 (green, plotted under the blue) however, there is good agreement between the altimeter and JGP95E (purple). Figure 11 is similar to figure 10 but this profile is in Bolivia. Figure 11 shows a very large gross error feature (hundreds of metres) in the three GDEMS. The profiles shown in figure 11 is across a one-degree DCW square at the foot of the Andes suggesting that the feature in the GDEMS may have been misplaced. These gross errors frequently occur in the DCW data throughout South America and Africa.

2.1.4. Interpolation Errors

Interpolation errors in the GDEMS occur in areas where a poorly constrained interpolation routine was used to produce a surface. The surfaces produced by such routines are found to be very mathematical and smooth hence profiles across the GDEM's surface, in areas where interpolation errors are found, often resemble a spline or polynomial function curve.

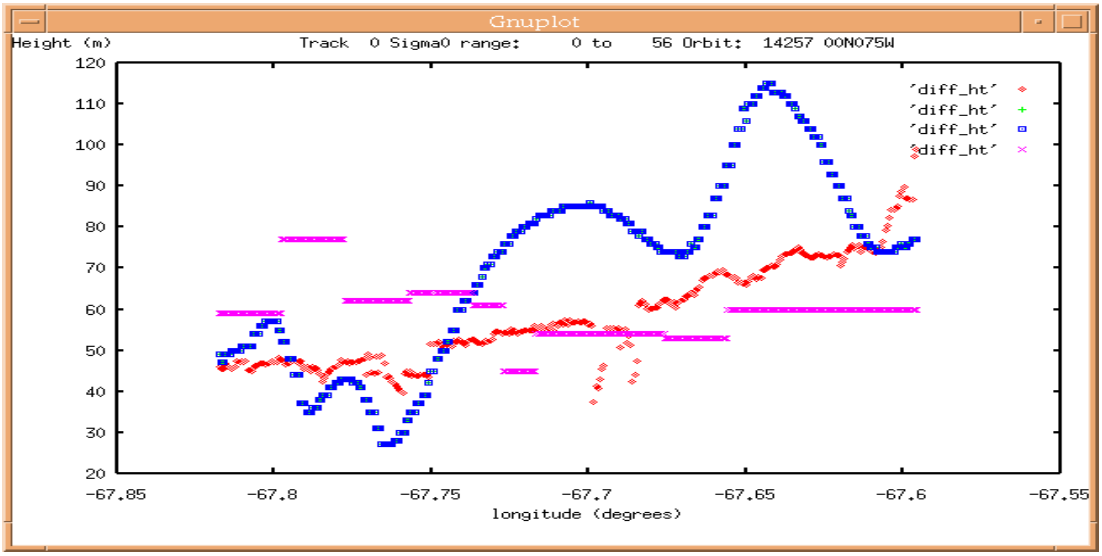


Figure 12

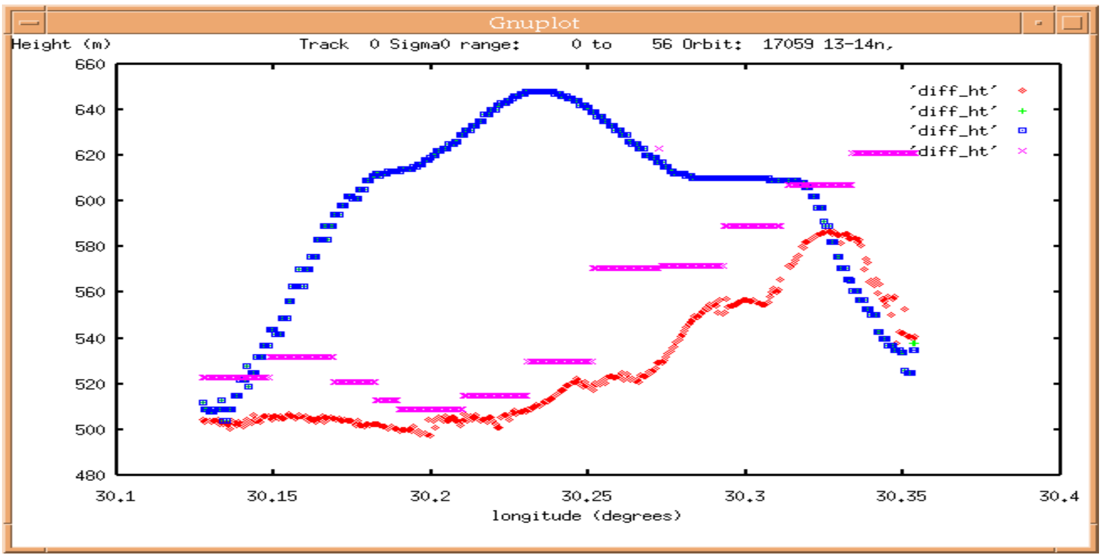


Figure 13

Figure 12 is a profile across a one-degree DCW square in Venezuela (67-68W, 8-9N). The altimeter profile (red) across Venezuela describes a gentle slope with small topographic changes however; GLOBE_v1 (blue) and GTOPO30 (green, plotted under blue) clearly show a mathematically derived surface resembling a polynomial function. Figure 13 is similar to figure 12 but goes across a one-degree DCW square in The Sudan (30-31W, 13-14N). Figure 13 shows that some sort of quadratic function was used to derive the surfaces in both GLOBE_v1 and GTOPO30. In both figures 12 and 13 JGP95E bears no relation to the surface described by the altimeter and contains no topographic detail.

2.1.5. Generalisation Errors

Generalisation errors occur in areas where there is no or very little high frequency data in the GDEM. The generalised GDEM surfaces are found to lack topographic detail. The generalisation observed is probably cause by subsampling lower resolution data up to the resolution of the GDEM. The lower resolution data used may be contour data with large intervals or sparse irregular gridded data points.

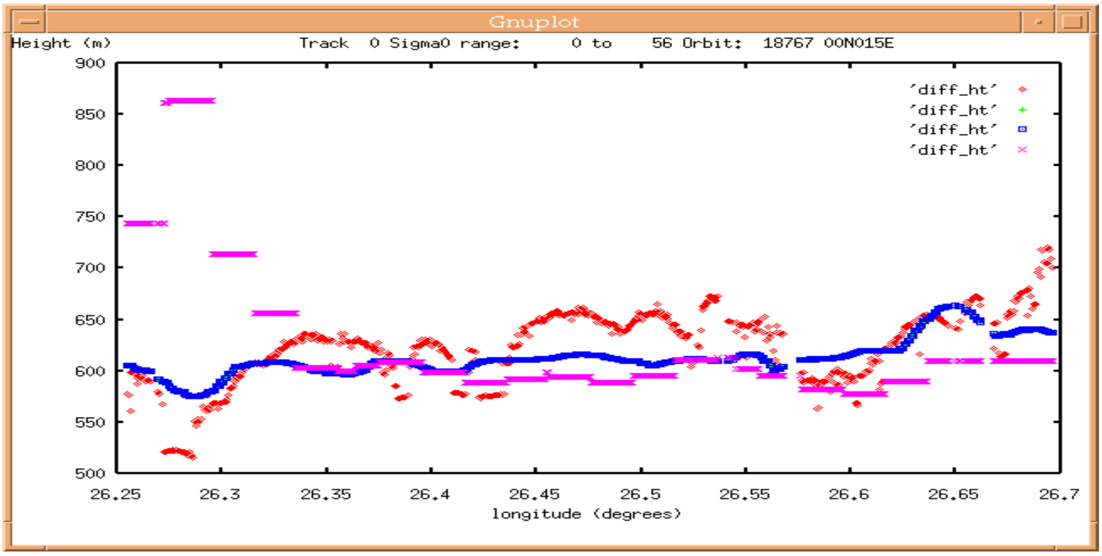


Figure 14

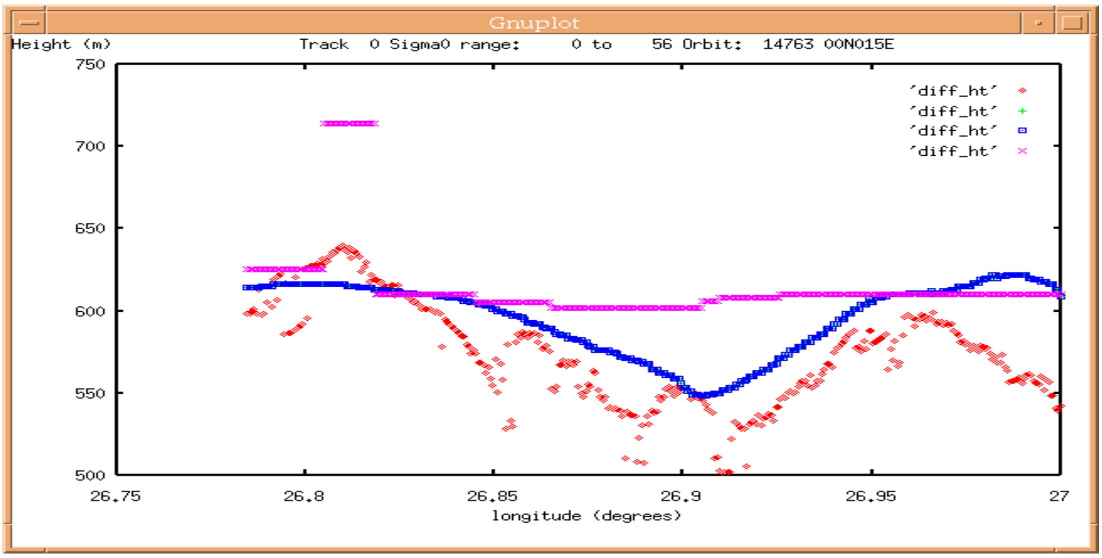


Figure 15

Figures 14 and 15 are profiles going across a two by two degree DCW region in Central African Republic (25-27E, 6-8N). In both figures the altimeter (red) describes a very detailed and topographically varying surface unlike the generalised surfaces described by three GDEMS. The GDEMS surfaces do not appear have very large or gross errors but lacks all the topographic detail shown in the altimeter profiles.

2.1.6. Horizontally Misplaced Error Features

These are features whose sizes an extent is inaccurately represented in the GDEMS. This misplacement of features my have been caused by previous co-ordinate transformations between datasets. The improper use or wrong co-ordinate transformation technique can result in miss-registration of data values resulting in horizontally displaced features.

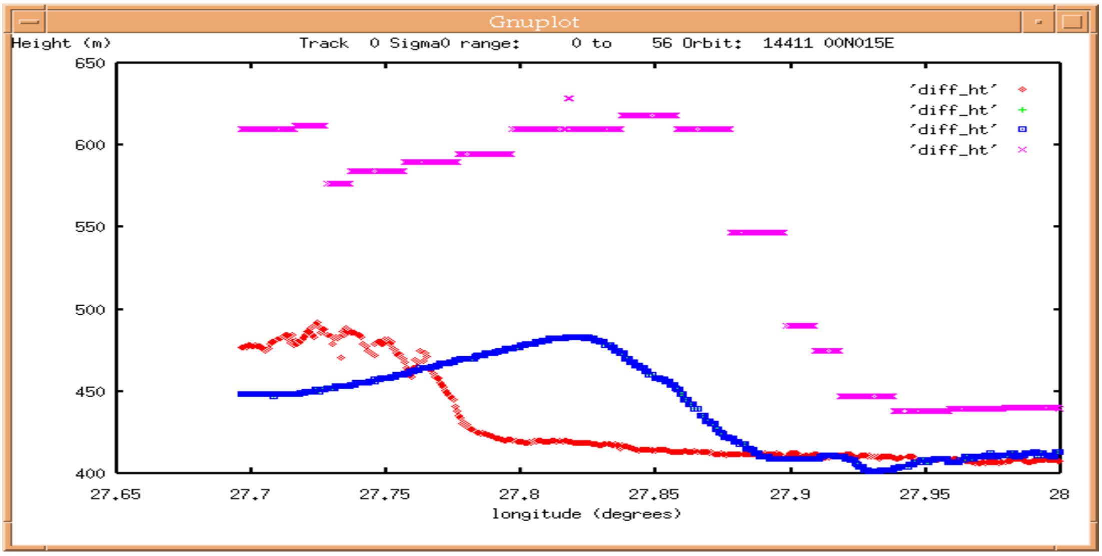


Figure 16

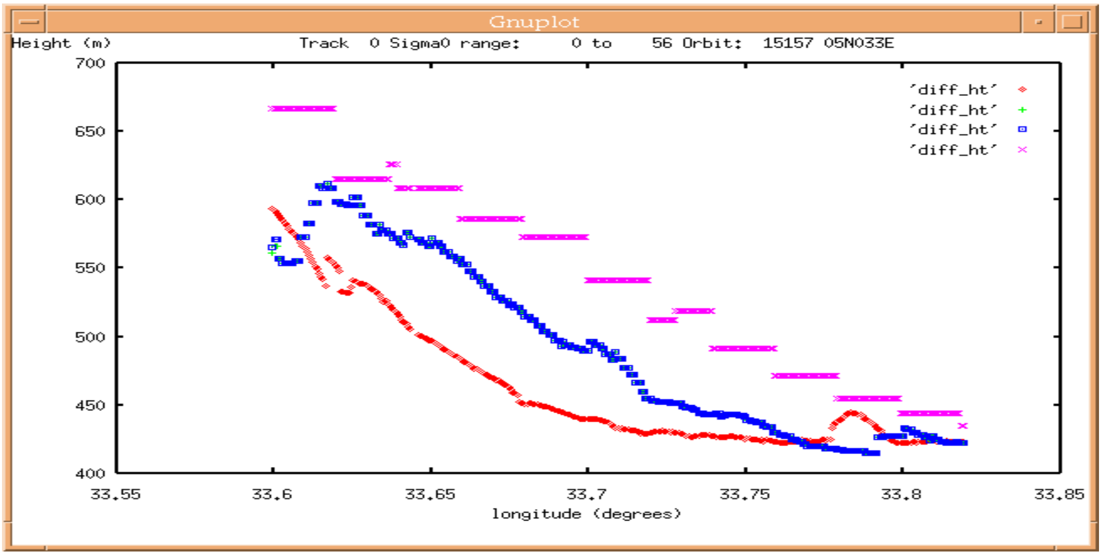


Figure 17

Figures 16 and 17 are profiles going across one-degree DCW squares in The Sudan (8-9N, 27-28E and 5-6N, 33-34E respectively). The profiles show similar features described by the four data sets (i.e. the altimeter and the three GDEMS). The figures also show that the profiles across the features do not coincide with each other suggesting some horizontal misplacement may have occurred in the GDEM datasets.

2.1.7. Random or Scrambled Looking Data

Profiles across some regions in the GDEMS showed very scrambled or random representations of the land surface. The cause of this is thought to the use of spot heights, obtained from higher resolution datasets or ground survey data. This procedure involved using either a spot height from a 3 arc-second dataset or the median height of the 3 arc-second pixels to represent the 30 arc-second pixels.

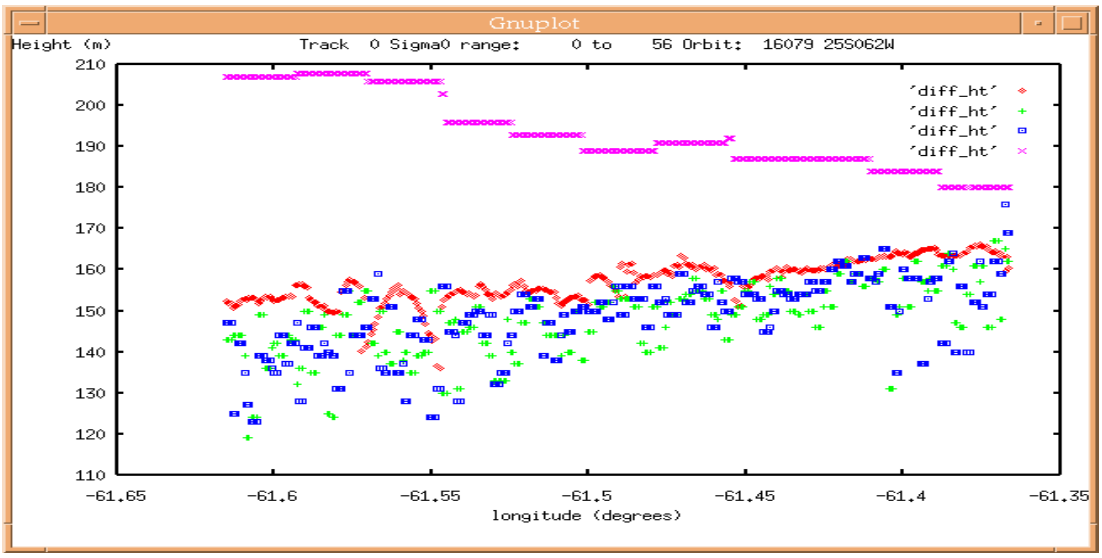


Figure 18

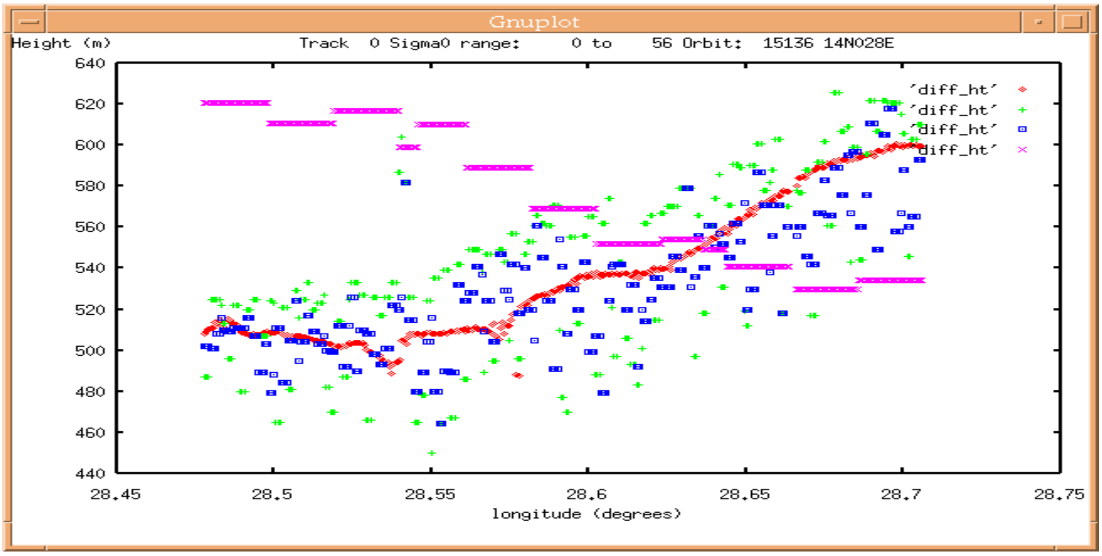


Figure 19

Figure 18 shows a profile across a one-degree DTED square in Paraguay (61-62W, 24-25S). In the figure the altimeter profile (red) describes a flat surface. The GLOBE_v1 (blue) and GTOPO30 (green) profiles are not identical but similar in this area. They both follow the same general trend (gradient) of the altimeter but are very pixelated making the surface appear rough. Figure 19 is similar to figure 18 but the profiles over sloping terrain in The Sudan (28-29E, 14-15N).

3. Uses of Altimetry Data

The previous GDEM comparison work has clearly shown the potential of the altimeter dataset to validate and assess GDEMS. This section discusses the capabilities and other uses for the altimeter dataset in mapping.

3.1. Altimeter Corrected Elevation (ACE) GDEM Project

The detailed assessment of the GDEMS in the public domain using the altimeter dataset showed how poor the quality of the different datasets used in the GDEMS were. At the Geomatics Unit a proposal was made to produce a better quality GDEM with a 30 arc-second resolution and with the aid of the altimeter dataset. Although there is dense along track sampling by the altimeter, the main limitation of the altimeter dataset in direct mapping is the wide across track spacing. The altimeter dataset consists of points along track for tracks covering the entire Earth between 81.5 ° N and 81.5 ° S. The tracks have varying across track spacing based on satellite's three repeat orbit patterns. Along these tracks, the points have a spacing of approximately 300m. Of the three repeat patterns, 3-day, 35-day and 168-day (geodetic mission), the 168-day ERS-1 repeat cycle had the smallest across track spacing of approximately 7 km at the equator and a closer spacing at higher latitudes. The 168-day repeat cycle was most suitable repeat cycle for direct mapping since, it had the smallest across track spacing which allowed the altimeter to sample a larger percentage of the Earth's surface. Apart from the across track spacing the altimeter also sampled the points in the 3-day and 35-day repeat cycles in the 168-day repeat cycle.

3.1.1. Interpolation of the Altimeter Dataset

In order to produce a GDEM from the altimeter dataset some method of spatial interpolation needs to be considered. The use of a spatial interpolation routine is essential for fitting a surface to the altimeter heights. The spatial interpolation procedure involves estimating height values at points unsampled by the altimeter but within the area covered by existing altimeter points. The rational behind spatial interpolation is the observation that points close together in space are more likely to have similar values than points far apart (Tobler's Law of Geography). The interpolation method to be used must therefore best suite the sampling pattern of the altimeter. The most suitable interpolation routine for the altimeter dataset was the use of Delaunay triangulation with bilinear interpolation. This procedure was suitable since the Delaunay triangulation routine was able to interpolate a grid of points from the irregularly spaced altimeter points. Once the grid of points is determined the bilinear interpolator is used on the straight line between each pair of grid points to regrid the data to the specified grid spacing (i.e. 30 arc-seconds). The bilinear routine was chosen since it is an exact interpolator and honours all the altimeter points unlike other approximate interpolators. Approximate interpolators often use polynomial functions, Fourier series or moving averages and therefore were not considered since they produce very mathematical surfaces and did not optimise the use of the altimeter dataset. The bilinear routine was also chosen since it wasn't computationally intense like other stochastic interpolators that incorporate the concept of randomness and probability theories (e.g. trend surface analysis, Fourier analysis and Kriging).

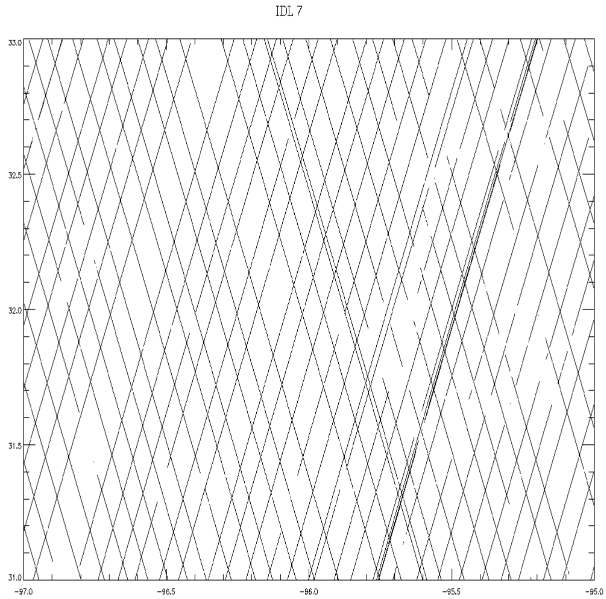


Figure 20

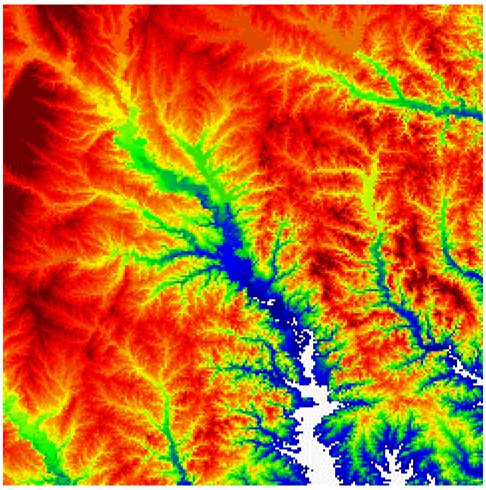


Figure 21

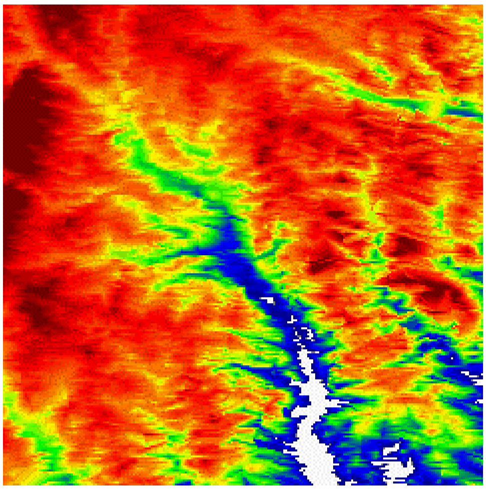


Figure 22

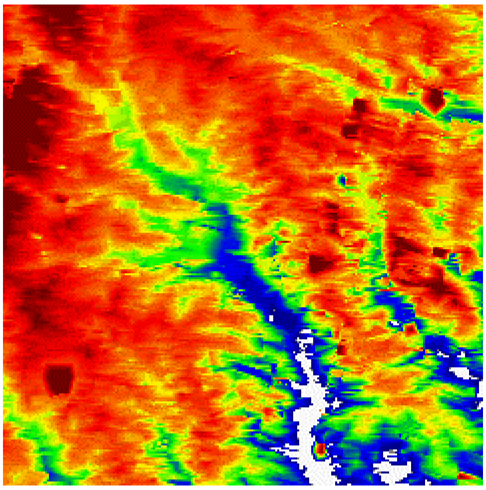


Figure 23

Figure 20 show the altimeter coverage for a 2-degree by 2-degree square in North America (95-97W, 31-33N). Figure 21 shows the GLOBE height map for the same 2-degree by 2-degree area in North America. Figure 22 show the reconstructed GLOBE surface for the same area. The surface in figure 22 is reconstructed by interpolating the subsampled GLOBE values using the sampling pattern of the altimeter. The subsampled GLOBE values (i.e. GLOBE pixels overflown by the altimeter) are interpolated using the Delaunay Triangulation and Bilinear Interpolation routines in Interactive Data Language (IDL - programming language). From the height map showing the reconstructed GLOBE surface you can see that some topographic detail is lost but the surfaces are still both very similar. In this area the altimeter heights and the GLOBE heights are in close agreement and Figure 23 shows the surface produced by interpolating the altimeter heights.

3.1.2. Protocol for the creation of the ACE GDEM

Once the altimeter dataset was interpolated and subsetted into one degree tiles a protocol for developing the ACE GDEM was developed. The new GDEM – ACE was generated continent by continent with South America being the first. The first assumption made, in the generation of ACE, was that all the ground truth data is erroneous and need to be assessed. The aim of the ACE project is to produce a GDEM, which will be a compilation of the highest quality data from either the altimeter dataset or the public domain GDEMS. The assessment of the four datsets (i.e. the altimeter dataset and the three GDEMS) is done for every one-degree square of the earth's land surface. Looking at one third of the altimeter profiles going across the one-degree region does this assessment. These profiles compare the existing ground truth to the altimeter heights and quantify the accuracy of the pre-existing datasets for every pixel overflown by the altimeter. This information is combined with knowledge of the altimeter coverage in the area to produce a decision matrix for each continent.
There are four classes of decision:

1) If the Ground truth (GDEM dataset) is poor and the altimeter coverage is good (i.e. there are a lot of altimeter points in the one-degree square) a one- degree tile of interpolated altimeter data is used.

2) If the Ground truth (usually DTED) is good but offset vertically the ground truth is warped to the altimeter point network. The warped dataset is used for the one-degree tile.

3) If the Ground truth is good it is retained and used in ACE.

4) If the ground truth cannot be assessed due to poor altimeter coverage the ground truth is retained.
This decision matrix forms the control matrix for ACE generation.

Global Altimeter Coverage

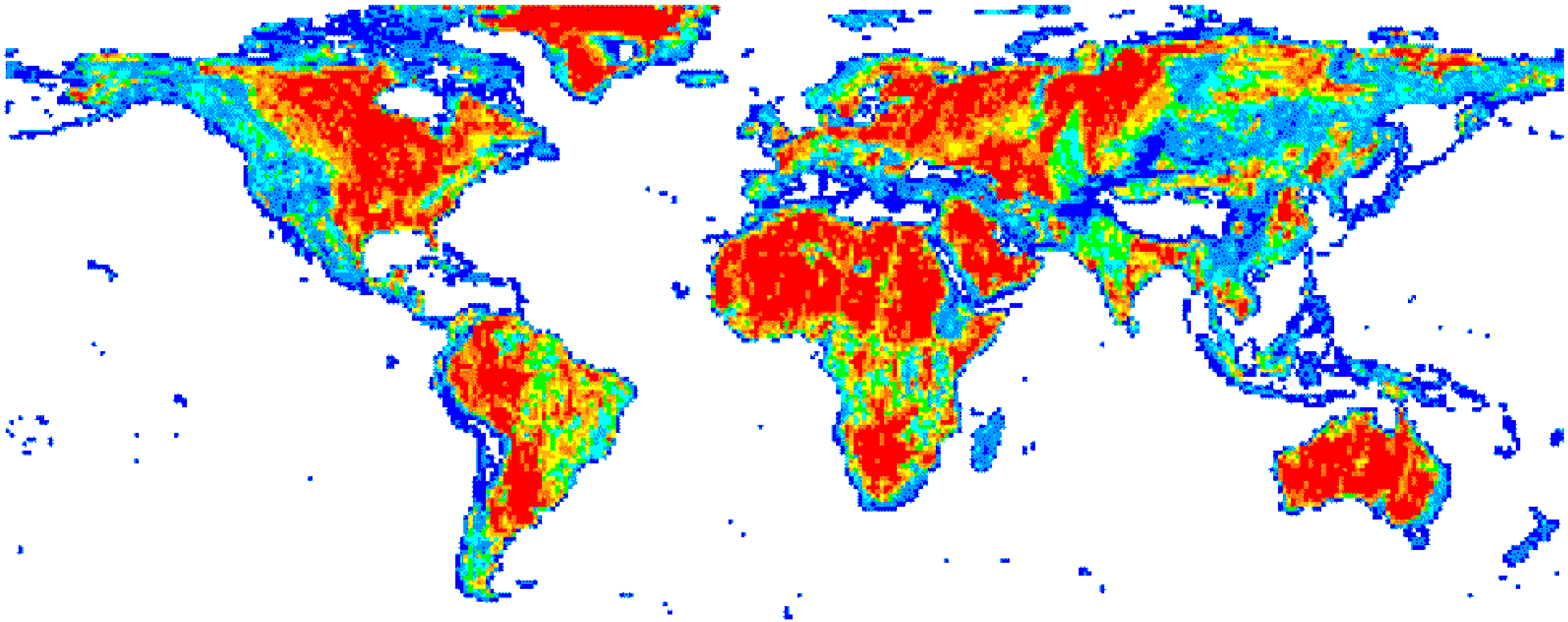


Figure 24

Fig. 24 - Global Plot of number of Altimeter height points in each one-degree square (Dark Blue <1000, Green 4000-5000, Dark Brown >10000)

Global Source/Decision Matrix for ACE Version1

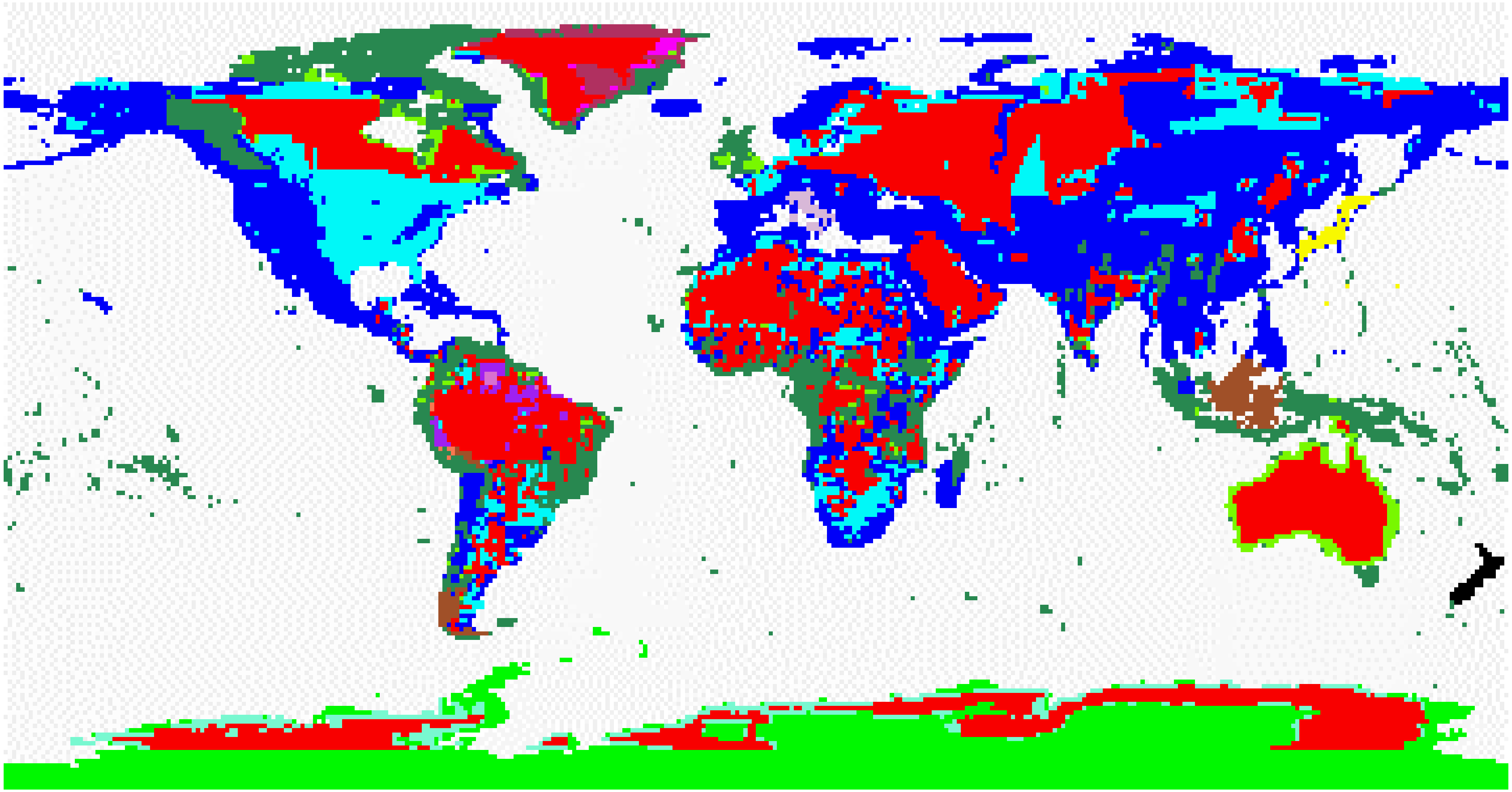


Figure 25

Legend for Global Source/Decision Matrix for ACE Version1 (Fig.25)

Colour	No. Of 1° Tiles	Data Source
	39375	Ocean
	7270	Altimeter Derived DEM
	7079	DTED non-shifted
	2340	DTED shifted
	2992	DCW developed by DMA, converted to 30” grid by USGS, non-shifted
	415	DCW developed by DMA, converted to 30” grid by USGS, shifted
	73	DEM of Japan, from GSI non-shifted
	48	DEM for Italy, at high resolution from SGN, converted to 30” grid by NGDC
	61	DEM of New Zealand at 500m gridded by LCR, reprojected to 30” by USGS non-shifted
	208	DEM of Greenland by Zwally (and others)/NSIDC, converted to 30” by JPL non-shifted
	39	DEM of Greenland by Zwally (and others)/NSIDC, converted to 30” by JPL shifted
	231	Army Map Service 1:1, 000, 000-scale maps, digitized by GSI, gridded by USGS non-shifted
	2	Army Map Service 1:1, 000, 000-scale maps, digitized by GSI, gridded by USGS shifted
	95	International Map of the World 1:1, 000, 000-scale maps for part of Brazil adapted by GSI, gridded by USGS non-shifted
	11	International Map of the World 1:1, 000, 000-scale maps for part of Brazil adapted by GSI, gridded by USGS shifted
	5	Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by GSI, gridded by USGS non-shifted
	4556	SCAR Antarctic Digital Database, converted by USGS, repaired by NGDC non-shifted

Table 1

Table 1 shows the colour coding for the Global Source/Decision Matrix in figure 25. The table also shows the statistics for the source data composition for the ACE Version1 release (based on 1° tiles). Table 1 shows that for the 25425 ACE land tiles 28.6% of ACE is made up of the altimeter derived DEM dataset. Table 1 also shows that a further 11.0% of ACE contains shifted or corrected public domain DEM data. The statistics in Table 1 therefore shows that approximately 40% of the data in the new ACE GDEM is either altimeter derived or altimeter corrected.

Global Height Map ACE Version1

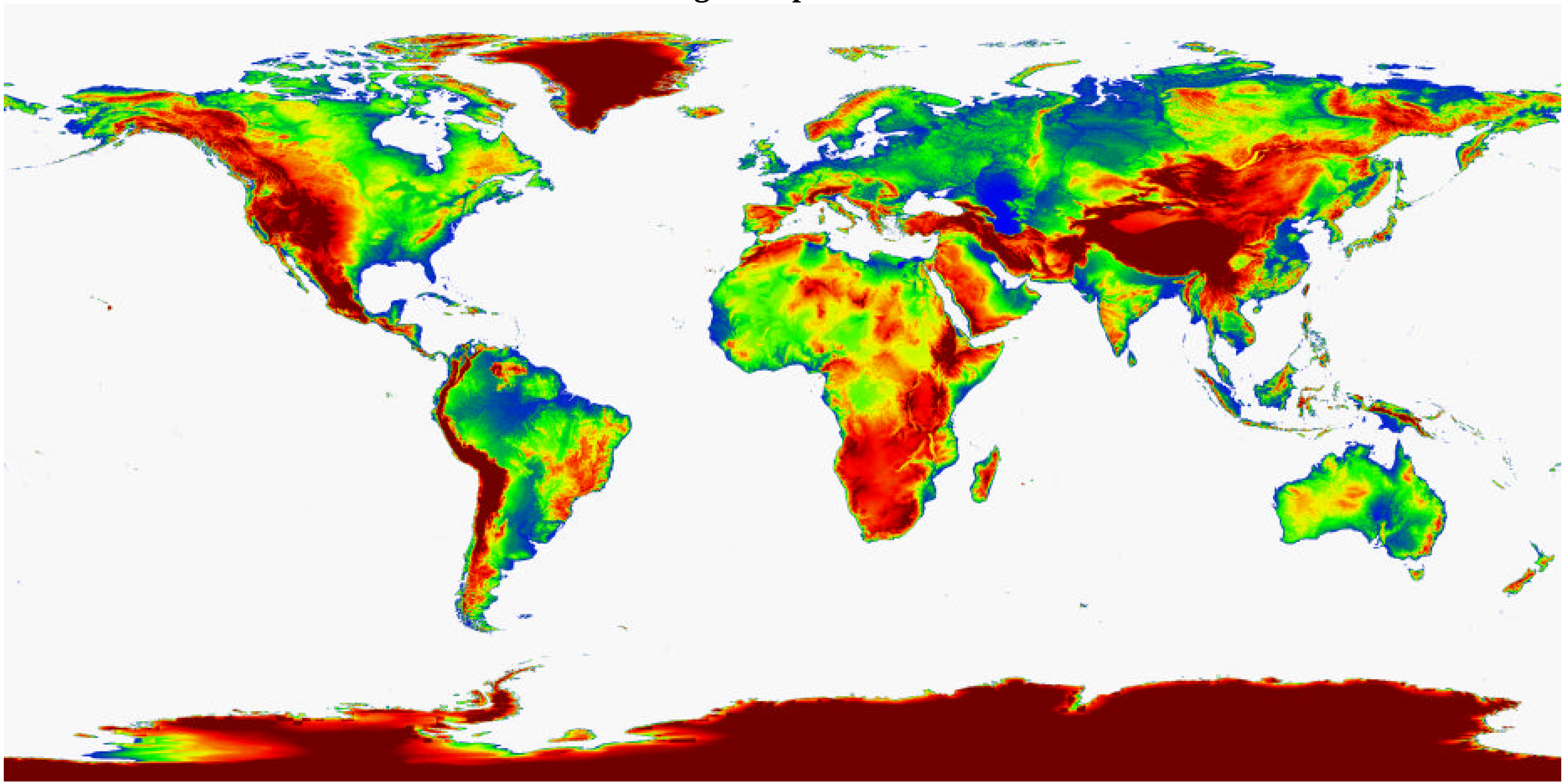


Figure 26

Figure 26 – Global Height Map for ACE Version1 with colour table (Blue low to Red high) and having a cut-off to reveal low-lying topography

Global ACE Version1 Quality Matrix

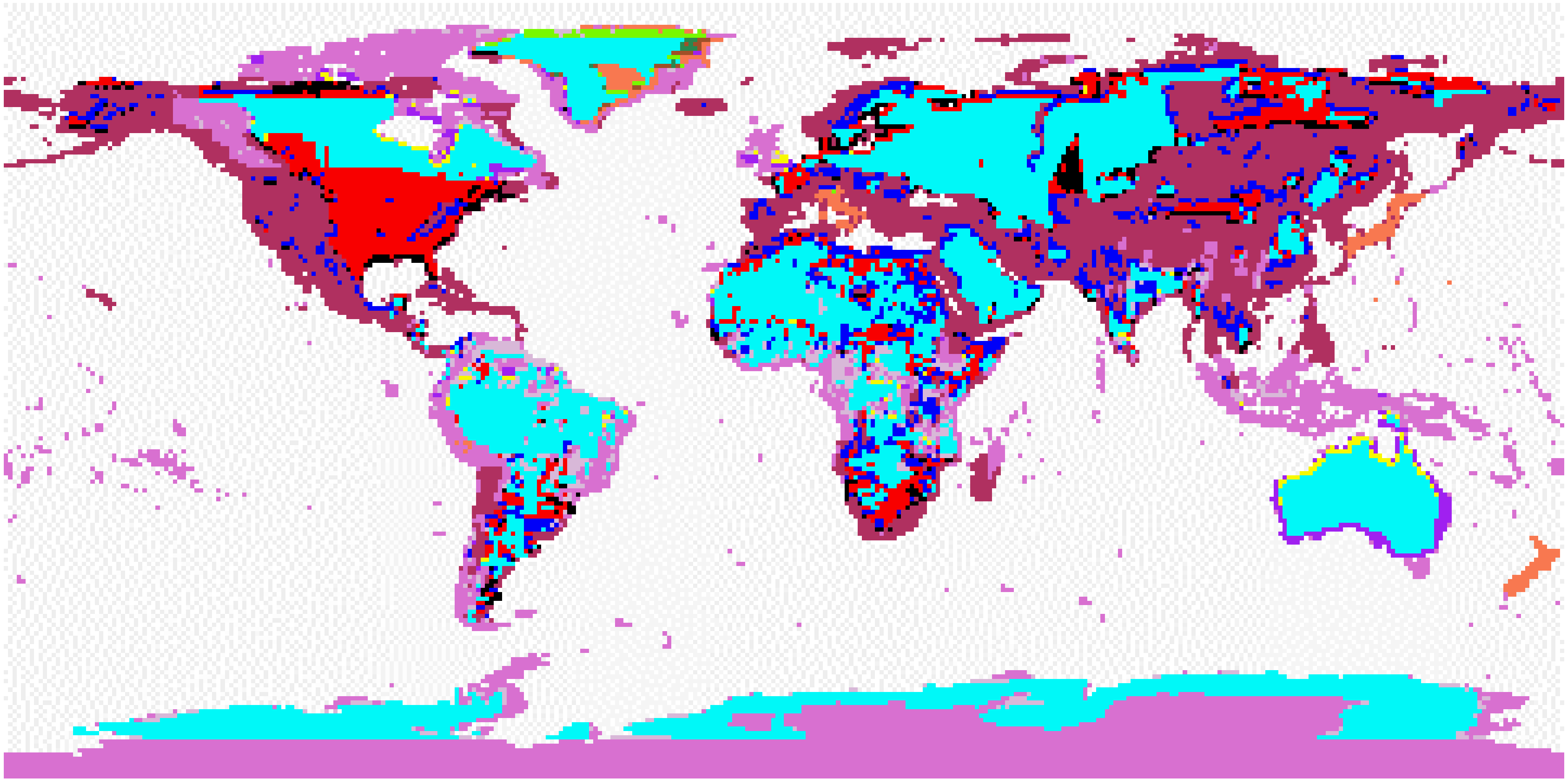


Figure 27

Legend for Global Quality Matrix for ACE Version1 (Fig.27)

Colour	No. Of 1º Tiles	Data Quality Codes
	39375	Ocean
	1766	1
	1436	2
	7270	3
	14	4
	91	5
	151	6
	669	7
	574	11
	5643	12
	0	13
	25	14
	304	15
	277	16
	7205	17

Table 2

Table 2 shows the colour coding for the Global Quality Matrix in Figure 27. The table also shows the statistics for the data quality composition for the ACE Version1 release (based on 1° tiles). Table 2 defines the data quality codes used for the ACE Version1 Quality Matrix with 1 to 7 being validated data and, 1 being of the highest quality and 7 the lowest. The quality codes from 11 to 17 represents non-validated data but of varying quality, these codes are obtained by adding 10 to the quality code for validated data of the same source (see the detailed description for the quality codes below in section 4.3).

4. Data Format and Source

4.1. Data Format

The ACE product comprises of a Height dataset and a Source dataset. To Facilitate Distribution the ACE Height and Source datasets have been divided into 288 smaller pieces, or tiles for each dataset. The area from 90 degrees south latitude to 90 degrees north latitude and 180 degrees west longitude to 180 degrees east latitude is covered by 288 tiles (for each dataset), with each tile covering 15 degrees of latitude and 15 degrees of longitude. The tiles names refer to the latitude and longitude of the lower left (southwest) corner of the tile. For example, the coordinates of the lower left corner of tile 45S015E.ACE are 45 degrees south latitude and 15 degrees east longitude. The extension in the tile name refers to the dataset. For example, 45S015E.ACE is from the height dataset, 45S015E.ACE.SRC is from the source dataset and 45S015E.ACE.QUAL is from the quality dataset.

4.1.1 ACE Files (.ACE)

The DEM is provided as 16-bit little endian (i.e. least significant byte first) short data in a simple binary raster. There are no header or trailer bytes imbedded in the image. The data are stored in row major order (all the data for row 1, followed by all the data for row 2, etc.). Each .ACE file is made up of 1800 rows and 1800 columns and contains one spectral band for the height values. The value used for masking (i.e. land/sea mask or nodata) is set to –500.

4.1.2. Source Files (.ACE.SRC)

The source data is provided as 8-bit little endian (i.e. least significant byte first) character data in a simple binary raster. There are no header or trailer bytes imbedded in the image. The data are stored in row major order (all the data for row 1, followed by all the data for row 2, etc.). Each .ACE.SRC file is made up of 1800 rows and 1800 columns and contains one spectral band for the source code values (i.e. from 0 to 21).

4.1.3. Quality Files (.QUAL)

The quality data is provided as 8-bit little endian (i.e. least significant byte first) character data in a simple binary raster. There are no header or trailer bytes imbedded in the image. The data are stored in row major order (all the data for row 1, followed by all the data for row 2, etc.). Each .QUAL file is made up of 1800 rows and 1800 columns and contains one spectral band for the source code values (i.e. from 0 to 7 and 11 to 17).

4.2. ACE Data Sources and Source Codes (i.e. for .ACE.SRC files)

0. Ocean

1. Digital Terrain Elevation Data (DTED), non-shifted.

2. Digital Terrain Elevation Data (DTED), shifted using warping technique developed at De Montfort University.

3. Digital Chart of the World (DCW) developed by Defence Mapping Agency (DMA), converted to 30” grid by U.S. Geological Survey (USGS), non-shifted.

4. Digital Chart of the World (DCW) developed by Defence Mapping Agency (DMA), converted to 30” grid by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

5. DEM of Japan, from Geographical Survey Institute, Japan (GSI), non-shifted.

6. DEM of Japan, from Geographical Survey Institute, Japan (GSI), shifted using warping technique developed at De Montfort University.

7. DEM for Italy, at high resolution from Servizio Geologico Nazionale (National Geological Survey (Italy))(SGN), converted to 30” grid by National Geophysical Data Centre (NGDC) (for SGN), non-shifted.

8. DEM for Italy, at high resolution from Servizio Geologico Nazionale (National Geological Survey (Italy)) (SGN), converted to 30” grid by National Geophysical Data Centre (NGDC) (for SGN), shifted using warping technique developed at De Montfort University.

9. DEM of New Zealand at 500m gridding by Manaaki Whenua Landcare Research, Ltd., New Zealand (LCR), reprojected to 30” by U.S. Geological Survey (USGS), non-shifted.

10. DEM of New Zealand at 500m gridding by Manaaki Whenua Landcare Research, Ltd., New Zealand (LCR), reprojected to 30” by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

11. DEM of Greenland by Zwally (and others)/National Snow and Ice Data Centre (NSIDC), converted to 30” by Jet Propulsion Laboratory (JPL), non-shifted.

12. DEM of Greenland by Zwally (and others)/ National Snow and Ice Data Centre (NSIDC), converted to 30” by Jet Propulsion Laboratory (JPL), shifted using warping technique developed at De Montfort University.

13. Army Map Service (AMS) 1:1, 000, 000-scale maps, digitized by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted

14. Army Map Service (AMS) 1:1, 000, 000-scale maps, digitized by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

15. International Map of the World (IMW) 1:1, 000, 000-scale maps for part of Brazil adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.

16. International Map of the World (IMW) 1:1, 000, 000-scale maps for part of Brazil adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

17. Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.

18. Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

19. Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database, converted by U.S. Geological Survey (USGS), repaired by National Geophysical Data Centre (NGDC), non-shifted.

20. Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database, converted by U.S. Geological Survey (USGS), repaired by National Geophysical Data Centre (NGDC), shifted using warping technique developed at De Montfort University.

21. Altimeter Derived DEM (ACE).

4.3. ACE Data Quality and Quality Codes (i.e. for .QUAL files)

0. Ocean

1. Validated: Digital Terrain Elevation Data (DTED), shifted using warping technique developed at De Montfort University.

2. Validated: Digital Terrain Elevation Data (DTED), non-shifted.

3. Validated: Altimeter Derived DEM (ACE).

4. Validated:

a) DEM of Japan, from Geographical Survey Institute, Japan (GSI), shifted using warping technique developed at De Montfort University.

b) DEM for Italy, at high resolution from Servizio Geologico Nazionale (National Geological Survey (Italy)) (SGN), converted to 30” grid by National Geophysical Data Centre (NGDC) (for SGN), shifted using warping technique developed at De Montfort University.
c) DEM of New Zealand at 500m gridding by Manaaki Whenua Landcare Research, Ltd., New Zealand (LCR), reprojected to 30” by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
d) DEM of Greenland by Zwally (and others)/ National Snow and Ice Data Centre (NSIDC), converted to 30” by Jet Propulsion Laboratory (JPL), shifted using warping technique developed at De Montfort University.
e) Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

5. Validated:

a) DEM of Japan, from Geographical Survey Institute, Japan (GSI), non-shifted.
b) DEM for Italy, at high resolution from Servizio Geologico Nazionale (National Geological Survey (Italy))(SGN), converted to 30” grid by National Geophysical Data Centre (NGDC) (for SGN), non-shifted.
c) DEM of New Zealand at 500m gridding by Manaaki Whenua Landcare Research, Ltd., New Zealand (LCR), reprojected to 30” by U.S. Geological Survey (USGS), non-shifted.
d) DEM of Greenland by Zwally (and others)/National Snow and Ice Data Centre (NSIDC), converted to 30” by Jet Propulsion Laboratory (JPL), non-shifted.
e) Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.

6. Validated:

a) Digital Chart of the World (DCW) developed by Defence Mapping Agency (DMA), converted to 30” grid by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
b) Army Map Service (AMS) 1:1, 000, 000-scale maps, digitized by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
c) International Map of the World (IMW) 1:1, 000, 000-scale maps for part of Brazil adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
d) Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database, converted by U.S. Geological Survey (USGS), repaired by National Geophysical Data Centre (NGDC), shifted using warping technique developed at De Montfort University.

7. Validated:

a) Digital Chart of the World (DCW) developed by Defence Mapping Agency (DMA), converted to 30” grid by U.S. Geological Survey (USGS), non-shifted.
b) Army Map Service (AMS) 1:1, 000, 000-scale maps, digitized by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.
c) International Map of the World (IMW) 1:1, 000, 000-scale maps for part of Brazil adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.
d) Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database, converted by U.S. Geological Survey (USGS), repaired by National Geophysical Data Centre (NGDC), non-shifted.

11. Non-validated: Digital Terrain Elevation Data (DTED), shifted using warping technique developed at De Montfort University.

12. Non-validated: Digital Terrain Elevation Data (DTED), non-shifted.

13. Non-validated: Altimeter Derived DEM (ACE).

14. Non-validated:

a) DEM of Japan, from Geographical Survey Institute, Japan (GSI), shifted using warping technique developed at De Montfort University.
b) DEM for Italy, at high resolution from Servizio Geologico Nazionale (National Geological Survey (Italy)) (SGN), converted to 30” grid by National Geophysical Data Centre (NGDC) (for SGN), shifted using warping technique developed at De Montfort University.
c) DEM of New Zealand at 500m gridding by Manaaki Whenua Landcare Research, Ltd., New Zealand (LCR), reprojected to 30” by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
d) DEM of Greenland by Zwally (and others)/ National Snow and Ice Data Centre (NSIDC), converted to 30” by Jet Propulsion Laboratory (JPL), shifted using warping technique developed at De Montfort University.
e) Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.

15. Non-validated:

a) DEM of Japan, from Geographical Survey Institute, Japan (GSI), non-shifted.
b) DEM for Italy, at high resolution from Servizio Geologico Nazionale (National Geological Survey (Italy))(SGN), converted to 30” grid by National Geophysical Data Centre (NGDC) (for SGN), non-shifted.

c) DEM of New Zealand at 500m gridding by Manaaki Whenua Landcare Research, Ltd., New Zealand (LCR), reprojected to 30” by U.S. Geological Survey (USGS), non-shifted.
d) DEM of Greenland by Zwally (and others)/National Snow and Ice Data Centre (NSIDC), converted to 30” by Jet Propulsion Laboratory (JPL), non-shifted.
e) Peru 1:1, 000, 000-scale maps for part of Peru by the Ministerio de Guerra of Peru, adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.

16. Non-validated:

a) Digital Chart of the World (DCW) developed by Defence Mapping Agency (DMA), converted to 30” grid by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
b) Army Map Service (AMS) 1:1, 000, 000-scale maps, digitized by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
c) International Map of the World (IMW) 1:1, 000, 000-scale maps for part of Brazil adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), shifted using warping technique developed at De Montfort University.
d) Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database, converted by U.S. Geological Survey (USGS), repaired by National Geophysical Data Centre (NGDC), shifted using warping technique developed at De Montfort University.

17. Non-validated:

a) Digital Chart of the World (DCW) developed by Defence Mapping Agency (DMA), converted to 30” grid by U.S. Geological Survey (USGS), non-shifted.
b) Army Map Service (AMS) 1:1, 000, 000-scale maps, digitized by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.
c) International Map of the World (IMW) 1:1, 000, 000-scale maps for part of Brazil adapted by Geographical Survey Institute, Japan (GSI), gridded by U.S. Geological Survey (USGS), non-shifted.
d) Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database, converted by U.S. Geological Survey (USGS), repaired by National Geophysical Data Centre (NGDC), non-shifted.

4.4. Data Distribution

The two different datasets are distributed as two compressed tar files. The Height dataset is in the **ACEV1_Height.tar.gz** data file and the Source dataset is in the **ACEV1_Source.tar.gz** data file and the Quality data is in the **ACEV1_Quality.tar.gz** data file. Each of these three **.tar.gz** files are archives of 288 fifteen degree tiles combined into one file using the Unix **“tar”** command, and the tar file is compressed using GNU **“gzip”** utility. To use the ACE height data files (.ACE) the ACE_Height.tar.gz file must be first decompressed and then the individual data files for each fifteen-degree tile extracted from the tar file. For example the following Unix command can be used:

```
gunzip < ACEV1_Height.tar.gz | tar xvf –
```

5. Discussion

The second release of ACE (ACE Version 1) have addressed the problems of significant tile offsets over Antarctica by replacing the shifted SCAR Antarctic Digital Database, converted by USGS, repaired by NGDC (Source code 20 in the ACEβ release) with the an Altimeter derived DEM (ACE, source code 21).

The second release of ACE (ACE Version 1) includes a full resolution Quality Matrix have also been included with all the description of all the codes described in section 4.3 of this documentation. The quality codes in ACE Version 1 range from 1 to 17. Table 2 in Section 3.1.2, and the list of descriptions for the quality codes in Section 4.3 of this documentation defines the data quality codes used in the ACE Version 1 Quality Matrix. Quality codes 1 to 7 represent validated data with 1 being of the highest quality and 7 the lowest. The quality codes from 11 to 17 represents non-validated data of varying quality, these codes are obtained by adding 10 to the quality code for validated data of the same source and quality (see the detailed description for the quality codes in section 4.3 above). It is therefore at the discretion of the user whether to assume that, for example, data quality codes 1 and 11 are of similar quality.

Whilst the availability of an altimeter based dataset of derived orthometric heights with a near-global distribution has improved the height representation in ACE significantly, particularly over parts of South America, Africa and Asia, the lack of data in regions of high topographic change limits the improvements over mountainous areas. Data from the Envisat mission will be incorporated when available; this should allow assessment of existing datasets over extreme terrain. However, it is expected that high frequency DEM data from the range of radar techniques currently being exploited may represent the best option for upgrading ACE over extreme terrain.

6. Acknowledgements

We would like to extend our thanks to the European Space Agency (ESA) for making ERA-1 and ERS-2 data available and R.S. Italia for providing us with much needed software. We would also like to thank Hillary Wilson for her assistance in times of need.

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