Assessment of SRTM-3 DEM in Portugal with topographic map data

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ABSTRACT: Digital Elevation Models (DEM) derived from the Shuttle Radar Topographic Mission (SRTM) are now freely available in a resolution of 3 arc-seconds. These data can be very useful for research purposes as well as to supply basic topographic mapping data for poorly mapped countries.
This paper describes an assessment carried out over the SRTM data for Portugal. First, an analysis of the gaps found in the SRTM DEM was done, identifying if they occur in water or steep terrain. That was done with a set of ortho-rectified ETM Landsat images (Global Land Coverage Facility). In the case of Portugal, empty pixels over land were below 500. That is an excellent result for a country with nearly 90 thousand square kilometers, with relatively steep Mediterranean mountains ranging from sea level to 2000 m.
This study was extended to the Iberian Peninsula, which has a larger variety of relief and land cover. It was possible to conclude that more than two thirds of void pixels occurred in water surfaces. A simple interpolation can be done by a Delaunay triangulation of the valid points, in order to fill these gaps by planar surfaces. Voids in mountains are often of very few pixels and interpolation can also be acceptable in these areas.
The second part of the study consisted in assessing the vertical accuracy of the SRTM DEM and if systematic displacements occur due to vegetation. DEMs were provided by the Portuguese Geographical Institute (IGP), with 10 m spacing. They were derived by photogrammetric means in the production of topographic maps of scale 1:10,000. Data sets were chosen for the different kinds of relief and land use.
For areas of relatively steep terrain (mainly with low vegetation) the RMS error was found to be 4 meters, agreeing with results found by other authors. In some areas covered with dense forest the RMS error increases to around 6 meters and systematic displacements are found, showing that in these areas heights refer to the top of trees. This effect was especially detected in dense eucalyptus plantations.

1 INTRODUCTION

The Shuttle Radar Topography Mission (SRTM), carried out during a period of 11 days in February 2000, provided a nearly global coverage (56º S to 60º N) of Synthetic Aperture Radar (SAR) interferometric data (Rabus et. al., 2003). The system was composed of two antennas, one in the shuttle body and the other in a mast 60 m long. The fact that images are acquired simultaneously allows for a good coherence and for height determination over vegetation and other surfaces. This data set allowed for the generation of accurate digital elevation models.

From the interferometric processing, DEMs were obtained in a resolution of 1 arc second (approximately 30 m) and were released for free distribution in a reduced resolution of 3 arc seconds. They are provided in the form of tiles of 1 by 1 degrees in geographic coordinates (a total of 14621 tiles of 1201 by 1201 pixels). The planimetric reference system is the WGS84 ellipsoid and heights are referred to the sea level (corrected from heights above the ellipsoid using the EGM-96 geoid model). The data were expected to have a vertical accuracy of 16 m (at 90% confidence).

These data is of great interest for various reasons: the relief of many areas in the world is not mapped with the resolution and accuracy achievable by the SRTM system (Rabus, 2003); in european countries equivalent data are expensive and many research projects can now be carried in a consistent manner using SRTM data. In order to use the DEM in Portugal it was found important to analyse the SRTM data in terms of its completeness and accuracy.

This paper presents an assessment, from a user point of view, of the characteristics of the freely available SRTM DEMs. The completeness was assessed, counting the percentages of void pixels and in particular for the Iberian Peninsula, distinguishing void pixels over water from other voids, such as in mountainous terrain. A method is proposed to fill the voids by a Delaunay triangulation, which is acceptable in order to fill voids over water surfaces and small voids in mountains.

The vertical accuracy was assessed with photogrammetric DEMs produced by the Portuguese Geographical Institute in the 1:10,000 scale national mapping program.

2 DEM COMPLETNESS

One of the limitations of SRTM DEMs is the fact that some voids remain in the data. The voids result mainly from two situations: in steep areas the layover and shadow effects, characteristic of SAR imagery, do not allow for height determination; over calm water surfaces the SAR signal is reflected and no energy returns to the antenna.
The 14621 tiles were analyzed and the percentages of voids were counted. They were grouped in 7 classes, their frequencies were counted and plotted in a histogram (Figure 1). More than 60 percent have less than 0.1% voids.

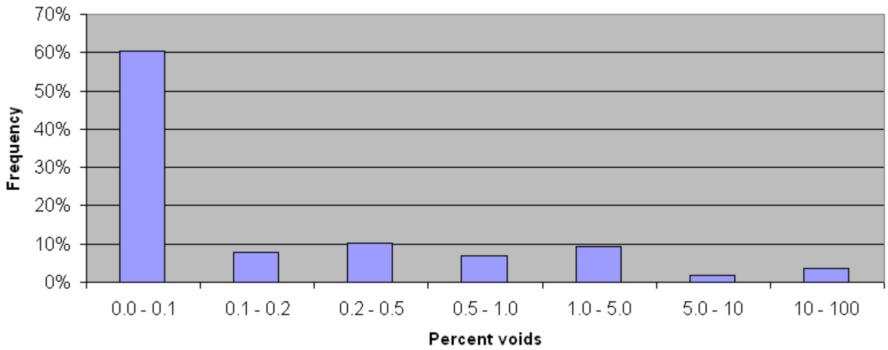


Figure 1 – frequencies of tiles in classes of percentage of voids

Some of the tiles with more problems are those lying on the coast line, since voids are frequent in sea water, the tiles completely within land (defined by the shore line of the Digital Chart of the World) were selected and coloured according to the same intervals of percent voids, as shown in figure 2.

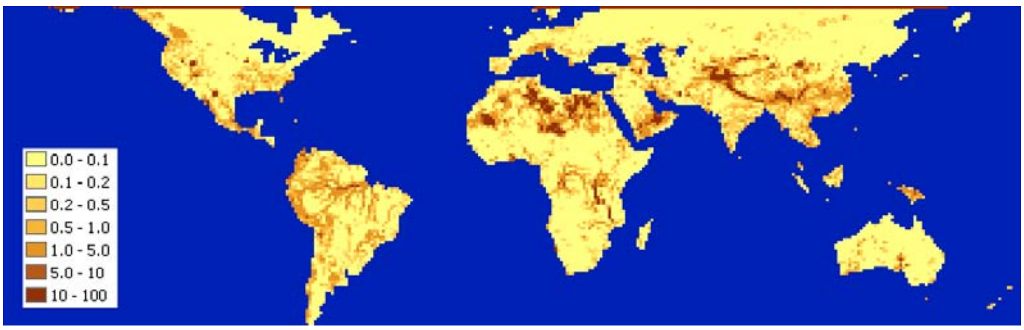


Figure 2 – frequencies of tiles in classes of percentage of voids

A brief analysis of the figure shows that, as expected, the main mountains have large percentages of voids, but the same happens with desert sands.
In many countries that do not meet those conditions, such as Portugal, SRTM data have few and small void areas. It may be possible to fill them by simple interpolation processes, keeping the overall accuracy of the DEM. Interpolation is certainly more reliable in planar surfaces, such as water, than in steep mountains, were voids mean a loss of information. In order to assess the proportion of voids in mountains, a visual inspection was carried out using a set of Landsat ETM images (GLCF, 2004). These images are freely available on the internet, from the Maryland University, through the Global Land Coverage Facility (GLCF). They were acquired in 2000 and 2001 and are available as pan-sharpened (15 m pixel) coloured combinations of bands 7, 4 and 2. This combinations allows for a very clear discrimination of land cover, in particular water surfaces. Images are ortho-rectified and projected in the UTM coordinates system (WGS84 datum). The registration with the SRTM DEM is very good.
The procedure followed was to build a mosaic of the SRTM tiles for Portugal, to create a raster layer of void pixels, which then was converted into vector format. All voids within the Portuguese border were inspected and classified as water or not water. From a total of void areas corresponding to 16080 pixels (0.13% of the area of the country) only 434 pixels (2.7% of the voids) were found not to be in water. Although the country has relatively steep Mediterranean mountains, only a few narrow valleys gave problems.
In order to have a broader view of the incidence of voids in water the study was extended to Spain (only to the longitude 0º). The results found for the Iberian Peninsula are listed in table I.

Table I – Comparison of amounts of void pixels

Location of voids	Total void pixels	Percentage of voids	Percentage of the area of the region
In water	146023	71%	0.18%
Not in water	58910	29%	0.07%
Total	204933	100%	0.25%

The more serious voids (in mountains) are less than one third of all voids. The larger areas occurred in the Cantabric and the Pyrenees mountains. Figure 3(a) shows the voids (red corresponding to mountains and blue to water). A mosaic of the ETM images used is represented in figure 3(b).

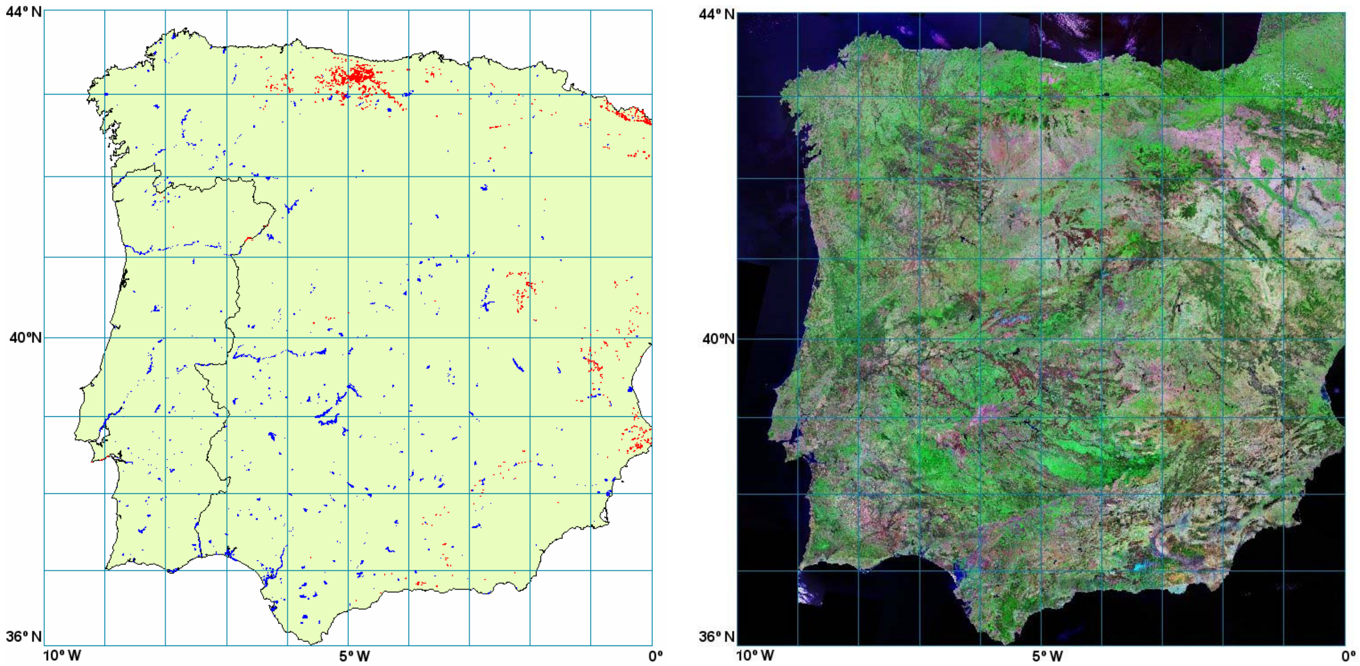


Figure 3 – (a) Location of SRTM void pixels in Iberia (red – mountains; blue - water);
(b) Mosaic of ETM images used to discriminate water

Gap filling in water surfaces is relatively simple. A possible method is the following: consider a set of points corresponding to pixel centres; a Delaunay triangulation can be applied to those points and then converted back to a grid by linear interpolation with the planar triangle surfaces; the valid heights are repeated and the empty space is filled with heights given by the triangles. Assuming valid points are near or even on the water, the new surface will be an approximately planar surface. Figure 4 represents this method for a gap in a reservoir that can be seen in the ETM image.

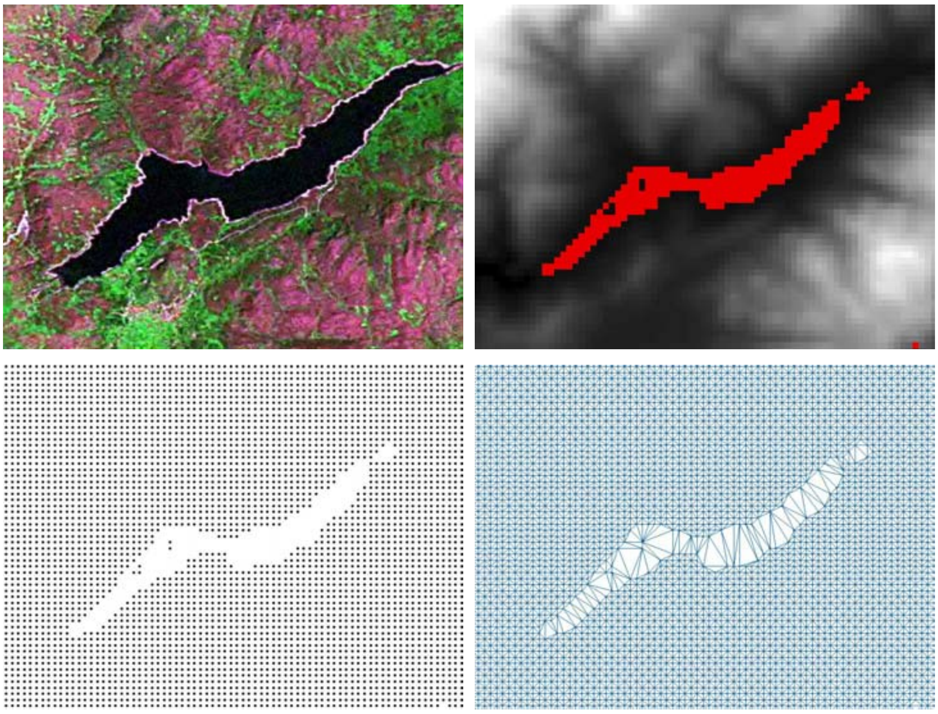


Figure 4 – (a) 4.5 km reservoir in ETM image; (b) DEM of the same area with void pixels in red; (c) centre points of valid pixels; (d) Delaunay triangulation

This procedure, as well as other interpolation procedures, provides reasonable completeness over water. The main difficulty is to distinguish the voids that are water. Anyway the manual procedure carried out for Iberian Peninsula, using the Landsat ETM data was relatively fast. Since these data are available for all the Earth it may be an acceptable method of refining the SRTM DEMs.

A new version of SRTM data will be released with some gap filling and correction of water level in the sea and other water surfaces (USGS, 2004). This procedures requires previous knowledge of a global coast line and boundaries of the main water bodies.

3 ACCURACY ASSESSEMENT

In order to assess the vertical accuracy of the SRTM DEM, photogrammetric DEMs were used. They were produced by the “Instituto Geográfico Português”, the Portuguese institution responsible by the production of topographic mapping at the scale 1:10,000. These DEMs in particular were derived to produce orthophotmaps from aerial photographs of scale 1:22,000. They are expected to have a vertical accuracy of 1 to 1.5 meters.

Three blocks of 20 km by 20 km were used, one in the north of the country, in a more mountaionous area, one in the centre and one in the south. All correspond to moderately steep hills. Table II summarizes the DEM characteristics. Figure 5 shows grey scale representations of the DEMs.

Table II – Characteristics of the photogrammetric DEMs: minimum, maximum, mean and standard deviation of heights in meters and mean slope in percentage.

DEM	Hmin	Hmax	Mean	St. Dev.	Mean Slope
Zone1	44.0	1377.4	812.9	288.6	27%
Zone2	14.8	464.3	171.3	86.4	17%
Zone3	13.7	301.0	161.4	59.8	14%

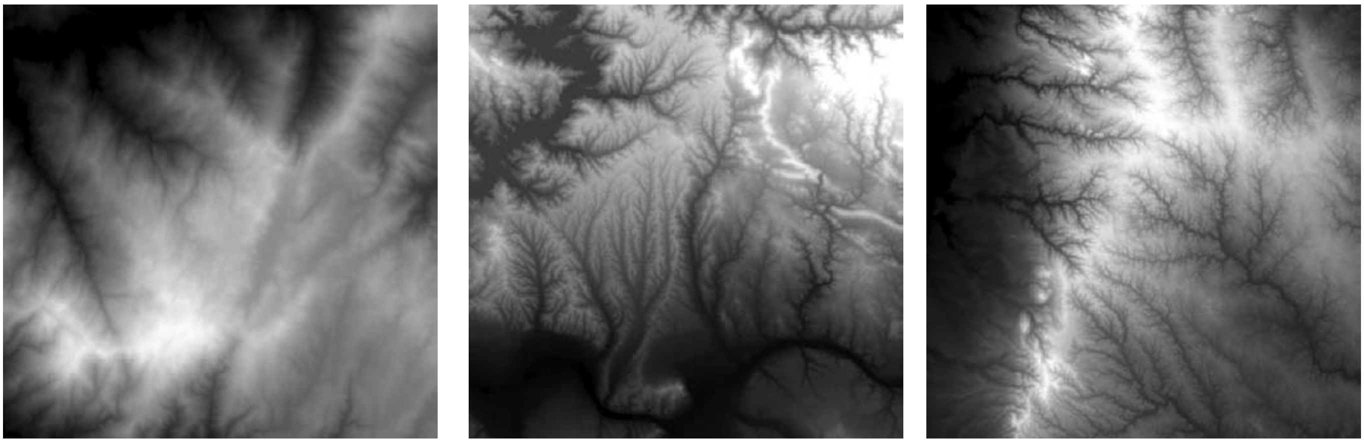


Figure 5 – Grey scale representation of the topographic map DEMs

Once the DEMs were projected from the local map projection (Standard portuguese Transverse Mercator projection) and local datum (Datum 73) to WGS84, using accurate parameters provided by IGP, they were subtracted to SRTM DEM (MAP minus SRTM). Table III contains the statistics of the differences. Only the valid points were considered and no interpolation was done to fill voids (a few pixels due to a reservoir, in zone 2). Figure 6 shows the histogram of the differences for zone 1.

Table III – Statistics of the difference between map and SRTM DEMs (values in metres)

DEM	Hmin	Hmax	Mean	St. Dev.	RMSE
Zone1	-34	24	-0.6	3.9	4.0
Zone2	-30	30	-3.8	5.0	6.3
Zone3	-22	17	-2.2	3.5	4.1

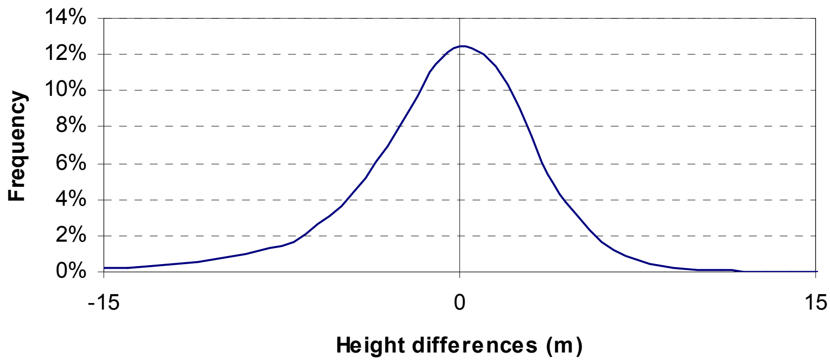


Figure 6 – Histogram of the difference MAP-SRTM

All the three zones show a negative mean (SRTM higher than MAP). This fact may be explained by systematic differences due to vegetation. Figure 7 represents the difference for Zone 1, which is a mountainous area with low vegetation, except for some woods along streams. In the shaded relief image it is possible to identify the streams,which coincide with the red areas of the difference image. Trees are concentrated in these areas.

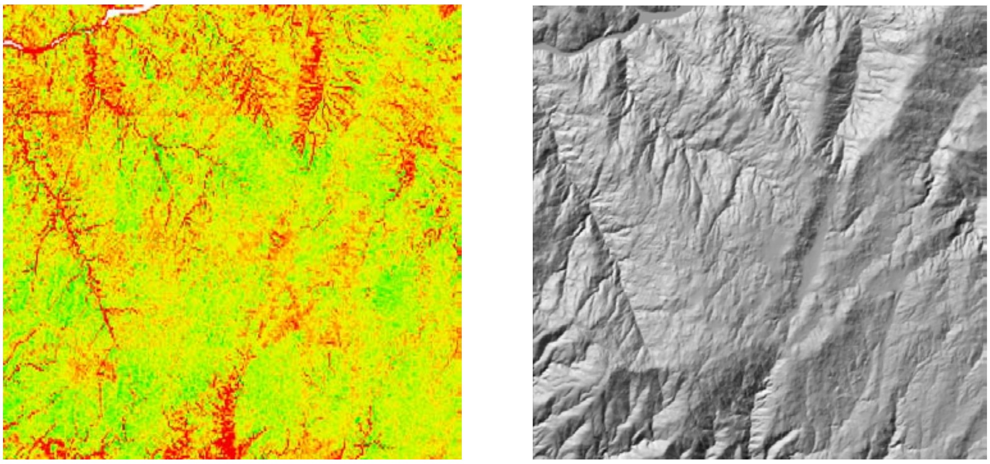
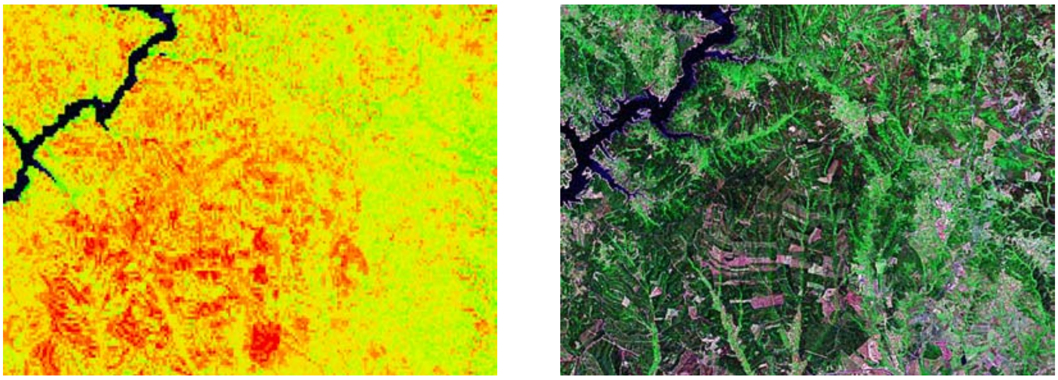


Figure 7 – (a) DEM differences for zone 1 (red for negative); (b) shaded relief of zone 1.

Figure 8 (a) represents the DEM difference for zone 2. Red areas aproximately coincide with dense eucalyptus plantations, which exist in the area and can be identified in the Landsat ETM image (b).



(a) (b)

Figure 8 – (a) DEM differences for zone 1 (red for negative); (b) shaded relief of zone 1.

SRTM DEMs are actually DSMs since they represent the surface of tree tops in dense forests. This fact should be taken into account: although globally mean square errors are in general small (e.g. 4 or 5 m) local systematic errors occur in forested areas.

Some other aspects should also be analyzed, such as spikes, for example. It is frequent to find tiles with a minimum height well below sea level in areas that are known to be above sea level. Such cases occur for example in water surfaces due to errors in the interferometric processing. In the data analyzed these cases were rare. They can be detected by searching for isolated pixels with very large slopes.

4 CONCLUSIONS

The completeness of the SRTM DEMs is, in general very good, especially for areas without large slopes. Globally the main mountains, but also desert sands, show the largest gaps not over water.

For Iberia a total amount of only 0.07% void pixels not in water were found. Considering a country like Portugal, without so steep mountains, the completeness of the DEMs is excellent (.

Gaps over water surfaces can be filled by simple interpolation procedures. Since global coverages of satellite imagery are now available, with a very good planimetric registration to SRTM, it is possible to identify water surfaces in a simple manual procedure.

The vertical accuracy of the SRTM DEMs was assessed with very accurate DEMs derived from photogrammetric restitution. Root mean square errors were found to be between 4 and 6 meters. These figures agree with what is comonly referred. Larger values are obtained if dense forest is present. Anyway SRTM provides excelent relief data, both for topographic mapping in remote areas and to overcome the expensive datasets derived from topographic mapping.

5 REFERENCES

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