

USE OF THE SRTM DEM AS A GEO-REFERENCING TOOL BY ELEVATION MATCHING

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Commission II, WG II/7

KEY WORDS: DEM, Co-registration, Digital Photogrammetry, Matching, Topographic Mapping

ABSTRACT:

This paper presents a methodology for planimetric adjustment of elevation data to the SRTM Digital Elevation Model (SRTM-DEM), by correlation. It can be applied to geo-reference any geographic dataset with an elevation component, such as rasterised maps with contours or DEMs. The accuracy around 5 meters was achieved by this geo-referencing method assessed using elevation data from Portugal derived by photogrammetric techniques. The method was then used to geo-reference old topographic maps of former Portuguese colonies, which were in local geodetic datums not well related to WGS-84. The consistency of planimetric datum shifts determined was consistent with the scales of the maps analysed. The method allowed for the use of these old maps without any extra field work.

1. INTRODUCTION

Ground control points (GCP) are frequently required to geo-reference geographic datasets. In many situations field surveys must be carried out, even when a high positional accuracy is not required. In remote areas the acquisition of GCPs may be very expensive or very difficult to carry out, with a consequent increasing of costs. Archived satellite and aerial photography data sets can be an important source of ground control points for users that need them for geo-referencing purposes.

This article describes a geo-referencing method with applications on geographic information, more specifically on images with an altimetric component. This application is important for cartography on local datum with an unknown relation to the global system, such as the case of most historical cartography of ex-Portuguese colonies, namely islands. The transformation from the local datum usually involves information acquired through field work.

Global datasets of georeferenced imagery can constitute an adequate source to provide the necessary information to the above mentioned applications. Presently a global coverage of Landsat ETM+ images named "Global Land Coverage Facility (GLCF) is freely accessible to the public. These are colour images with 15 meters spatial resolution, resulting from data fusion between the panchromatic and three multispectral bands. They are rectified to the UTM WGS84 coordinate system, with a root mean square error (RMSE) of 40 meters (GLCF, 2004). Existing archives of images with different resolutions do not provide a higher georeferencing precision when compared with the one provided by sensor navigation equipment. This is the case of high resolution sensors such as Ikonos and Quickbird, with a spatial accuracy of 10 meters for Ikonos and slightly worse for Quickbird. In spite of their commercial characteristic, many Quickbird images are currently available through Google Earth, with easy point identification and coordinate values. However, there is not a global coverage and the spatial

accuracy is about 20meters decreasing with high relief areas. In both cases (Google Earth and GLCF) the spatial uncertainty will always be around dozens of meters.

The alternative presented in this paper uses another dataset, also derived from remote sensing techniques, with an almost total global coverage: the Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM). This mission took place during eleven days in February 2000 and provided an almost global altimetric dataset between 56° and 60.25°N latitudes. One arc second grids were automatically produced through interferometric processing of the acquired SAR images. This resolution was only provided to the USA and made freely available with a 3 arc seconds resolution (93 meters at the Equator), as a generalisation by pixel average (Rodriguez, *et al*, 2006). They consist of 1 by 1 degree files, georeferenced to the WGS84, with heights above sea level as 16 bits integers.

These digital elevation models present some void pixels at mountainous zones, mainly due to the layover and shadow effects, common on SAR images causing difficulties on the phase unwrapping (Eineder, 2005). In extreme cases this can be a limitation to the described method; however this does not occur in most situations. Figure 1 shows two examples of extracted STRM-DEMs: Faial Island in Azores and Santo Antão Island in Cape Verde. In this case there are a relatively large number of void pixels represented in black.

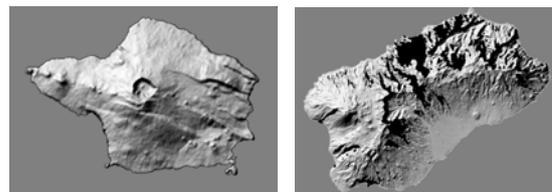


Figure 1. Examples of SRTM-DEMs

The expected precision for the SRTM DEM was 16 meters (90°) in height and 10 meters in planimetry (Rabus, et al, 2003). These expectations were exceeded especially on the vertical component, with many studies referring 5 meters RMSE (8 meters at 90%) or better (Smith and Sandwell, 2003, Jacobsen, 2005, Gonçalves and Fernandes, 2005).

This paper presents an analysis of the planimetric precision of the SRTM DEM with 3 arc second. This analysis is based on a correlation technique between two altimetric datasets: the SRTM DEM and a more detailed DEM resulting from medium scale cartography. Once the SRTM DEM precision is evaluated the same methodology is used to georeference the other altimetric dataset using an approximate georeferenciation and the SRTM DEM. This method will be described in detail and it is applicable to georeference products with an altimetric component. It was applied to georeference into WGS84, using existing contours from maps of several ex-portuguese Islands, where no information of the transformation parameters between the local datum and global datum was available.

2. PLANIMETRIC ADJUSTMENT OF A SET OF 3D POINTS TO THE SRTM-DEM

2.1 Method description

The approach followed in this work is based on the correlation between a height dataset, normally covering a region of a few square kilometres, and the SRTM-DEM. Both datasets are not spatially correctly registered, due for example to a datum difference. Since both are in geographic coordinates it is expected that a shift would be enough to make them coincide. The method is based on the search of that shift that provides a maximum correlation between the two models. Other parameters, such as rotation and scale, will not be considered but could also be computed in a similar way.

Consider A as the set of N points, $\{(\lambda_i, \phi_i, H_i)\}_{i=1, \dots, n}$, (geographic coordinates and height), to be shifted in order to be adjusted to the SRTM-DEM as the reference model. The correlation coefficient is given by (Scheck, 1999):

$$\rho = \frac{\sum_i (z_i - \bar{z}) \cdot (z'_i - \bar{z}')}{\sqrt{\sum_i (z_i - \bar{z})^2} \cdot \sqrt{\sum_i (z'_i - \bar{z}')^2}} \quad (1)$$

Where \bar{z} is the Z_i ($i=1, \dots, N$). values average, Z'_i is he height given by the SRTM model at the (λ_i, ϕ_i) position, using a bi-linear interpolation and \bar{z}' is the average of those values. A value close to 1 represents a good correlation between the two datasets.

As a start the correlation factor between the two datasets can be computed. A short longitude and latitude shift ($\Delta\lambda$, $\Delta\phi$) will be applied to the coordinate points of A. This procedure is performed for a group of shifts, on a grid with a single step. Extreme values of possible variation in longitude and latitude as well as the step for those variations are selected. Using a language similar to Basic, the algorithm can be described as follows:

```
FOR dlon=dlon_min TO dlon_max STEP lon_step
FOR dlat=dlat_min TO dlat_max STEP lat_step
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FOR i=1 TO N
lon_shift = lon(i)+dlon
lat_shift = lat(i)+dlat
Z2(i) = MDT2(lon_shift,lat_shift)
NEXT i
CORR = CALC_CORREL (Z1,Z2)
If(CORR > CORR_MAX) CORR_MAX = CORR
NEXT lat
NEXT lon
```

The computation of the maximum correlation value and the shift that originated that value would be determined. The search can be refined defining a new narrower interval and a smaller step. If the correlation function is regular and only a single maximum is found in the area, the process will converge to the required value.

Figure 2 presents the isolines expressing the correlation function between the group of points and the SRTM DEM, of a specific case study. The longitude ($\Delta\lambda$) and latitude ($\Delta\phi$) variations are expressed in seconds.

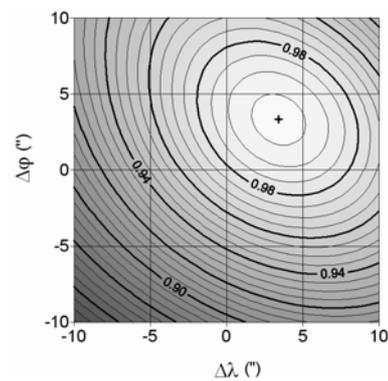


Figure 2. Graphic representation of the correlation coefficient as a function of the shifts applied to a data test (10Km² area)

In this example a distinct maximum value can be observed with a value very close to 1 (more precisely 0.997) for a 3.4'' longitude and 3.3'' latitude (after iteration). The method does not work on flat terrain, but in a general way the tests that will be described provided considerably good results, even in areas with relatively low relief. In the majority of the cases, for areas between 10 Km² and 20 Km², a very well defined correlation maximum was achieved. For a good performance of the matching process the points should be on areas with some height difference, on slopes with different orientation.

In cases with vegetation, a correlation lower than normal is expected, since the SRTM-DEM presents the vegetation height in cases of dense vegetation instead of the terrain representation as the DEM derived from cartographic information. However that does not prevent the method from working. Once the correlation is determined the higher difference between the heights of the two DEMs can be computed. In case this difference is significantly different from zero, that value will indicate a systematic discrepancy due to the vegetation.

The method is applied to small areas, where slight differences of datum would result on an almost systematic shift. For large regions, local variations will be expected. In particular cases when the cartographic projection is unknown, the method can be applied with the SRTM-DEM on a standard position, for

example UTM and admit parameters to model the transformation between the two DEMs (for example rotation besides translation).

2.2 Precision evaluation of the method using data from Portuguese cartography

This technique was evaluated applying it to highly accurate cartography of Portugal, with a very well known georeference system. Six different areas (5 Km by 5 Km) were selected (Figure 3) and the respective contour lines were extracted from 1:10 000 digital cartography, obtained according to norms of the Geographic Portuguese Institute, with a 2 meters precision in planimetry and altimetry (IGP, 2007).

This information uses the national Gauss projection and the local geodetic datum (Datum 73), with precise known relation to the WGS-84 (better than 0.5 meters).

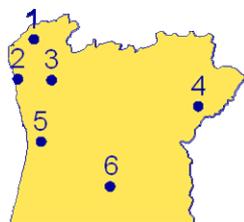


Figure 3. Test areas location considered for the analysis of the method

In each area the vertexes of the contour polylines were extracted. Each group of points was transformed from map into geographic coordinates (in the local geodetic datum) and the algorithm was developed in order to determine the shift to be performed to adjust each group to the SRTM-DEM. The difference between Datum 73 and WGS84 is determined, using a 7 parameters transformation, allowing a precision higher than 0.5 meters. (IGP, 2005). Table 1 presents the results obtained, for the 6 locations: the shift found through the adjustment (in arc seconds) and the error, i.e, the difference to the shift predicted by the datum transformation. This error was converted to meters, taking into account the 1 arc second dimension at each area. The table also presents the height range of the areas.

Loc. #	Height range	Shifts found		Errors	
		λ (")	ϕ (")	λ (m)	ϕ (m)
1	429	3.48	3.10	-6.2	-0.3
2	273	3.58	3.19	-9.6	-2.9
3	426	3.28	3.11	-0.8	-1.1
4	203	3.60	3.28	-1.2	-6.4
5	223	3.44	3.27	-5.3	-5.9
6	322	3.26	3.02	0.8	-0.5
RMSE				5.2	3.8

Table 1. Results found in the assessment of the method using local digitised elevation data.

In all cases the differences between predicted and computed shifts did not exceed 10 meters, with RMSE of 5.2 and 3.8 meters in longitude and latitude. This fact shows the non-existence of significant systematic errors on the SRTM and supports the applicability of this technique to georeference terrain models associated with medium scales such as 1:25000.

2.3 Method evaluation using USA cartography available through the Internet

In order to validate the method using data from different locations and sources, some altimetric data samples were obtained from web sites of cartographic producers. These samples consist of contour lines files (5Km by 5 Km) of sixty six locations from Texas (1:24 000 scale cartography – USGS). Figure 4 shows the location of the test areas.

The method was applied to the points extracted from the contours and the respective shifts were computed. These data are on NAD83 Datum, very similar to the WGS84, therefore the expected shifts were almost zero. In four cases the correlation obtained was relatively low, (below 0.9). These regions had height ranges lower than 50 meters. A statistical analysis was applied to the other sixty two areas and separately to the cases where the height range is higher than 100 meters. The results are presented in Table 2.

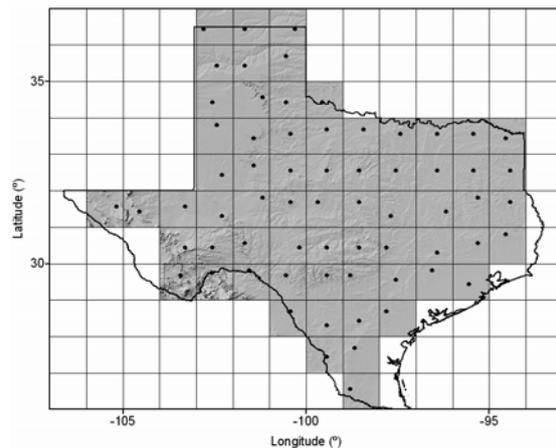


Figure 4. Location of the sixty six areas to test the adjustment to the SRTM model

The results showed a 5 meters precision, similarly to the previously presented in section 2.2.

	Errors in 62 cases ($\Delta h > 50$ m)		Errors in 37 cases ($\Delta h > 100$ m)	
	λ (m)	ϕ (m)	λ (m)	ϕ (m)
	Mean	0.2	3.0	1.1
Std. dev.	5.1	6.8	3.9	4.8
RMSE	5.1	7.4	4.0	5.7

Table 2. Results found in the assessment of the method using digitised elevation data from the US.

3. APPLICATION IN THE GEOREFERENCIATION OF OLD MAPS

An interesting application of this method consists of the possibility to georeference to a global coordinate system the digitised topographic maps. In case of old cartography there is usually no knowledge of the parameters relating the geodetic map datum to the global datum. In actual projects of geographic information analysis, such as change detection studies, old cartography can be useful and in many cases the old cartography is still the only one available.

In this paper Cape Verde, S. Tomé and Príncipe and East Timor cartography produced during the 60's and 70's, while these countries were still Portuguese colonies, will be used as study cases.

In case of the Archipelagos diverse geodetic datums exist, almost one for each island. This is justified by the lack of enough visibility between the islands to allow the connection between the geodetic networks. In some cases some work was developed to find the parameters to convert between datums, however that information is usually not included in the lists of coordinate systems of geographic information processing software.

Considering small islands it was assumed that the transformation between the local datum and the WGS84 system would consist of a constant shift between geographic coordinates. It is important to mention that making use of a map at a certain scale the computed datum shifts will not have a precision higher than the related with that scale.

3.1 São Tomé and Príncipe case study

The S. Tomé and Príncipe cartography was produced during the 60's by Junta de Investigação do Ultramar, named nowadays Instituto de Investigação Científica Tropical. This cartography was produced on the Mercator projection system at the 1:25 000 scale, based on a local datum. Actually both islands present different geodetic datums, besides different projections with different parameters.

Contour lines were digitised on steep areas with different orientation. The required rigour is not high since assuring that the vertexes of the digitised contours – the points which will be used – are positioned on the contour lines. The workload is relatively low, much less than the manual digitisation of the whole altimetry.

Contour lines of four different locations were digitised, covering a 5 Km by 5 Km, one on each map. After the vertexes of the digitised contours were extracted and the conversion into geographic coordinates was performed the adjustment to the SRTM-DEM was then performed for the four locations. The values found for the shift which maximise the correlation, as well as the correlation value and the height shift which minimises the quadratic average of the height differences, are shown in Table 3.

Location	$\Delta\lambda$ (")	$\Delta\phi$ (")	Corr Max	ΔH
1	-20.2	-2.0	0.9971	11
2	-20.4	-3.1	0.9800	18
3	-20.5	-2.9	0.9958	19

4	-20.6	-2.7	0.9900	21
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Table 3. Datum shifts found for maps of S. Tomé island

The computed shifts have an average value of $\Delta\lambda = -20.42''$, $\Delta\phi = -2.65''$ and standard deviation, converted into meters of $\sigma_\lambda = 5.9$ m and $\sigma_\phi = 14.7$ m. The relatively high value for the standard deviation in latitude can be explained by various reasons. The dense island vegetation, the high number of void pixels on the SRTM DEM (particularly on the S. Tomé Island) or the quality of the cartography itself can explain such differences. However taking into account the situation they can still be adequate for the original map scale (1:25 000). It should be mentioned the relatively high values found for the shift in height. The positive values show a systematic shift due to vegetation, since the height values given by the SRTM DEM correspond to the top of the dense vegetation and the map heights correspond to the terrain.

3.2 Cape Verde case study

The maps were acquired for a research project on biogeography by the Portuguese Biodiversity Research Centre (CIBIO) in collaboration with the authors. The maps at 1:25 000 scale were digitised and georeferenced using the map grid points. That grid is based on the UTM projection, Hayford ellipsoid, zone 27 in the case of the four first islands, on zone 26 in the case of the other six.

As in the S. Tomé study case, contour lines were digitised on selected limited areas. Figure 5 presents the Fogo Island digitised contours.

The SRTM-DEM adjustment was then performed using the altimetric datasets for each island in order to compute the respective shifts. These values are presented on Table 4.

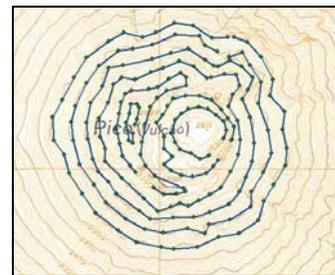


Figure 5. Fogo Island digitised contours

Island	Datum name	$\Delta\lambda$ (")	$\Delta\phi$ (")
Boavista	Curral	15.2	-3.7
Maio	Monte Vermelho	33.1	9.1
Sal	Monte Vermelho	11.6	-1.0
Santiago	Boa Entrada	35.2	7.7
Brava	Monte Fontainhas	33.1	10.3
Fogo	Ponto Alto do Sul	33.6	9.6
Sto. Antão	Gudo Cavaleiro	17.8	-11.0
Sta. Luzia	Gudo Cavaleiro	17.5	-11.1
São Nicolau	Monte Bissau	15.3	12.7
São Vicente	Base NW	16.5	-10.6

Table 4. Datum shifts found for maps of 10 islands of Cape Verde archipelago.

These shifts could be applied to each map georeferenced on the local system, turning them into the WGS84 system. There were no available data to evaluate the results besides the Landsat ETM+ (from the GLCF datasets). The coincidence of the maps with the satellite imagery is generally good and according to the positional precision of those images (around 40m as previously mentioned).

3.3 East Timor case study

Three East Timor 1:50 000 maps (1/4 degree), produced in the 60's on UTM projection (zone 51. south) were provided by Instituto de Investigação Científica Tropical. Since the three maps (Dili, Maubisse and Ermera) are adjacent, similar differences from local datum to WGS84 are expected. Those maps were digitised and georeferenced using grid points and, as the previous cases, some points on the contour lines were vectorized. For a total of six areas, two from each map, the results obtained during the adjustment are shown in Table 5.

Map sheet	Location	$\Delta\lambda$ (")	$\Delta\phi$ (")
Ermera	1	-5.5	28.1
	2	-4.5	28.1
Maubisse	1	-5.5	28.2
	2	-5.3	27.4
Dili	1	-5.5	26.9
	2	-5.1	26.9
Mean		-5.2	27.6
Std. Dev.		0.4	0.6

Table 5. Datum shifts found for 3 maps of East Timor.

The computed standard deviations (equivalent to about 12 and 18 meters) confirms the possibility to georeference these maps into WGS84 with a precision adequate to their scale.

4. CONCLUSION

The method to adjust the altimetric data indicated a 5 meters planimetric precision for the SRTM models. Taking the SRTM DEM as reference this technique provides an adjustment of other data with a 5 meters precision, which means 1/20 of the SRTM resolution. This allowed the georeferenciation of old cartography into WGS84 without any field work, with various types of geodetic data, maintaining a rigour generally accepted for the map scale. The work involved on contour lines

digitisation is relatively small, making this technique simple but effective to use.

The method has a potential to be applied in other situations, namely in the orientation of optical satellite images with stereo capabilities. A relative DEM can be extracted and then correctly georeferenced to WGS84, without the intervention of ground control.

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ACKNOWLEDGEMENTS

To Instituto de Investigação Científica Tropical and Centro de Investigação em Biodiversidade for providing the cartography used by this study.

To Instituto Geográfico Português for the altimetric information. SRTM provided by NASA/NGA/USGS.

