Quality checking of DEM derived from satellite data (SPOT and SRTM)

Simon Kay, Peter Spruyt, Rafał Zielinski

Joint Research Centre of the European Commission, Ispra, Italy

Peter Winkler, Szabolcs Mihály, Gyula Ivan

Institute of Geodesy, Cartography and Remote Sensing – FÖMI. Budapest, Hungary

Keywords: DEM, elevation, datum transformation, Reference 3D, SRTM

ABSTRACT:

The widespread availability of good quality digital elevation data opens the door to systematic and improved automation of orthoimage production, in the context of the Common Agricultural Policy and the checks on aid applications with remote sensing activity. Best practice for production of VHR (<1m pixel imagery) meeting these requirements usually states a quality of 5m RMSE in Z is required.

During 2004, two sources have emerged: the "open source" SRTM C-band (3 arc second, approx. 90m grid size) data, released to the general public via the internet and requiring careful processing, and SPOT Image's commercial Reference 3D® product, which is created using the stereo HRS sensor on the SPOT5 platform. Both data sources have official general specifications somewhat lower than the 5m $RMSE_Z$, but given the usually limited relief in agricultural areas, an investigation into the quality of these dataset was considered an important task.

This paper will report on the test carried out by the FOMI and JRC to determine the suitability of the SPOT Image Reference 3D® product, and the corresponding SRTM 3 arc second data, covering a single production tile (46-47° North / 18°-19° East, approximately 10,000 km^2) in Hungary. The quality assessment methodology was developed at the JRC, and executed using reference data available in Hungary by FÖMI. The data set used for comparison consisted of high resolution (5 m x 5 m pixel size, $RMSE_Z$ 0.7 m) digital elevation model derived from topographic maps at scale 1:10 000 and points of IVth order triangulation network (accuracy in X,Y – 0.05 m, in Z – 0.1 m; approximately 5,000 points). For the transformation between the Hungarian EOV projection system and the international Word Geodetic System (WGS 84, EGM96 geoid) the model elaborated at FÖMI has been used.

The results show that both datasets performed better than their standard specifications, and are suitable for rectification of most VHR imagery in the context of EU Common Agricultural Policy without further processing, besides projection and datum transformations.

1 INTRODUCTION

1.1 *Objective of the study*

The objective of this test was to determine the suitability of the SPOT-Image Reference 3D® and Shuttle Radar Topography Mission (SRTM) products for use in production-process ortho-rectification of satellite imagery. The theoretical geometric accuracy of the InSAR data like SRTM (Balmer, 1997) or of more conventional optical correlation (Buyuksalih, 2004) is already partially documented; that of the Reference 3D product is less well recorded. Many of these tests correspond to specific localised comparisons, and results are difficult to generalise; nevertheless the availability of such data open the door to important, continental scale use in operational applications, if the issue of data quality determination can be addressed.

An example of an application requiring a standard, operational product is the verification of agricultural subsides in the regulatory context of the European Union Common Agricultural Policy (CAP). In this application, very high resolution (1m ground sampling distance or smaller) imagery are used to determine the area and land-cover of agricultural parcels claimed by a farmers for subsidy. For this purpose, a geometric accuracy of better than 2.5m $RMSE_{1D}$ (Root Mean Square Error in one dimension, either X, Y) is necessary, in accordance with the guidelines proposed by European Commission (Kay et al. 2003, Kay 2005). Such accuracy is generally only attainable by orthorectifying with a suitable digital elevation model (DEM). Through the ten years of this operational programme, experience has shown that best practices tend to impose a minimum data quality of 5m $RMSE_Z$ (i.e., vertical linear error) for use with the typical off-nadir collection mode of the imagery used (incidence angles of up to 30°).
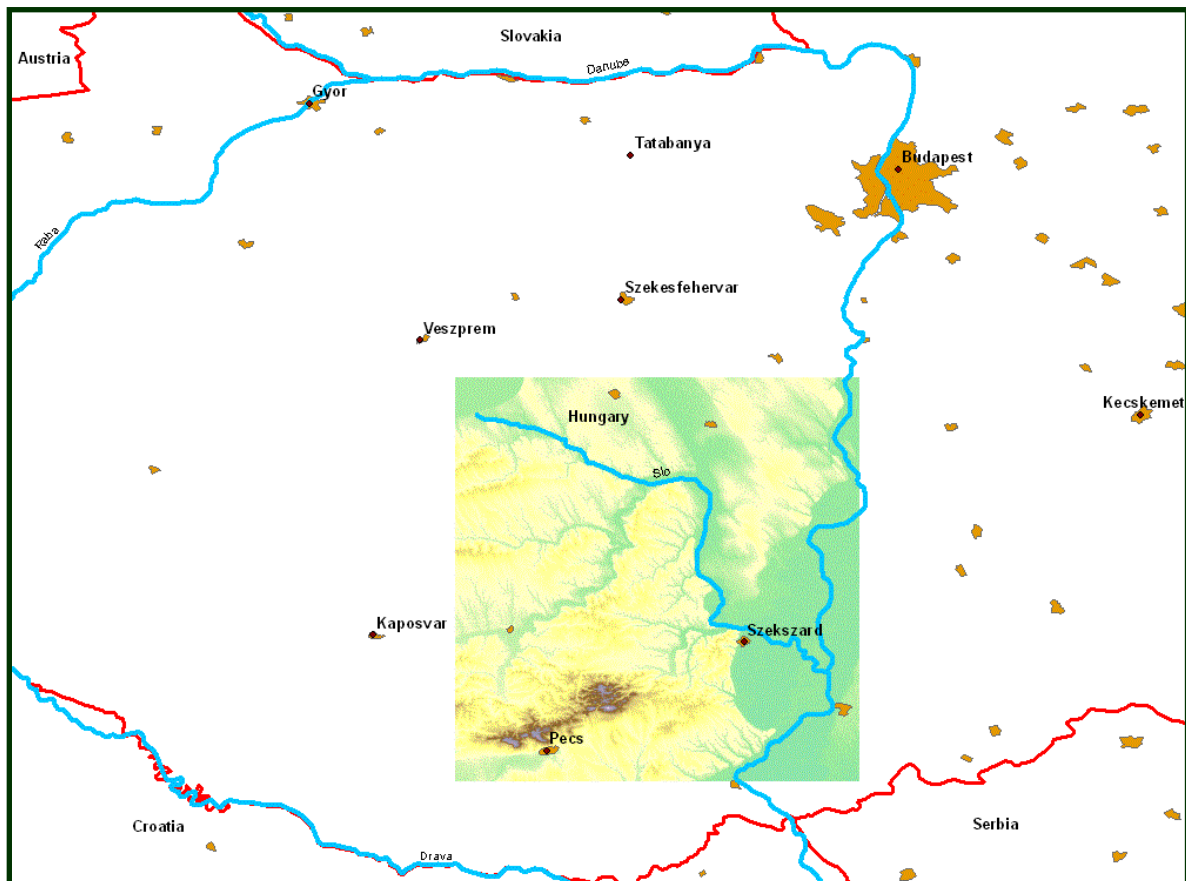

Figure 1: location of the study site. The region chosen represents a typical productive agricultural landscape, with moderate relief.

Chmiel et al. (2004) showed, in an EU-wide assessment of very high resolution image orthorectification on 34 agricultural sites, that a dominant constraint on successful processing was DEM quality; many sites in Europe still do not have readily available suitable data. However, in 2004, two sources emerged as potential solutions:

- the "open source" SRTM C-band (3 arc second spacing, approx. 90m) data, released to the general public via the internet and requiring careful processing,

- and SPOT Image's commercial Reference 3D® product, which is created using the stereo HRS sensor on the SPOT5 platform.

Both data sources have official general specifications somewhat lower than the 5m $RMSE_Z$, but given the usually limited relief in agricultural areas, an investigation into the quality of these dataset was considered an important task.

A collaboration agreement was made between SPOT Image, the JRC and FÖMI to carry out the study, using a large test site in located in an agricultural region in Hungary.

2 DATASETS AND STUDY SITE

2.1 *The Reference 3D product*

The Reference 3D product is a uniform grid of terrain elevation values and is obtained through automatic correlation of SPOT HRS stereo-pairs (SPOT IMAGE, 2005). The tile, subject for this study, was produced within a block of 14 stereo-strips. Bundle block adjustment was performed only using vertical control points (so called 0-level points) of which 16 points where on coastlines in the block (i.e. at great distance from the study site itself). The test site data were delivered with a pixel size of 1 arc second for the DEM (approx 20mx28m for the scene tested); the raster grid was made up of 3601x3601 cells (nearly 13M data values). The Reference 3D accuracy specification statement is quoted at the 90% confidence level, in terms of linear error relative to the EGM 96 geoid, and is 10m for slopes below 20%, 18m for slopes between 20% and 40%, and 30m for slopes above 40%; we interpret that this corresponds to an $RMSE_Z$ of ~ 7m in a typical case.

Two regions in the delivered DEM – a first for which the source imagery where cloud covered, a second of marshland – representing 5.32% of the tile were created using SRTM data (90 m resolution) since the autocorrelation process was unsuccessful (Bernard, *pers. comm.*).

The product also includes information on correlation quality, and an orthoimage derived from the HRS instrument (the source data also for the DEM product). The sample orthoimage product tested was delivered as a geographic tile of 1° by 1° aligned along parallels and meridians, and with a pixel size of 1/6th arc seconds (approx 5m x 3m for the scene under test). The stated geometric accuracy is circular error (i.e., two dimensional linear statement) of 16m at the 90 % confidence level, corresponding again to around $RMSE_{1D}$ of ~7m.

2.2 *SRTM product*

The Shuttle Radar Topography Mission (SRTM) is a joint project between NASA and NGA (National Geospatial-Intelligence Agency) to map the world in three dimensions. SRTM utilised dual Spaceborne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X-SAR) configured as a baseline interferometer, acquiring two images at the same time. These images, when combined, can produce a single 3-D image (Bamler, 1997). Flown aboard the NASA Space Shuttle Endeavour February 11-22, 2000, SRTM successfully collected data over 80% of the Earth's land surface, for most of the area between 60°N and 56°S latitude (USGS, 2005).

SRTM data has been used to generate a digital topographic map of the Earth's land surface with data points spaced every 3 arc second for global coverage of latitude and longitude (approximately 90 meters). The absolute horizontal and vertical accuracy is 20 meters (circular error at 90% confidence) and 16 meters (linear error at 90% confidence), respectively (USGS, 2005).

2.3 *Study site*

The region chosen for the test was located south of the Hungarian capital Budapest, covering typical moderate relief, agriculture and forest land use; the Reference 3D product being delivered as a 1° tile, an area between the 18°E and 19°E meridians and 46°N and 47°N parallels was selected (Figure 1). The area is just less than 13,000 km^2; maximum altitude of the terrain is 678 m, with the hilliest region being north of the city of Pecs. The Danube River flows to the South of the site from Budapest.

3 STUDY METHODOLOGY

The test methodology relied upon the existence of high quality reference data covering the entire site. Through FÖMI, it was possible to access data of an assured level of quality (Winkler, 2004); the reported RMSE$_Z$ value (calculated using more then 55,000 points) of the benchmark digital elevation data used in the comparison is 70cm, i.e. an order of magnitude improvement compared to the specification of either Reference 3D or SRTM data.

The benchmarking depended upon two types of reference data (Winkler, 2004):

- Existing large scale mapping data (ortho-photos, DEM, GCPs) available in Hungary
- The trigonometric points from the 4th order network

3.1 *Land cover stratification*

An analysis of the Corine Landcover CLC 2000 map – produced in line with the Corine Land Cover programme – from FOMI was made to produce three broad land cover categories (Urban, Agriculture, Forest) over the test site (Table 1).

Table 1: Land cover categorisation using CLC 2000 codes

Urban classes		Agricultural classes		Forest classes		Water classes	
CODE	class name	CODE	class name	CODE	class name	CODE	class name
111	Continuous urban fabric	211	Non-irrigated arable land	311	Broad-leaved forest	511	Water courses
112	Discontinuous urban fabric	221	Vineyards	312	Coniferous forest	512	Water bodies
121	Industrial or commercial units	222	Fruit trees and berry plantations	313	Mixed forest		
122	Road and rail network	231	Pastures	324	Transitional woodland/shrub		
124	Airports	242	Complex cultivation patterns				
131	Mineral extraction sites	243	Agriculture with natural vegetation				
132	Dump sites	321	Natural grasslands				
141	Green urban areas						
142	Sport and leisure facilities						
411	Inland marshes						

The three grouped categorisations corresponded to 5% of the test area (Urban), 75% of the test area (Agricultural), and 20% of the test area (Forest). The water class was insignificant; in any case areas corresponding to this class were excluded from the test.

As a further means of stratifying land cover, an elevation slope mask was made from the Reference 3D image. This slope-mask was classed into 4 levels: between 0% and 10%, 10% - 20%, 20% - 40%, and more then 40%, corresponding with the stated performance classification by SPOT Image.

3.2 *Reference 3D HRS Orthoimage quality check*

The orthoimage was tested according to the general guidelines of the JRC (Kay, 2005), namely exterior control using independently acquired check points. The reference data is the MADOP orthorectified imagery with stated geometric accuracy equal to +/- 60 cm in x and y.

The JRC guidelines are intended for batch processing of somewhat smaller (10x10km up to 60x60km) orthoimages. However, they can be adapted to the Reference 3D HRS orthoimage quite easily, and due to the widespread availability of high quality check points (Winkler, 2004), a set of 200 well defined points was identified and used in the test.

3.3 *Methods and procedures for SRTM and Reference 3D performance measurement*

With two datasets in raster format, it at first seems obvious to make a direct comparison by the superimposition of the equivalent samples. However, a number of factors complicate this procedure: different raster cell sizes, vertical datums, projections to name the principle complicating factors. Whilst these issues can all be addressed – through relatively sophisticated GIS processing – the potential loss of information during the re-sampling has to be taken into account. After comparing several approaches below, we propose an approach based upon the conversion of the raster SRTM data into a 'point vector' data, which is then compared with points derived from the reference DEM.

3.3.1 *Absolute accuracy determination on the basis of the GPS check points*

The test raster (SRTM or Reference 3D) data was superimposed with the set of approximately 5,000 check points and the elevation derived from the test raster using bilinear interpolation. On the basis of the differences between the calculated Z-coordinates derived from test data and the check points, the RMSE, standard deviation and mean values are calculated. In addition, analogous analysis was performed on the national DEM raster data (used in the tests below) to ensure homogeneity of results.

3.3.2 *'Raster to raster' method*

The 'raster to raster' (R2R) method directly compares two raster data sets, namely: reference national DEM and the SRTM or Reference 3D raster data by superimposing equivalent raster matrices. Common pixel size, projection system and matrix size (number of rows and columns) are the necessary conditions for comparing two data sets; therefore, at the start, the reference data was reprojected to each test product system, and a nearest neighbour approach used to avoid generating new sample values for the reference dataset. The overlay resulted in values that quantify the difference between the two data sets with height differences calculated for every pixel. For these differences RMS, standard deviation and mean values are calculated.

The main advantage of the R2R method is that the value of every individual pixel is analyzed and the analysis covers the complete test area; nevertheless, the lack of the interpolation during the elevation determination process is a potential weakness of this method.

3.3.3 *'Raster to vector' method*

The second applied method is called 'raster to vector' (R2V). Again, it deals with the superimposition of the SRTM or Reference 3D grid and the reference DEM data. In the preliminary stage, the test raster data has to be converted into an ASCII co-ordinate pairs file to be imported as a vector layer of regularly distributed points (grid vertexes). These vectors are then transformed into the particular national reference system. Then, it is possible to superimpose the two data sets and determine the elevation of every test grid vertex on the base of the reference raster layer. The standard deviation and mean values of the elevation's differences (between the original DEM point and the corresponding vertex) are calculated for the quality control purposes. The major benefit of the R2V method is that the points' density and distribution is the same for every test area; however, it still does not include interpolation during the elevation determination process.

3.3.4 *'Raster to vector' method with bilinear interpolation*

The third method (R2VB) is similar to R2V as it also deals with the comparison of two data sets by superimposition of the test grid and reference DEM, and the determination of every grid vertex elevation from the reference raster. However, the process of the elevation determination now includes a bilinear interpolation algorithm instead of the simple nearest neighbour sampling.

The main advantages of the R2VB method are:

- Fixed point density and distribution for every test area,

- Elevation determination by bilinear interpolation between 4 neighbouring pixels.

4 RESULTS

4.1 *Reference3D*

The Reference3D product has a predictable performance (Table 2, Figure 2 below), working better on terrain that is of lower slope angles and in general following the optical surface of the object under view. This corresponds well with the official specification of the product.

For example, in areas of agricultural land of low slope (<20%) the product performs consistently (3.03m $RMSE_Z$) inside the expected requirements for EU Common Agricultural Policy orthoimage production for checking farmers with VHR satellite data. Even on steeper slopes, the data could be considered – for this land cover category – as generally being of acceptable quality.

For the other two land cover classes, the results are partially satisfactory. Urban classes show more variability ($RMSE_Z$ generally over 5m) but the area checked is marginal in the test site. Forest areas presented a more significant part of the dataset, and the product typically shows a mean value suggesting that the top of tree canopies is the reference point for the Digital Surface Model.

The HRS orthoimage product also performed well inside the stated product accuracy, with a $RMSE_X$ of 2.64m, and $RMSE_Y$ of 5.09m, although the mean values appear slightly shifted with a mean Y value of -4.10m.

4.2 *SRTM*

The SRTM product – like the Reference 3D – has a predictable performance in the site tested, working better on terrain that is of lower slope angles (Table 3, Figure 3). Again, the result corresponds favourably with the official product specification and other reports.

Table 2: Reference 3D Results by land class and slope category

Forest					Arable					Urban			
slope, %	RMSEz (m)	nr. of pixels	%		slope, %	RMSEz (m)	nr. of pixels	%		slope, %	RMSEz (m)	nr. of pixels	%
<10	4.74	1433913	55.9%		<10	2.65	8462994	90.1%		<10	3.22	558595	91.0%
10 - 20	5.23	660224	25.7%		10 - 20	3.03	759905	8.1%		10 - 20	4.81	45642	7.4%
20 - 40	5.98	446315	17.4%		20 - 40	3.57	165457	1.8%		20 - 40	5.78	9268	1.5%
> 40	7.28	24037	0.9%		> 40	4.07	2724	0.0%		> 40	5.72	223	0.0%
	total	2564489				total	9391080				total	613728	

Table 3: SRTM Results by land class and slope category

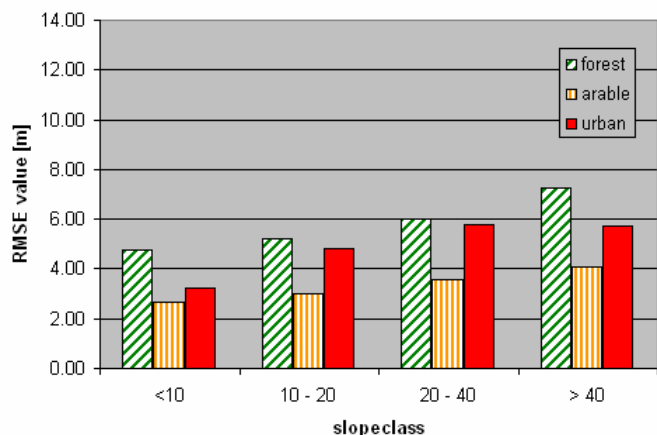| Forest					Arable					Urban			
slope, %	RMSEz (m)	nr. of pixels	%		slope, %	RMSEz (m)	nr. of pixels	%		slope, %	RMSEz (m)	nr. of pixels	%
<10	6.22	159317	55.9%		<10	1.91	940526	90.1%		<10	1.89	62044	91.0%
10 - 20	8.44	73378	25.7%		10 - 20	2.64	84234	8.1%		10 - 20	3.11	5086	7.4%
20 - 40	9.60	49580	17.4%		20 - 40	3.28	18459	1.8%		20 - 40	3.98	1015	1.5%
> 40	12.06	2697	0.9%		> 40	4.08	298	0.0%		> 40	8.28	24	0.0%
		284972					1043517					68169	

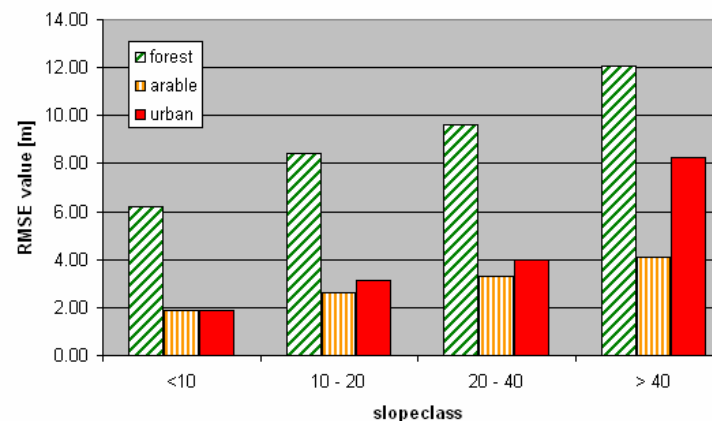
Figure 2: Reference 3D result summary

Figure 3: SRTM result summary

Like Reference 3D, SRTM performs well in areas of agricultural land cover with low slope (<20%). The results −2.64m $RMSE_Z$ – are well inside the requirements for operational orthoimage production, and even marginally better than the Reference 3D tile tested.

For the other two broad classes (urban and forest areas), the results are partially satisfactory. Urban classes show more better results (below 4m RMSE) than for Reference 3D, but Forest areas presented significant decrease in performance, again in line with typical reports of SRTM results, with a $RMSE_Z$ generally under 10m.

5   CONCLUSIONS

The results show that, for the tile tested, both products performed better than their standard specification, with consistent behaviour for the generalised land classes in the site (agricultural land, urban zones, forest areas) and the slope categories. On this basis, it was concluded that both products are useful alternatives or even primary sources for operational programmes, and in particular suitable for rectification of most VHR imagery in the context of the EU programmes without further processing, besides projection/datum transformations.

6   ACKNOWLEDGEMENTS

7   REFERENCES

BUYUKSALIH, G., ORUC, M., TOPAN, H., JACOBSEN, K. 2004, Geometric Accuracy Evaluation, DEM Generation and Validation for SPOT-5 Level 1B Stereo Scene, EARSeL Workshop "Remote Sensing for Developing Countries", Cairo, 2004.

CHMIEL, J, KAY, S., SPRUYT, P. 2004, Orthorectification and geometric quality assessment of very high spatial resolution satellite imagery for Common Agricultural Policy purposes, Proceedings of XXth ISPRS Congress, 12-23 July 2004 Istanbul, Turkey, Commission 4, pp 1019-1025.

DUSART J., 2004, Pan-European DEM based on SRTM data, v. 1.0, IES/JRC, Soil & Waste Unit, Internal technical note.

KAY, S. (ed.), 2005, Guidelines for Best Practice and Quality Checking of Ortho Imagery, Issue 2.4 http://agrifish.jrc.it/documents/lpis/2402v2_4.pdf (viewed 20/05/2005)

KAY, S., SPRUYT, P., AND ALEXANDROU, K., 2003, Geometric quality assessment of orthorectified VHR space image data, Photogrammetric Engineering & Remote Sensing, Vol. 69, No. 5, pp. 484-491.

SPOT IMAGE, 2005, Technical Information: HRS instrument on SPOT 5 - http://www.spotimage.fr/html/_167_224_807_.php (Viewed 20/05/2005)

USGS, 2005, Shuttle Radar Topography Mission (SRTM) 3 Arc Second (~90 meter) - Description http://seamless.usgs.gov/website/seamless/products/srtm3arc.asp (viewed 20/05/2005)

WINKLER, P., 2004, The national orthophoto program of Hungary completed under strict quality control, Proceedings of XXth ISPRS Congress, 12-23 July 2004 Istanbul, Turkey, Commission 4, pp 376-381.