COMPARISON OF SPOT, SRTM AND ASTER DEMs

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ABSTRACT:

Digital Elevation Models (DEMs) represent the terrain elevation in discrete form in three-dimensional space. This is the simplest form of 3D-terrain representation and the most common. The accuracy and morphologic details of the height models represent the quality.
With SPOT-5 and ASTER stereo models DEMs have been generated in the Zonguldak test field, located in Turkey at the Black Sea coast. In addition to these, also the height models of the Shuttle Radar Topography Mission (SRTM) from C-band and also from X-band have been analyzed. The SRTM C-band and X-band data have been obtained with single-pass Interferometric Synthetic Aperture Radar (InSAR) technique. SRTM C-band has 3 arcsec and X-band 1 arcsec point spacing with 1 arcsec corresponding to approximately 30m at the equator. The height models from the optical space sensors have been generated with three times the ground sampling distance (GSD) corresponding to 15m for SPOT-5 and 45m for ASTER. As reference a DEM from large scale aerial photos with a spacing of 10m is available.
The height models from image matching as well as from SRTM are digital surface models, showing the visible surface presented by the top of the vegetation and buildings. By this reason and the fact of matching problems in forest areas, the analysis has been made separately for open and forest areas. A standard deviation of the heights based on SPOT for flat terrain of 2.97m for open and 3.66m for forest areas, for SRTM X-band 3.97m for open and 4.49m for forest areas, for SRTM C-band 4.25m for open and 6.14m for forest areas and for ASTER 7.29m for open and 8.08m for forest areas has been achieved. Also the morphologic details of the SPOT height model are better than for the other DEMs; this is dominated by the point spacing.

1. INTRODUCTION

Digital Elevation Models (DEMs) are used in a large variety of engineering disciplines and can be generated by several techniques. They can be generated by ground survey, stereo photogrammetry, laser scanning and InSAR. The height information of the Turkish topographic maps 1:25000 is based on ground survey and stereo photogrammetry, it is not better than the height models to be analyzed, but large scale photogrammetric height models made in 2005 for the municipality of Zonguldak with approximately 1m accuracy could be used.
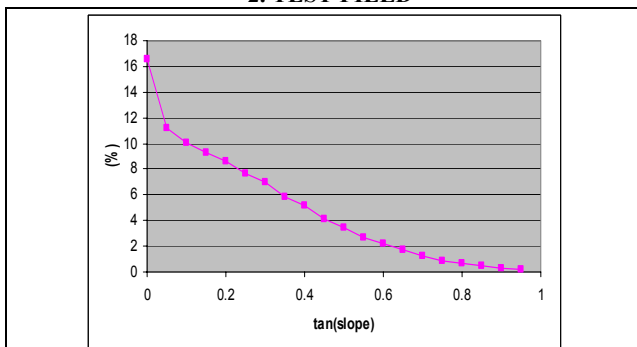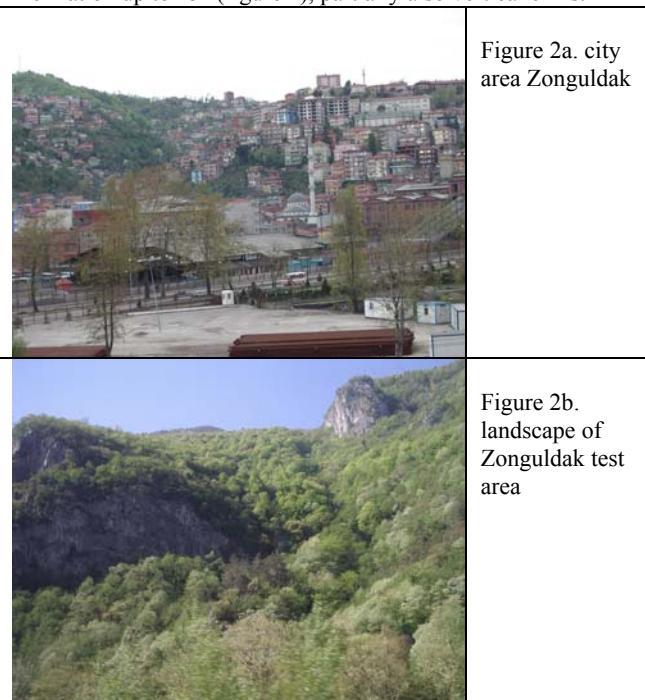
2. TEST FIELD

Figure 1. Frequency distribution of terrain inclination in Zonguldak test area

The test area Zonguldak is located in north-west part of Turkey. It has a very rough and mountainous topography with terrain inclination up to 45° (figure 1), partially also vertical cliffs.

Figure 2a. city area Zonguldak

Figure 2b. landscape of Zonguldak test area

The rough terrain as it can be seen in figure 2 causes problems of image matching, but also lay-over of the SRTM Synthetic Aperture Radar.

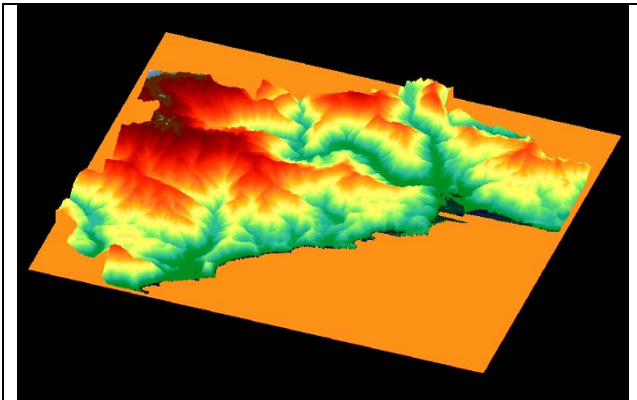
Figure 3. colour coded 3D-view of test field Zonguldak

3. USED DATA SETS

3.1 Reference Data

The reference DEM with 10m grid spacing – named as DEM2005 - has been generated in 2005 based on a photo flight made for the Zonguldak Municipality. Figure 4 shows the DEM2005 as grey value and colour coded representation.
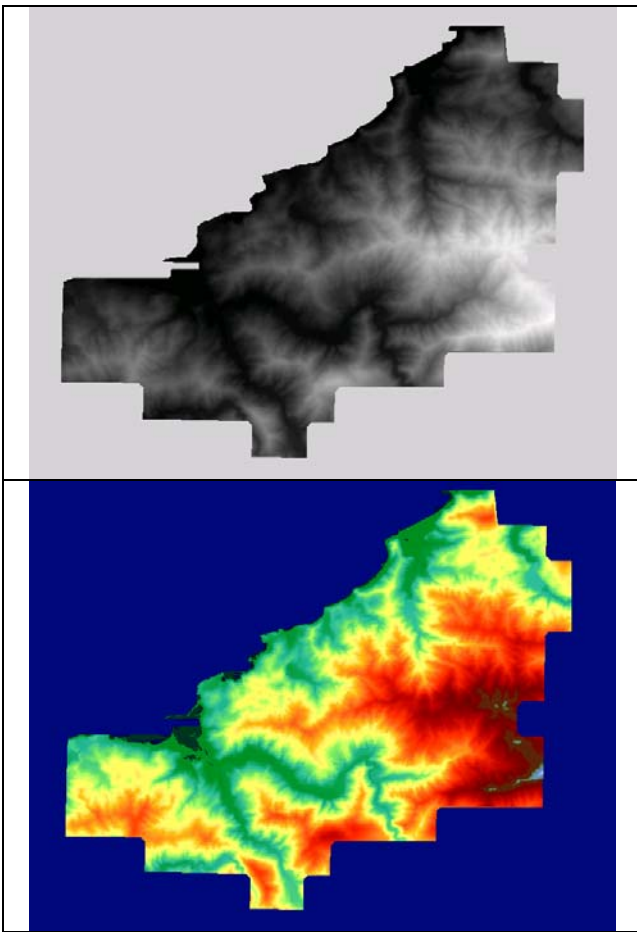

Figure 4. reference DEM – DEM 2005 as grey value and colour coded representation

3.2 DEM based on SPOT-5

The SPOT-5 stereo combination taken at 13th and 14th of August 2003 has 5m GSD. The incidence angles of 13.52° and -16.65° corresponds to a height to base relation of 1.85. For the orientation 44 ground control points (GCPs) are available leading to a standard deviation for X and Y of approximately 1.0GSD. The control points are well distributed over the stereo model. The panchromatic SPOT images have some problems with the grey value variation in forest areas. Figure 5 shows on the left hand side the histogram of the SPOT scene from August 14th with a mean value of 119 and a standard deviation of +/-24.3 grey values. In a typical forest area the standard deviation of the grey values is just +/-6.3. The second scene is very similar. In some homogenous forest areas, especially in shadow parts, the grey value variation even was smaller leading to problems with the image matching. As tolerance level for the image matching a correlation threshold of 0.6 has been used.

Figure 5. histogram of SPOT 5 image Zonguldak
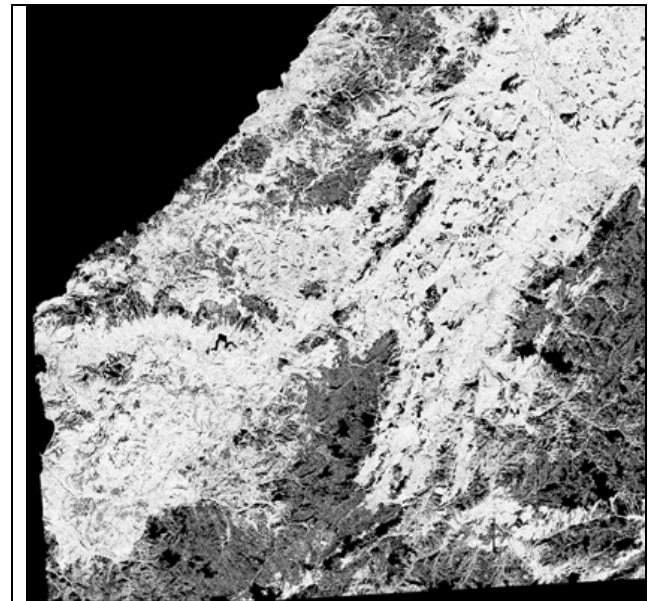left: whole image   right: forest

Figure 6. quality map of SPOT-5 image matching
grey value 51 = correlation coefficient 0.6
grey value 255 (white) = correlation coefficient 1.0

The problems of matching forest areas are obvious in figure 6 – all dark parts, showing areas with lower correlation coefficient, are forest areas.

3.3 ASTER

A cloud free ASTER scene combination is covering 61.5km*63km of the test field. It comprises the nadir and backward views with a height to base relation of 2.1 and has 15m GSD. The stereo combination of ASTER is using the near

infrared band. This has the advantage of a very good grey value distribution also in forest areas (figure 7).

Figure 7. histogram of ASTER infrared band
left: open areas   right forest

Corresponding to the grey value distribution also the completeness of matching with ASTER images (figure 9) is quite better than the matching with the panchromatic spectral range of SPOT. Only water areas and very steep forest in shadow areas have not been accepted. Also the frequency distribution of the correlation coefficients demonstrates the better conditions for ASTER (figure 8).
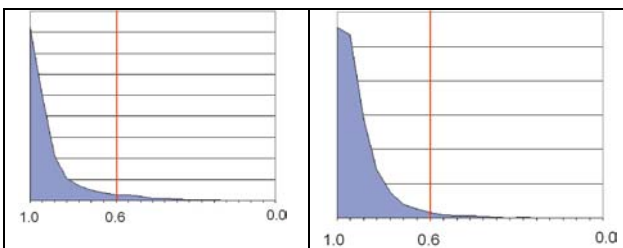

Figure 8. frequency distribution of correlation coefficients
horizontal = size of correlation coefficient
vertical = number of points
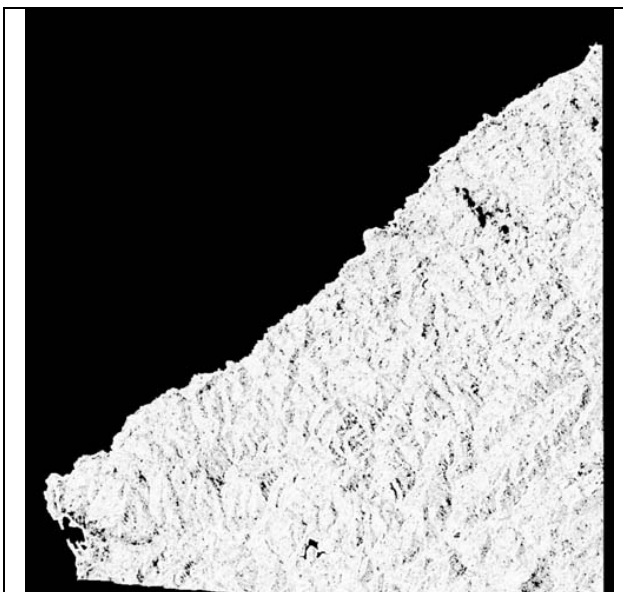left: SPOT-5   right: ASTER

Figure 9. matched points in ASTER scene   white = successful
upper left = Black Sea

The image orientation based on a sufficient number of control points was in the range of 0.8 up to 1.0 GSD standard deviation for X and Y.

3.4 SRTM Height models

The Shuttle Radar Topography Mission (SRTM) used the single-pass Interferometric Synthetic Aperture Radar (InSAR) technique for the determination of a nearly world wide height model. The Space Shuttle carried in 2000 two Radar antenna combinations - one of these located in the Shuttle's cargo bay and the other at the tip of a 60m long mast, both for C-band and X-band. The US C-band used the scan-SAR mode with a swath width of 228 km, while the German-Italian X-band was limited to a swath width of 45km. So the STRM-X-band height model, available with a point spacing of 1 arcsec (~ 30m) has large gaps between the covered areas. But the Zonguldak test field is mainly covered, the city area is even located in an area with crossing coverage from ascending and descending orbit.
Like SAR, also InSAR has problems with lay-over and foreshortening in the partially steep area of Zonguldak. This can be seen in the coherence map, in the case of the SRTM X-band delivered together with the height model as height error map with estimated point accuracy (figure 10).
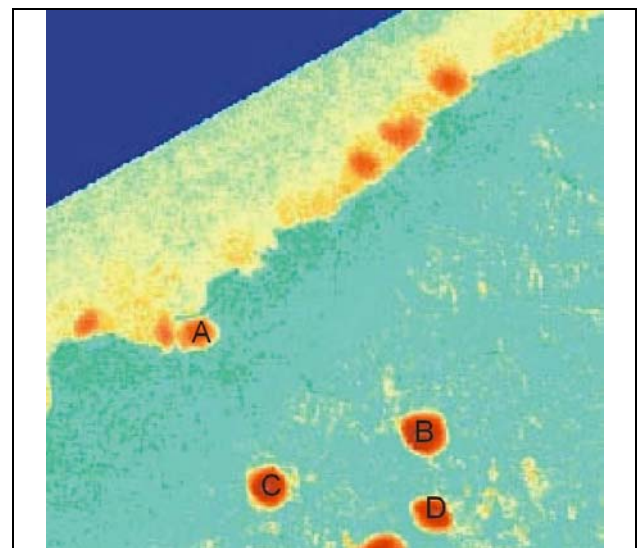

Figure 10. colour coded height error map of SRTM X-band in the area of the reference DEM – A to D show areas with problems caused by large terrain inclination, A = steep build up area

The areas indicated by the X-band height error map are confirmed by larger discrepancies against the reference height model.

4. ACCURACY ANALYSIS

A first comparison of the different data sets indicated horizontal shifts of some height models. This typical problem partially is caused by not precise known datum of the Turkish national coordinate system against the WGS84 / ITRF, but also without this, horizontal shifts between different height models often are present. A shift of the height models to the reference model DEM2005 has been made by adjustment with the Hannover program DEMSHIFT.

	SPOT	ASTER	X-band	C-band
before shift	11.44m	11.84m	6.49m	6.13m
after shift	8.65m	9.31m	6.60m	6.08m
Table 1: root mean square height differences in relation to the reference height model before and after horizontal shift			

The adjustment of the horizontal fit of the height models in relation to the reference height model is improving the result

from SPOT and ASTER, while the SRTM-data are not improved.

The short wavelength Radar as well as the optical data are leading to digital surface models (DSMs) showing the visible surface. Under usual conditions the influence of buildings and isolated vegetation can be removed by filtering. Closed forest areas cannot be improved because at least some information about the ground height must be available. In the Zonguldak test area the terrain is extremely rough. Over a spacing of 40m the change of the terrain inclination is even larger than the inclination itself, by this reason the filtering of the height models for elements not belonging to bare ground was not successful like in other areas (Passini et al 2002).

The root mean square height differences of the different height models against the reference height model are depending upon the terrain inclination as it can be seen in figure 11. By this reason the accuracy has to be described by a constant value plus a constant value multiplied with the tangent of the terrain inclination. This relation is determined by adjustment in the Hannover program DEMANAL.
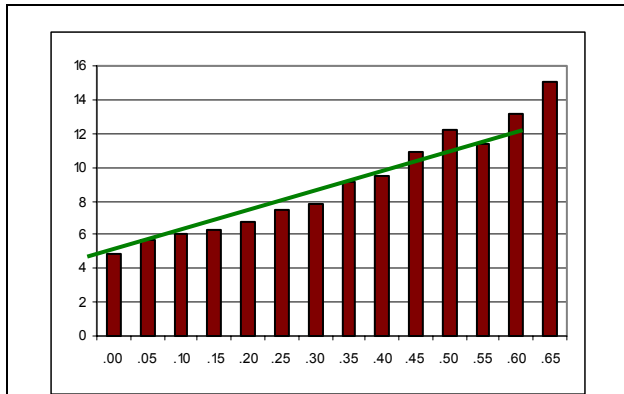

Figure 11. root mean square height differences SRTM X-band DSM against reference DEM for open areas as function of terrain inclination

horizontal axis: tan (terrain inclination)
vertical axis : RMSE [m]

	open area	forest
SPOT-5	$2.97+18.9*\tan\alpha$	$3.66+18.1*\tan\alpha$
ASTER	$7.29+3.4*\tan\alpha$	8.08
SRTM X-band	$3.97+7.3*\tan\alpha$	$4.49+8.4*\tan\alpha$
SRTM C-band	$4.25+6.6*\tan\alpha$	$6.14+1.4*\tan\alpha$

Table 2: root mean square height differences against the reference height model [m] as function of the terrain inclination α

The accuracy of the SPOT-5 and ASTER height models have to be seen in relation to the GSD and the height to base relation leading to the standard deviation of the x-parallax (SZ=h/b * Spx). The standard deviation of the x-parallax in units of the GSD can the compared between quite different optical sensors. For open and flat terrain the standard deviation of the x-parallax of SPOT-5 corresponds to 0.31GSD while it is 0.23GSD for ASTER. The better accuracy for ASTER can be explained by the advantage of the near infrared spectral band used for the stereo combination.

The accuracy of SRTM X-band and C-band is in the same range – for flat parts the X-band height model is a little better like the C-band, but the X-band data are more depending upon the terrain inclination. This can be explained by the coverage of the area more than once by the C-band data. This leads also to a dependency of the X-band data upon the aspects (terrain inclination against north direction), while for C-band no dependency upon the aspects can be seen.

5. MORPHOLOGIC QUALITY

The accuracy of the points available in the height models are only one aspect of the quality of the DEMs, the point spacing is important as well, both leads to the morphologic quality, visible at contour lines.

SPOT-5

15m spacing

ASTER

45m spacing

SRTM X-band

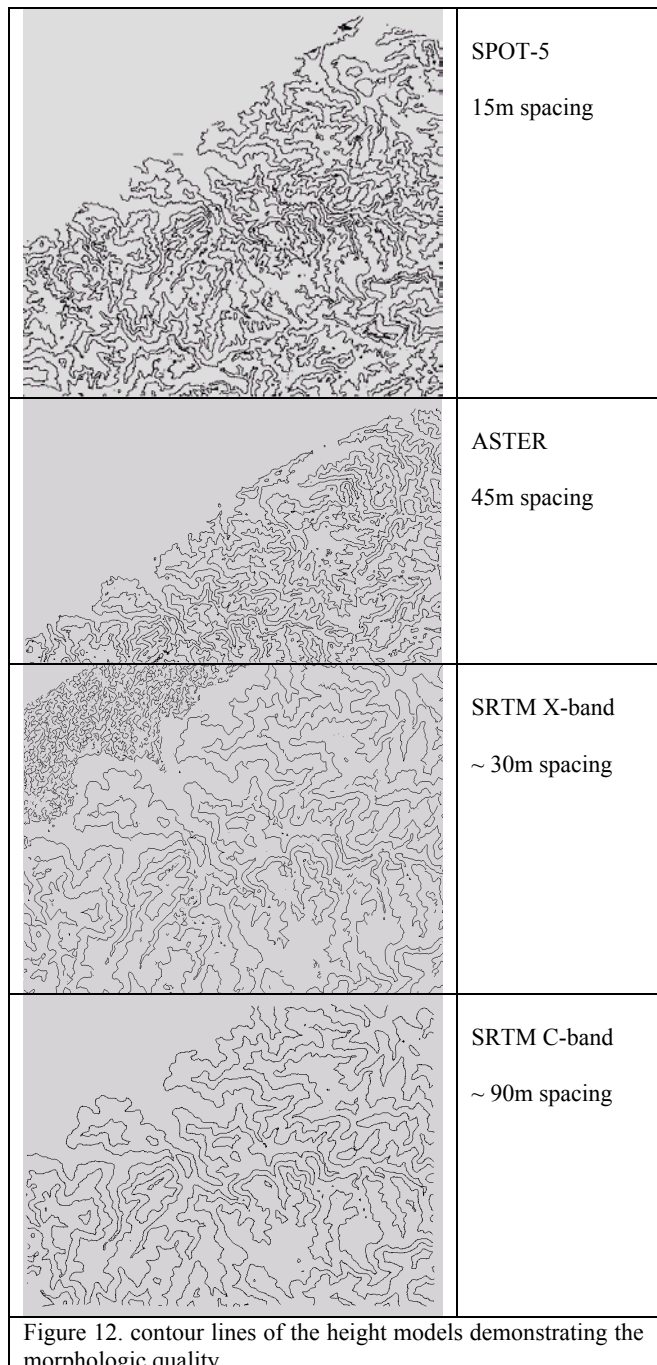~ 30m spacing

SRTM C-band

~ 90m spacing

Figure 12. contour lines of the height models demonstrating the morphologic quality

There is a clear dependency of the contour line details depending upon the point spacing, while in the rough terrain the height accuracy does not have the most important function.

6. CONCLUSION

Digital elevation models can be generated by automatic matching of optical stereo models as well by InSAR. There is only a reason to generate or to buy DEMs if they are better than the free of charge available SRTM C-band height model given with 3 arcsec point spacing (~92m at the equator). This is the case for the SPOT-5 DEM which is more precise and more detailed, while in the ASTER DEM the individual height values are not so precise like for the C-band DEM, but the ASTER DEM can be generated with 45m spacing having some advantages in very rough terrain. The X-band height model has approximately the same accuracy of the height points like the C-band, but the X-band DEM is delivered by the German DLR with 1 arcsec point spacing, showing quite more details like the C-band DEM available in the internet.

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