VALIDATION OF RADARGRAMMETRIC DEM GENERATION FROM RADARSAT IMAGES IN HIGH RELIEF AREAS IN EDREMIT REGION OF TURKEY

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ABSTRACT:

In this paper, we describe the technique for deriving digital elevation models (DEM) from a synthetic aperture radar (SAR) stereo pair and apply it to an image pair over the Golf of Edremit in Western Turkey. The objective of this paper is to evaluate DEMs from RADARSAT fine beam mode images as a function of pixel sampling and also of the terrain relief. In addition, throughout the different processing steps the contribution of various effects into error budget (i.e. ground control point acquisition, stereo-model set, image matching and DEM editing) are taken into account.The study area overlaps four 1:25 000 scale maps, which is about 50 km by 50 km. The elevation ranges from 0 m to 1767 m. The land cover consists mainly of a mixture of urban areas, agricultural lands and clear-cut areas. The agricultural areas mostly lay in the flat areas and partially take place along the slopes up to 60°. In addition to small rivers, a few loose rivers are also found. The roads are at most dual carriageways surrounding the urban areas. Experiments were done with a stereo pair of RADARSAT-1 data. Two fine beam mode scenes with 6.25 m pixel spacing are acquired with a shallow look angle from descending orbits (F1 and F5) to generate a stereo configuration with a small intersection angle of 8°. The images are orbit oriented, and coded in 16 bits without any radiometric processing. The topographic data were obtained from the Turkish General Command of Mapping. The 10 m counter lines were used to create gray-scaled DEMs, which are then transferred into a 10 m grid file. A corner reflector was installed before the flight and used as a GCP.

1. INTRODUCTION

Digital elevation model (DEM) is a digital representation of the Earth's relief that consists an ordered array of elevations relative to a datum, and referenced to geographic coordinate system DEMs are being used increasingly in many applications ranging from GIS based topographic data bases to tower sitting in the telecommunication industry (Hijazi J., 2001). In order to derive 3D ground coordinates, it is necessary to have two or more images of the target that are collected with different projection geometries. Due to its cloud-penetrating capability, synthetic aperture radar (SAR) allows data acquisitions in large parts of the world where imaging with conventional optical systems has previously been problematic and expensive. Moreover, there is a great potential of SAR to generate detailed and accurate terrain data from a type of SAR stereo processing that makes use of the coherent nature of SAR radiation. SAR backscatter is very sensitive to local incidence angle, and the elevation information can be extracted to generate a radargrammetric DEM from two overlapped SAR images using similar techniques as those employed with data in visible spectrum. However, since SAR is an active sensor using coherent illumination to produce an image, the preferred relative collection for SAR stereo are considerably different than for optical images. The relative geometry of stereo images strongly affects geometric accuracies and visual fusion.

Radar's many beam modes offer a variety of stereoscopic configurations of a given location that are very different in terms of geometry and radiometry. This paper describes how, with proper processing techniques, stereo Radarsat-1 data can be precisely processed to produce elevation models. A couple of Fine 1 and Fine 5 Beam mode data, covering 50 square km over a flat and rolling topography is evaluated. Aspects of SAR processing and automated image matching critical to to processing this beam mode are described. The use of GCPs, including a corner reflector is discussed. Accuracy assessment is done comparing final DEMs with a reference DEM generated from digital contour lines of 1/25 000-scaled topographic maps, and resulting DEMs are evaluated in terms of accuracy and suitability for various terrain types.

2. STUDY AREA AND STEREO SAR PROCESSING

2.1 Study Area and Data Sets

The study area overlaps four 1:25 000 scale maps, which is about 50 km by 50 km. The elevation ranges from 0 m to 1767 m. The land cover consists mainly of a mixture of urban areas, agricultural lands and clear-cut areas. The agricultural areas mostly lay in the flat areas and partially take place along the slopes up to 60°. In addition to small rivers, a few loose rivers are also found. The roads are at most dual carriageways surrounding the urban areas.To generate the DEM and DTM a couple of stereo RADARSAT images were gathered on 6th of May 2002 (Figure 1) and 1/25 000 scaled topographic sheets and digital contour lines are obtained from General Command of Mapping. Generating DEM, DTM and creating the height difference and slope maps is done by PCI and Bentley Software. The properties of the images are given in Table 1. A GARMIN 12 branded hand held GPS receiver and ASHTECH Z-Surveyor double frequency GPS receivers are used in field works.

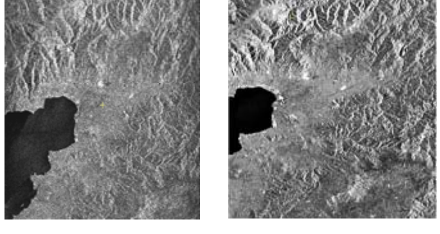


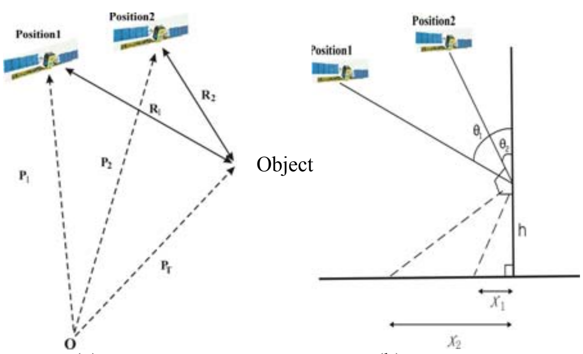
Figure 1. Stereo RADARSAT-1 data gathered in F1 (left) and F5 (right) fine beam modes and descending orbits

IMAGE –1		IMAGE-2	
Scene ID	M0292196	Scene ID	M0282948
Scene Start Time	16.05.2002 04:14:39.372	Scene Start Time	06.05.2002 04:06:20.682
Scene Stop Time	16:06:2002 04:14:47.929	Scene Stop Time	06.05.2002 04:06:30.238
Orbit Path	34080 Descending	Orbit Path	33937 Descending
Beam Mode	SAR Fine 1 Beam	Beam Mode	SAR Fine 5 Beam
Num. of Img.Lines	9083	Num. of Img.Lines	10093
Num. of Img Pixels	7120	Num. of Img Pixels	6028
Pixel Spacing	6.250m.	Pixel Spacing	6.250 m.
Scene Centre	39°33'N 27°01'E	Scene Centre	39°32'N 27°04'E

Table 1. Radarsat–1 Scene description of stereo image pairs

2.2 Principle of DEM Generation from Stereo SAR Images

Radargrametry or stereo SAR technique is derived from the corresponding optical technique called photogrammetry. However SAR images are very different than the optical ones in the way that the data is organized. Also there are some differences between the processing of these two stereo data types. The basis for stereo elevation is depicted in Figure 2(a). In this simplified two dimensional geometrical representation, the height of an object with respect to the reference surface can be deduced from the parallax difference as perceived from two different point of view, provided the slant range distances (satellite to common target) and satellite locations are known. In radar, the important parameters are Doppler Centroid, which gives the look angle (angle from nadir), and the slant range, which is the distance from sensor to target. From these parameters and the orbit model it is possible to derive a three-dimensional position vector of a target point. Using standard geodetic equations, the three-dimensional position vector can be transformed in to map coordinates. The height accuracy depends on spatial resolution and the differences in look angle between the stereo views.



(a) (b)

Figure 2. Same Side Stereo SAR Geometry (Min-Ho Ka and Man-Ja Kim., 2001)

Considering the same side viewing configurations depicted in Figure 2(b), a target with a height of h is viewed at incidence angles "θ_1" and "θ_2" respectively. With simple trigonometric relations, the displacement of the target from its true position when viewed from position 1, caused from the foreshortening effect of radar is given by x_1

$$x_1 = h * \cot\theta_1 \quad (1)$$

Similarly the displacement caused by viewing from position 2 is given by x_2

$$x_2 = h * \cot\theta_2 \quad (2)$$

The difference in the displacement caused by viewing from the positions (i.e. position 1 and 2) shown in Figure 2 can be obtained from the equations as:

$$|x_2 - x_1| = p \quad (3)$$

where p = spatial resolution of the image

This equation can be inverted to find minimum height difference that is measurable from stereo SAR for any given spatial resolution and incidence angle as (Min-Ho Ka and Man-Jo Kim):

$$H = p / (\cot\theta_2 - \cot\theta_1) \quad (4)$$

where H is the minimum height difference

In general, using same side stereo pairs reduce radiometric and geometric disparities. However, side looking SAR satellites are gathering data in slant range which must be converted in to ground range.

2.3 Data Processing

In this research, Ortho Engine module of PCI Geomatics is used to generate DEM from stereo RADARSAT-1 images and DTM from digital contour lines. PCI software employs the geometric modelling method, based on the co-linearity condition method, developed by Toutin (1995) at Canada Centre of Remote Sensing (CCRS). Ground Control Points (GCP) are collected to compute the stereo-model geometry with an iterative least square bundle adjustment process that enables the parameters of the geometric model to be refined in order to obtain a cartographic standard accuracy (Toutin, Th., 1998). Different types of GCPs are used as: full control points with known XYZ coordinates, altimetric points with known Z coordinate and tie points (TP) with unknown cartographic coordinates. Cartographic coordinates of GCPs are obtained from global positioning system (GPS), digital topographic sheets and geocoded image files. The 3D intersection is performed using the previously computed geometric model to convert the pixel coordinates in both images determined in the image matching of the stereo pair to three-dimensional data. Cartographic coordinates (palnimetry and height) in the user defined map projection system are determined for the measured point with a least squares 3D-intersection process based on geometric model equations and parameters. Once the GCPs are collected and the geometric model is computed for each image of the stereo pair, in the next step quasi epipolar curve images are generated. An area based automated image matching technique is used to extract the elevation parallax and DEM through a comparison of the respective grey values on each of these images (Figure 3). Cartographic coordinates in UTM projection system are calculated using ED50 Datum parameters for Turkey, and geometric model is defined. RADARSAT raw stereo images in FINE1 (F1) and FINE5 (F5) beam modes are processed by PCI automatic DEM extraction software. DEMs are processed from the same stereo couple by trying different parameters to investigate the best parameters for F1 and F5 stereo RADARSAT couple. The objective of the verification process is to obtain the most detailed DEM possible for a given stereo pair without introducing too many gross errors. The recommended process is to process several small areas of the stereo pair with different terrain and land cover types such as urban and agricultural costal plains rangeland in foothills and forest mountains, and to establish best overall processing for a given scene.

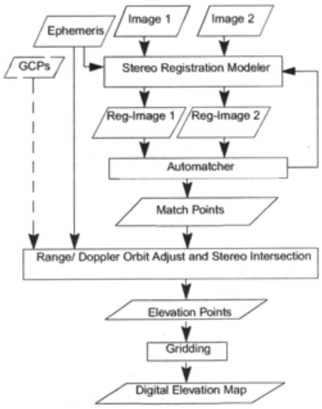


Figure 3. Stereo processing flow diagram (Marra, M., et al., 1998)

A DEM provides the elevation in meters for each pixel in an image. The main digital processing steps for DEM generation are; epipolar image generation, automatic DEM generation, DEM editing and DEM geocoding respectively.

2.3.1 Creating Epipolar Images

The geometry of the two images is given by the satellite models. The models are derived from the GCPs, the ephemeris and the orbital data from the satellite, and knowledge of Earth size and shape. The model derivation is based on the methodology developed by Toutin (PCI, 2001). First the stereo-model geometry is computed with an iterative least square bundle adjustment process. Parameters of the geometric model are refined by collecting GCPs from different sources and TPs. In this research GCPs are collected from 1/25 000 scaled topographical maps. The planimetric accuracy of cartographic coordinates is around 5 m. Due to the fact that the radar images used in this research have 6.25 m pixel resolution, 1/25 000 scaled topographic sheets are in appropriate precision to derive GCPs. Although four to six GCPs are theoretically sufficient to compute the stereo model, to prevent an over-determination in the least square adjustment and to reduce the impact of GCP errors, a larger number (89 GCPs) is acquired from topographic sheets and orthorectified images. Therefore 105 TPs are collected from RADARSAT F1-F5 stereo images both of which are in descending orbits. Additionally, 7 GCPs one of which is a corner reflector are collected by relative GPS positioning. After applying bundle adjustment process on these GCPs, residual errors related to the points are given in Table 2.

According to prior estimation of the stereo model, GCP residual errors are about 6m, and this is acceptable for creating stereo models. Since stereo model set-up and 3D intersection are geometric issues, the number and accuracy of GCPs and viewing and intersection angles of stereo image pairs have an important role on the accuracy of the model.

Elevation can be extracted when the two factors are known: the viewing geometry of the images and X and Y displacements between matching pixels of the two images. Registering the images in an epipolar projection removes Y parallax. With an epipolar image most of the displacement is in X direction and the displacement in Y direction is very small. This significantly speeds up the image matching searches.

Residuals			
	Nub. of Points	X_{RMS} **(m.)**	Y_{RMS} **(m.)**
GCP	89	5.26 (0.82 pixel)	6.19 (1.00 pixel)
TP	105	0.62 (0.19 pixel)	2.45 (0.41 pixel)
Residuals for left image			
GCP	46	4.64 (0.74 pixel)	5.44 (0.87 pixel)
TP	105	0.62 (0.20 pixel)	2.46 (0.42 pixel)
Residuals for right image			
GCP	43	5.90 (0.91 pixel)	6.96 (1.14 pixel)
TP	105	0.62 (0.18 pixel)	2.46 (0.40 pixel)

Table 2. RMS error report for the DEM file

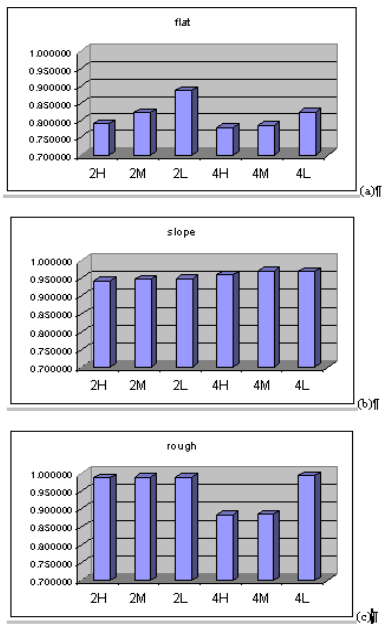
The image matching is finding corresponding pixels in both images relating to the same point on the ground. It is principally a radiometric issue. Most automated matching relies on correlation between two images using different primitives such as points, gradient, semantic lists to produce a disparity map (Greenfield, J.S., 1991). However a normalized area correlation with the computation of maximum correlation coefficient is considered to be one of the most accurate and appropriate methods, and is commonly used with SAR images (Leberl, F., et al, 1994). It is the solution used in this research, which is adapted in PCI Ortho Engine digital image analyst system in addition to a multi scale strategy by Toutin, Th. (1995). The number of steps involved in the multi-scale image pyramid varies from five to eight with a maximum resolution reduction of sixteen. The correlation window size varies from eight reduced pixels at the coarsest resolution to thirty-two pixels at the full resolution. In this research, after several trials the results of matched points extracted every 2 pixels with medium detail and extracted every 4 pixels with high detail are defined successful for the applied topography.

Final DEM file contains three-channel imagery and a segment data. These are two 8 bit images, one 16 bit signed DEM image (elevation in meters), and a segment saving satellite model of the first uncorrected image. The first 8-bit channel contains a compressed copy of the input image, at a reduced resolution if necessary, and the second channel contains score values for the DEM correlation. These two channels are useful during DEM editing to observe failed areas with corresponding image correlation score.

2.3.2 Automatic DEM Generation

3 Dimensional (3D) intersection is performed using previously computed stereo model to convert image coordinates (parallaxes) of the matched points to 3D. Cartographic coordinates in UTM projection system using ED-1950 datum are determined for the measured point with the least squares intersection process based on geometric model equations and parameters (Toutin, Th., 2002). The result is an irregular grid in the map projection system, which is transferred in to a raw regular DEM.

Parameters defining the quality of the resulting them are defined after creating epipolar images. First the minimum and maximum elevations that are in the area covered by the imagery are specified. These values are required to determine search areas and reject invalid out-of range matches. Since the search area includes costal areas, the minimum elevation is specified lower than 0. DEM extracted from RADARSAT F1-F5 fine beam mode images is quite noisy due to the damaging effect of random speckle noise and rough topography that causes radiometric disparities. Because of these disparities a successful matching cannot be done for each pixel. A failure value is defined for pixels where the digital elevation value cannot be extracted. Not to confuse the mismatched pixels and the background pixels, a background value is defined. High, Low and Medium DEM details are tried using different pixel spacing. If the terrain is fairly flat Low detail is defined good whereas Medium detail gives better result for sloppy terrain in this research area. DEM detail determines how precisely you require to represent the terrain in the DEM. Selecting High, Medium or Low details determines at which point the correlation process will be terminated. Low means that the process stops during the coarse correlation phase on aggregated pixels so the level detail in the DEM will be quite low. High means the process is continuous until the correlation is performed on images at full resolution. Pixel sampling controls the size of the pixel in the final DEM relative to the input images. The higher the number is chosen, the larger the DEM pixel will be, and the faster the DEM is processed. On the other hand, terrain relief and land cover type strongly affect the quality of extracted DEM. For example, while the rough terrain increases the changes of dissimilarity between the two images leading to matching failures, smooth and featureless areas, as agricultural fields, contain insufficient texture for the matching algorithms to find corresponding algorithms. Thus, different combinations of these features are tested and the solutions 2L (2 pixel spacing using low detail) and 4M (4 pixel spacing using medium detail) are defined successful for the RADARSAT F1-F5 stereo images used in our research area (Figure 4). Due to the fact that RADARASAT Fine Beam mode raw images have 6.25 m pixel spacing, using 2 and 4 pixel spaces ends up creating 12.5m and 25m DEM resolution respectively.



Figur 4. Image mating results according to chosen DEM detail and pixel spacing for flat, slope and rough areas respectively.

Decreasing the required detail through DEM detail parameters often eliminates most of the problems. However, this usually results in smoothing out finer details of the terrain like small ridges and valleys. Thus it is a trade-off between a smother and less detailed DEM and the DEM failed in most part of the terrain but having finer details.

The accuracy is assessed in terms of the correlation using score channel of created DEM. The software prints scores as fractional numbers between 0.000 and 1.000 as they are the true values of coefficient of correlation between the two windows. The mean scores of correlation coefficient drops down by 0.1 or more between high and low detail levels. This indicates that image and terrain characteristics make matching less successful at this resolution and the preceding level might be the better (PCI, 2001). As a conclusion, in this research it has been experienced that using the detail levels medium and high affect the success of image matching algorithm and contaminate the quality of generated DEM. Thus for flat and moderate terrains (having slopes ranging between 0% and 6%) instead of high or medium detail levels, the low detail level is preferred. Besides, generated DEMs are visually interpreted and for pixel groups not more than 20-30 pixels that elevation cannot be calculated, elevation is interpolated by using hole-filling option of the software.

2.3.3 DEM Editing

In the research area where the extracted DEM is still incorrect due to the nature of image scene including water body (e.g. Edremit Golf) and other featureless areas (some of the agricultural fields that cause image matching errors) is edited manually. The quality of extracted DEM is improved through editing. Editing tools are used to remove blunders to correct the water surface and to interpolate mismatched areas causing incorrect pixel elevations. Interpolation, smoothing, noise removal and mask editing functions are used partially. Filling small gaps up to 20 to 30 pixels is part of editing, and according to the user defined size and options it is done automatically by interpolation during the DEM execution. Since this function is only adequate for small areas, large mismatched areas are edited using other editing tools. Each of editing tools has different functions. For example, noise removal tool is a statistical filter, which attempts to automatically identify “bad” elevation pixels and to remove them. By this tool, elevation values, which are more than 3 standard deviations away from the neighbouring pixels, are replaced and additionally elevation points surrounded by many failure values are also changed to failure values. Interpolation editing tool interpolates values for missing elevations from neighbouring good elevations, and smoothing uses a small gaussian filter to smooth elevations. Mask editing allows the user to draw a mask over an area and fill it up with elevation values. It also allows the user to draw masks over areas of bad elevations and fit in new elevations or failure values thus an interpolation can be applied later in the area. In this study, two final DEMs are extracted as 2L and 4M, i.e., 2 pixel spacing and low detailed and 4 pixel spacing and medium detailed respectively. The DEM extraction was failed for both on the shorelines of Edremit Golf, and water body was assigned incorrect elevation values along the border as a corridor. Part of the corridor matching the sea border is masked using the digital borderline digitised from 1/25000 topographic sheets and then burned in “0” elevations together with the entire water body. Both DEMs also have blunders in different areas and sizes (Figure 5). Blunder removal function is used to remove these artefacts. Extracted DEM is improved dramatically for water bodies by removing the noise, applying interpolation, smoothing and as a last step burning proper elevations in. Except for the sea surface, only a small part of the DEM is edited as in Figure 5.

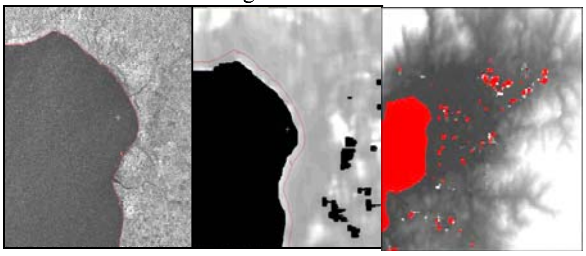


Figure 5 Failed areas and blunders in the extracted DEM

2.3.4 DEM Geo-coding

After completing the editing, extracted DEM is transferred to a geo-coded UTM file. File is geo-coded using the information from the model segment. The research area takes place in zone 35 raw S of UTM projection systems. European Datum 1950 (ED50) parameters are used for geo-referencing (Figure 6).

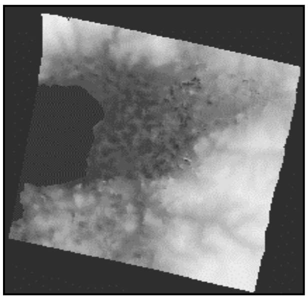


Figure 6. Geo-coded DEM generated from RADARSAT F1-F5 stereo pairs

The model is derived from ground control points collected previously, the ephemeris and the orbital data from the satellite, and from the knowledge of the Earth size and the shape. The accuracy of the model depends mostly on the accuracy of GCPs. The acquisition of GCPs from SAR imagery is difficult as the radar sensor response to ground relief and cover is very different from the familiar optical sensors. To collect GCPs homogeneously covering the stereo overlapping area and on the altitudes of extreme elevations is very important. When unexpectedly large Y parallax occurs, the only solution is to acquire additional GCPs in the affected area.

Collecting GCPs are important also to remove the bias, or the offset of a DEM. In order to match the actual terrain coordinates, bias is removed. To measure absolute accuracy the amount of vertical and horizontal shifts must be removed. Zero offset is ideal which is aimed in this research by collecting GCPs to correct the images. Besides acquiring GCPs in the field with static GPS, a 1/ 25 0000 scaled reference digital map is used. Reference map is generated by scanning 8 analog topographic sheets obtained from the General Command of Mapping. Topo sheets are first rectified, and a mosaic map is generated. GCPs are collected from this mosaic map as well as from other orthorectified images related to the research area.

2.4 Accuracy Assessment of Stereo RADARSAT DEM

The absolute accuracy is a measure of the error between the extracted DEM and the geographic coordinates of the actual terrain. To assess the accuracy, a reference digital terrain model (DTM) is generated from 1/25000 scaled contour maps. Planimetric accuracy of 1/25000 scaled maps are about 5 m, and elevation accuracy is expected to be equal to one thirds of elevation differences between contour lines. Since the contour interval is 10m in 1/25000 scaled maps, the accuracy of the reference DEM is assumed to be 3m, which is acceptable using for the accuracy assessment of the elevations calculated from stereo radar images. In order to calculate the difference of the elevation models, the DTM is subtracted from the DEM using subtraction model of PCI software.

Absolute accuracy is expressed as the vertical RMSE, or root mean square error measured at geographic coordinates. Using that disparity map (Figure 7), standard deviations are calculated first for the entire training area.

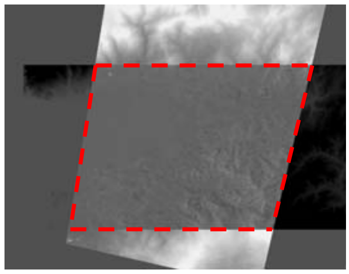


Figure 7. Elevation disparity map calculated as topographic DEM (DTM) from radargrammetric DEM

It is observed that errors are in ascending character according to the type of the terrain and the slope (Figure 8), (Table 3). In order to increase the confidence level of the accuracy assessment, the elevation accuracy of final DEM is evaluated as a function of topographic surface. A digital slope model (DSM) was computed from the topographic DEM (Figure 9). Accuracy assessment is repeated for flat, moderate and mountainous areas and histograms are evaluated separately. It is inferred from mean, standard deviations and min/max errors that elevation accuracy of stereo pairs decrease consistently as the slope increases. It is determined that elevation accuracy and slope are almost linearly correlated.

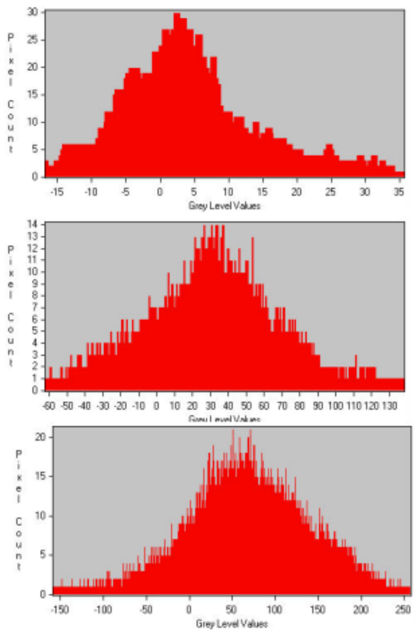


Figure 8. Error histograms for flat, slope and rough topography respectively.

Test Areas	Nub. Of Points	Min/Max	Mean	Standard deviation
Flat	442525	-18,776 / 58.369	5,756	8,732
Flat	259488	-16,800 / 35.512	3,133	7,537
Flat	159600	-31,121 / 65.109	17,888	16,955
Flat	75369	-8,155 / 18.853	4,101	3,485
Slope	101592	-37.509 / 135.586	24.580	18.813
Slope	101592	-62.112 / 137.722	30.785	28.164
Slope	117196	-37.509 / 135.857	37.406	21.089
Slope	108724	-37.509 / 135.857	42.962	24.536
Rough	190350	-82.079 / 275.138	67.910	47.264
Rough	190350	-116.527 / 237.497	19.340	35.326
Rough	190350	-232.174 / 172.750	2.489	41.679
Rough	190350	-158.581 / 256.810	69.867	57.341

Table 3. Minimum/maximum errors, mean and standard deviations of chosen test areas in different topography.

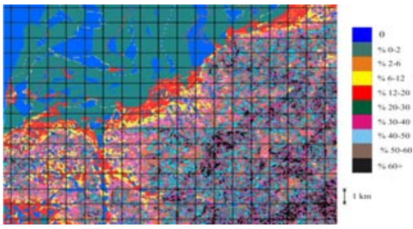


Figure 9. Slope map

Elevation accuracy is decreasing dramatically especially for rough areas with high altitudes. For smaller slopes (up to 6°) better (significant) results can be obtained since the radiometric disparities between F1and F5 images of stereo pairs are small due to their high resolution. According to the evaluation of the two of the extracted radargrammetric DEMs (i.e., 2L and 4M solutions) our results revealed that 2L solution is better for flat and moderately sloped areas. However for high altitudes larger deviations, which can be accepted as gross errors, are observed. On the other hand, using 4M-detailed DEM, better elevations are calculated for high altitudes whereas inferior elevations are calculated for flat areas.

3. CONCULUSIONS

As a result of imaging geometry of radar, elevation accuracy is strongly related to the relief type and slope. Execution of DEM from SAR imagery is a difficult task due to the characteristics of SAR imagery and conflicting requirement of stereo DEM extraction. SAR images respond very strongly to the terrain slope. Radiomatically, slopes facing the sensor are very bright due to the direct reflection, while slopes facing away from the sensor are dark. Geometrically, mountain peaks are shifted towards the sensor, causing foreshortening of the slopes facing the sensor and stretching of slopes facing away from sensor. In extreme cases tops of mountains are imaged before bottoms and back slopes are completely shadowed. Automatic DEM derivation based on image matching requires that the same area looks similar in two images of the stereo pair. Radiometric disparities and geometric distortions of SAR images may cause too large differences between images for a successful matching. In addition to strong radiometric terrain induced distortions, SAR images are corrupted by random speckle noise. The noise may cause spurious matches that forces the use of relatively large templates for matching and also decreases the sharpness of the determined peaks. All these factors contribute to the lower quality of SAR DEMs (PCI, 2001). In this research RADARSAT fine beam images offer separations (convergence angle) 8°. Due to the high resolution of F1-F5 images, for the flat areas with small slopes (0% to 3%) effect of radiometric and geometric disparities are less and the quality of DEM is better. It is determined that standard deviation is ranging from 4m to 8m for small slopes. Standard deviation increases up to 20 m for medium slopes (3%-15 %). However, for steep slopes (higher than 15%) the stronger geometry of F1-F5 is completely cancelled out because of too large geometric disparities, and calculated elevations are not significant. In the research area there is a linear relation between orthometric heights and extracted stereo DEM. The major characteristic of the research area is that slope increases as altitude increases. This nature of the relief causes significant deviations for calculated elevations of rolling topography of the research area. Consequently, for flat and small slopes difference value of stereo and topographic DEMs gives better information about land use types than the terrains with strong slopes on high altitudes.

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