Investigations on the Relation of Geomorphological Parameters to DEM Accuracy

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1. Introduction

In recent years, collection and processing techniques for Digital Elevation Models (DEMs) generation have improved rapidly, providing DEMs with higher resolution and accuracy. Each DEM contains errors due to the primary data acquisition technology and subsequent processing software, the surface relief and landcover (Li 1992). Parameters such as elevation, aspect, slope, vertical curvature and tangential curvature are useful to identify and describe geomorphological characteristics. Preliminary research studies have partially addressed the correlation between DEM accuracy and terrain relief (Toutin 2002, Crosetto and Crippa 2000). The morphology of the terrain and the sampling density used can have a significant influence on the accuracy of the DEM (Li 1992, Gao 1995, Gao 1997, Weng 2002). Some geomorphological parameters, such as average terrain slope, seem to be positively correlated with the decrease in accuracy of the DEM (Felicísimo 1992).

Our work is embedded within the EU FP6 project Pegase (Pegase, 2009), which aims at the development of an autonomous landing and take-off system for aircrafts. This system should use geodata on-board of each aircraft and DEMs are a crucial part of this geodata. To generate higher quality products covering all airports worldwide, DEM fusion is needed. DEM (and generally data) fusion needs first a quality characterisation of each input. Unfortunately, almost all available DEMs come with one global accuracy measure, which does not represent correctly the local accuracy variations. Thus, we try to exploit various parameters that influence the DEM accuracy, in order to assign to the DEM locally (ideally for each DEM point) a quality factor. The parameters that influence DEM accuracy are many, including geomorphology, landcover, DEM generation technology etc. with interrelations among them. In this paper, we report on investigations regarding the relation of some geomorphological parameters to the accuracy of DEMs. As DEMs, we mean both Digital Terrain Models (DTMs) and Digital Surface Models (DSMs). Till now, we have worked mostly on DSM fusion. Although Pegase relates to airports, the DEM fusion process should be applicable to any dataset.

After developing the basic methodology, a test, using various DEMs at a site with varying terrain relief and landcover, was conducted and discussed here.

2. Methodology

We compare five DEMs in the region of Thun, Switzerland produced with different technologies. The only available a priori information on the DEMs is their generation technology (e.g. airborne laser scanning, image matching, SAR interferometry, map contour digitisation), a global DEM accuracy measure and the raw data acquisition date. To perform the comparison of multiple DEMs, the procedure described below is proposed.

First, the DEMs are converted to a common coordinate reference system (CH1903). Then, the DEMs are co-registered to remove remaining global systematic errors, and the 3D differences between the DEMs are computed. After the DEM co-registration, we calculate geomorphological parameters (slope, roughness and aspect), using the DEM with the highest resolution and accuracy. Finally, we analyse the relation between the DEM differences after co-registration and these geomorphological parameters.

2.1 Co-registration

The input DEMs must be co-registered in order to compensate major systematic discrepancies between them. The DEMs are co-registered using the ETHZ software LS3D (Gruen and Akca 2005). The method performs 3D least squares matching. After the co-registration, the Euclidean distances (E) between the two DEMs are computed point-wise, together with their X, Y, Z components. The distances are computed as slave minus master DEM, where slave is the nominally less accurate DEM. The Euclidean distances and their X, Y, and Z components provide the so-called “residual maps”. LS3D generally uses a 7-parameter similarity transformation but in most cases three translations suffice.

2.2 Geomorphological Characteristics

Geomorphological parameters (slope, aspect, roughness, curvature, etc.) can be derived from a DEM using local operations. Three geomorphological parameters (slope, aspect and roughness) were calculated and their relation to co-registration residuals was analyzed. Slope and roughness relate to DEM quality for many DEM generation technologies, with DEM quality deteriorating with increasing slope and roughness. Aspect, in relation with significant slopes, relates mainly to shadows that cause DEM errors, when the DEM is generated by image matching. It also relates to DEM errors produced by SAR interferometry and airborne laser scanning, but to estimate these relations one needs more detailed knowledge of the data acquisition parameters (e.g. flight path, viewing angle), which we assume that are unknown.

Slope gives the deviation from the horizontal. Slope is the first derivative of a surface.

Aspect indicates the direction that slopes are facing. Aspect is defined as the direction of the biggest slope vector on the tangent plane projected on the horizontal plane, and here it is measured clockwise from 0 (North) to 360 degrees.

Roughness is a particular useful diagnostic tool because of its sensitivity to local elevation changes in the DEM. There are many ways to calculate the DEM roughness (e.g. standard deviation, variance, fractal dimension, entropy). We experimented with all these methods and found out that the entropy method performs best for our purposes. Entropy is a statistical measure of randomness (Haralick et al. 1973) that can be used to characterize the local variation of the input DEM. This measure is low when the heights within a local window have similar values and high when they vary significantly. Each output grid cell contains the entropy value within a n-by-n neighbourhood around an input DEM grid cell. In our case, we use a neighbourhood 9-by-9. For grid cells at the borders, symmetric padding is used.

3. Test Area and Data Description

The study site is an area around the town of Thun, Switzerland, characterized by steep mountains, smooth hilly regions and flat areas, both rural and urban. The elevation range is more than 1600m, varying from 530m to 2190m. The landcover is extremely variable with both dense and isolated buildings, open areas, forests, rivers and a lake. The available DEM data are:

- **SRTM C-band**, with 90 m grid spacing and estimated accuracy ± 5-15 m. The acquisition year is 2000.
- **DHM25** (Swisstopo), with 25 m grid spacing and estimated accuracy for the Thun tile ± 2.5 m. The digital height model DHM25 was essentially derived from the height information of the Swiss National Map 1:25,000 (NM25). It is a DTM. The raw data acquisition date is the year 1981.
- **Lidar DSM** (Swisstopo), with 2 m grid spacing and estimated accuracy (1 sigma) of 0.5m and 1.5m for vegetation and buildings. The acquisition date is spring 2000. The initial raw point density is about 1 point per 2 m^2.
- **A photogrammetric DSM**, with 4 m grid spacing. Over this test area, two IKONOS image triplets were acquired in December 2003 and a DSM was produced using image matching techniques with the ETHZ software Sat-PP. The estimated accuracy (RMS) is 1−2m in open areas, about 3m on the average in the whole area, excluding vegetation and 8m in vegetated areas (Baltsavias et al. 2006).
- **Reference 3D DEM**, obtained through automatic image matching of SPOT-5 HRS stereopairs. The grid spacing is 1 arcsecond (~ 30 m at the equator, varying according to latitude), the absolute elevation accuracy is 10 m for slopes < 20° and the absolute planimetric accuracy is 15 m. The acquisition date is November 2006.

Fig. 1 shows the shaded Lidar DSM.

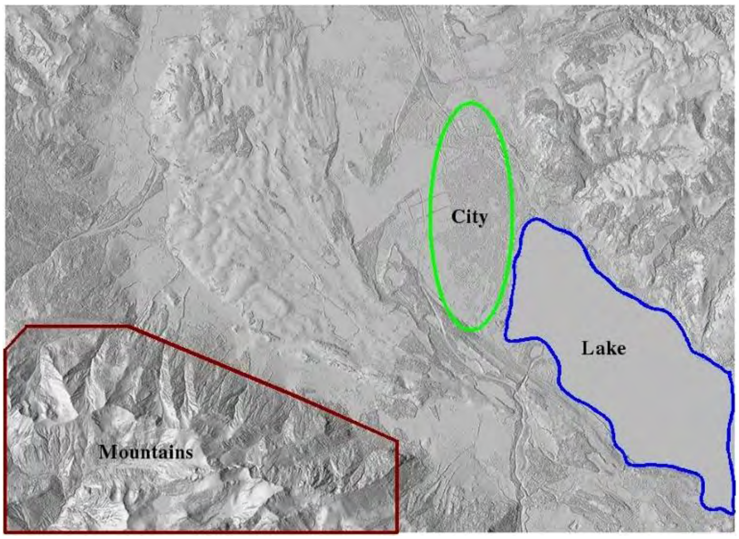


Figure 1. The Lidar DSM visualized in shaded mode.

4. Results and Discussion

At the co-registration step, we set as master DEM the lidar DEM. Among the 7 parameters, only the three X, Y, Z shifts were significant. The results of the co-registration step are summarized in Table 2. After co-registering the DEMs, the Euclidean distances between the two datasets are computed, as well as the X, Y, Z components, and their statistics. The residual distribution (see Figs. 2 and 3) shows that the larger ones are mainly located on the southern part, especially in the shadowed northern steep mountain region.

Template DEM	Slave DEM	Sigma a Priori (m)	Sigma a Posteriori (m)	Iterations	Tx (m)	Ty (m)	Tz (m)
Lidar	**Ikonos**	1.00	5.49	17	1.77	-3.97	0.45
Lidar	**DHM25**	1.00	9.07	6	3.73	8.60	4.50
Lidar	**SRTM**	5.00	9.11	5	42.69	83.42	1.35
Lidar	**Ref3D**	5.00	10.64	8	-24.17	-17.61	2.57

Table 1. Results of the co-registration of the available DEMs for the test area of Thun, Switzerland. T shows the translations.

	Lidar- SRTM					**Lidar-Ikonos**				
Residuals	**Minimum (m)**	**Maximum (m)**	**Mean (m)**	**St. Dev. (m)**	**RMSE (m)**	**Minimum (m)**	**Maximum (m)**	**Mean (m)**	**St. Dev. (m)**	**RMSE (m)**
E	-721.27	88.45	-0.61	15.68	15.69	-85.69	88.41	0.04	5.96	5.97
X	-333.79	235.47	-0.06	5.23	5.23	-51.78	57.47	0.01	2.62	2.62
Y	-325.59	305.66	-0.11	9.39	9.39	-79.91	78.78	0.04	3.08	3.08
Z	-632.70	69.96	-0.23	11.44	11.44	-50.87	54.41	-0.01	4.38	4.38
	Lidar-DHM25					**Lidar-Ref3D**				
Residuals	**Minimum (m)**	**Maximum (m)**	**Mean (m)**	**St. Dev. (m)**	**RMSE (m)**	**Minimum (m)**	**Maximum (m)**	**Mean (m)**	**St. Dev. (m)**	**RMSE (m)**
E	-64.37	63.48	-0.13	9.07	9.07	-147.09	170.50	0.34	11.84	11.84
X	-29.79	54.11	0.00	2.31	2.31	-70.28	131.58	0.03	3.65	3.65
Y	-36.36	36.70	-0.00	2.81	2.81	-112.69	130.90	0.10	5.88	5.88
Z	-64.00	36.87	0.00	8.31	8.31	-128.67	130.22	0.10	9.60	9.60

Table 2. Statistics of the residual maps (E = Euclidean distances, and their X, Y, Z components) after co-registration of the available DEMs for the test area of Thun, Switzerland.

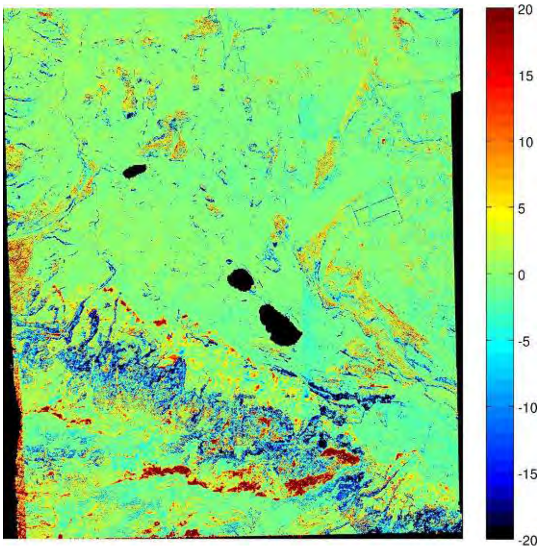
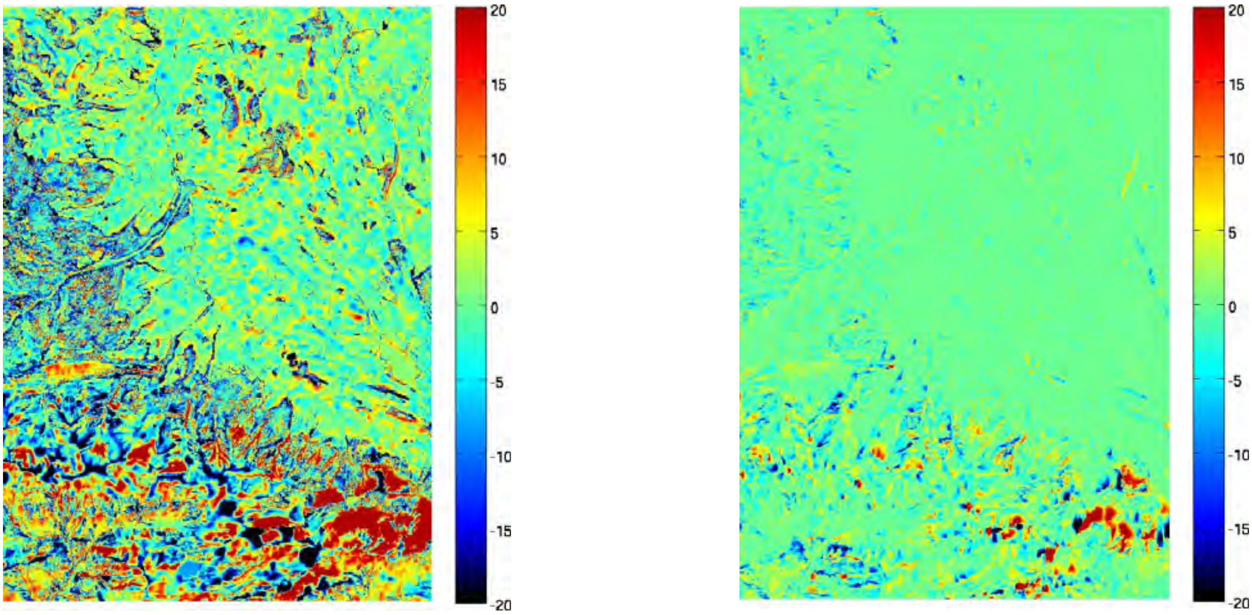
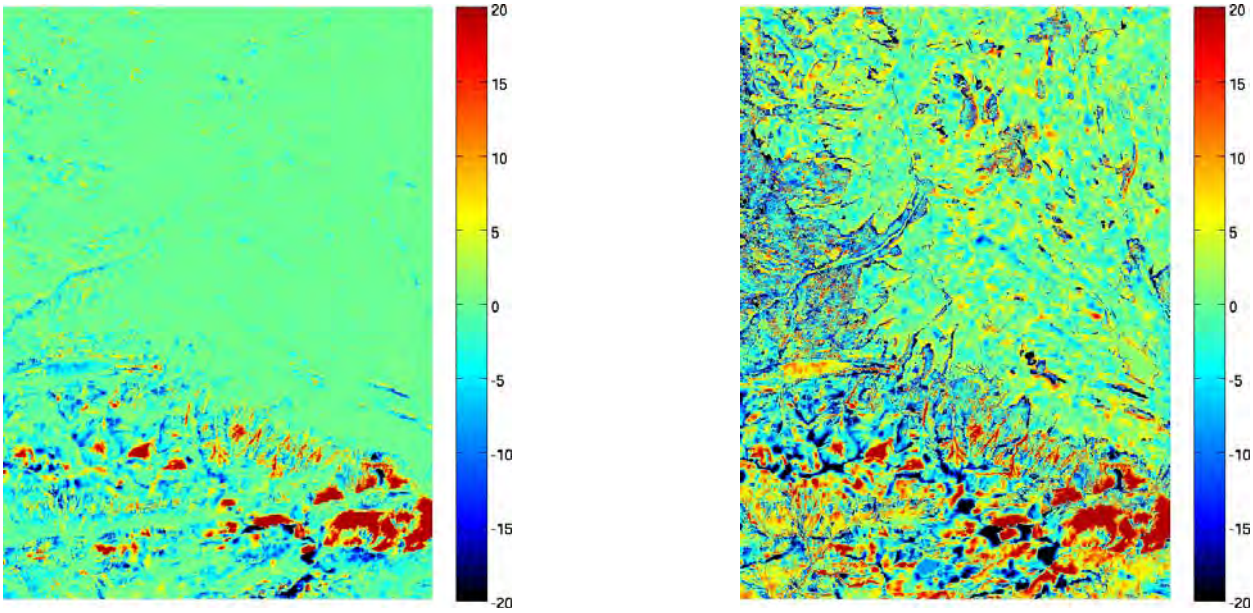


Figure 2: Color-coded Euclidean distance residuals (in m) between the Ikonos and the Lidar DSMs after co-registration.



(a) Euclidean residuals (b) X residuals

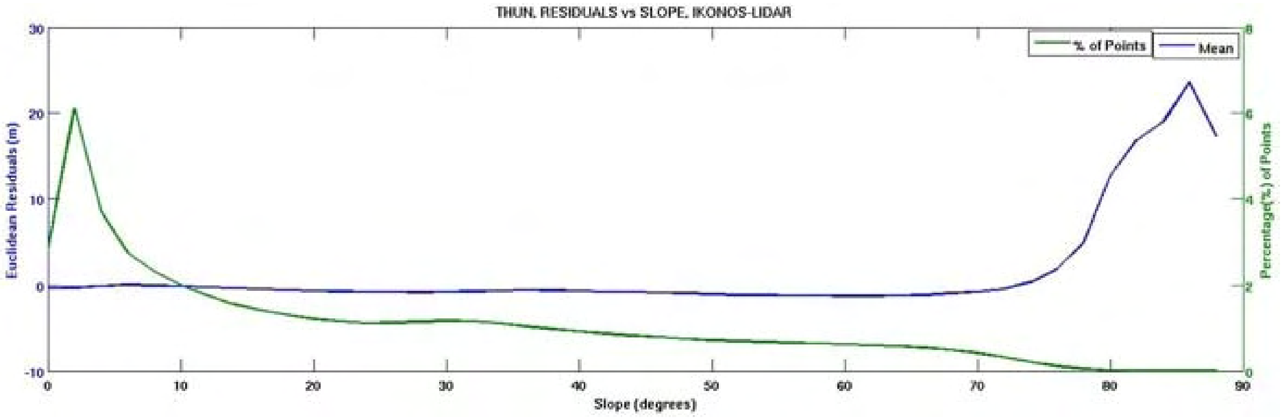


(c) Y residuals (d) Z residuals

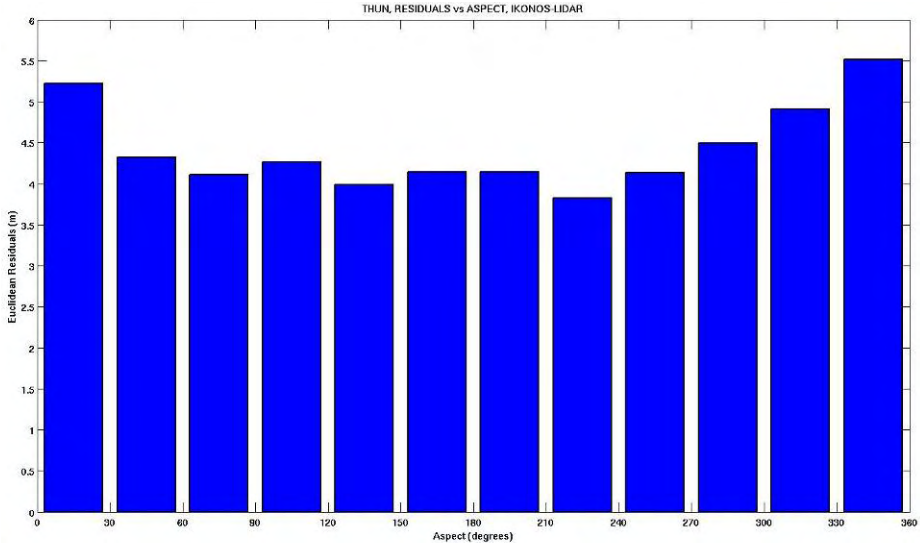
Figure 3: Color-coded residuals (in m) between the Reference3D and Lidar DSMs after co-registration.

The residuals between the DSMs were studied in relation to the geomorphologic characteristics, which were previously computed. By plotting the residuals with respect to slope, aspect and roughness (see Fig. 4), it can be noted that:

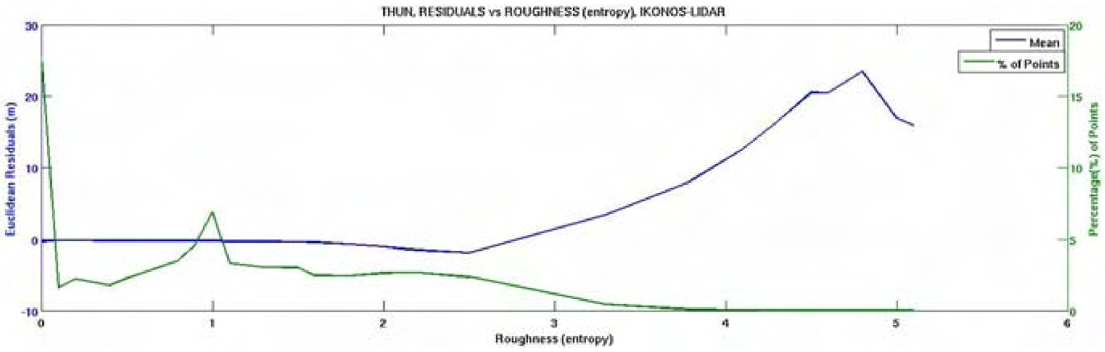
- Slope is one of the principal parameters that relates to the differences between the DSMs. The steeper the slope is, the larger the differences between the DSMs, whatever the aspect (Fig.4a).
- Northern aspect correlates with the highest residuals. It corresponds to shadows, especially at mountain slopes, in the Ikonos images where the matching DSM has large errors because of the low image texture but also high slope and roughness (Fig 4b).
- Differences increase consistently as roughness increases. In general, above a certain roughness, elevation accuracy and roughness are almost linearly correlated (Fig 4c).



(a) Euclidean distances (mean every degree) versus slope. The green line shows the percentage of points.



(b) Euclidean distances (mean every 10 degrees) versus aspect. Grid cells with slope <10◦ are not used; 0◦ : North, 90◦ : East, 180◦ : South, 270◦ : West.



(c) Euclidean distances (mean values every 0.2 units of entropy) versus roughness. The green line shows the percentage of points.

Figure 4: Plots of the 3D residuals (mean values) as a function of the (a) slope, (b) aspect, and (c) roughness of the Lidar DSM.

The above mentioned results demonstrate a combined correlation between DEM accuracy and DEM slope, aspect and roughness.

Further work is needed regarding usage of other geomorphological parameters (like DEM surface discontinuities), the quantification of the influence of each geomorphological parameter on DEM accuracy and the combination of these influences (as well as others relating to landcover and DEM generation technology) in order to derive local DEM accuracy measures, ideally for each DEM point.

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References

Aguilar F.J., Agüera F., Aguilar M.A., Carvajal F., 2005, Effects of Terrain Morphology, Sampling Density, and Interpolation Methods on Grid DEM Accuracy. *ISPRS Journal of Photogrammetry and Remote Sensing*, 71(7): 805-816.

Baltsavias E., Zhang L., Eisenbeiss H., 2006, DSM Generation and Interior Orientation Determination of IKONOS Images Using a Testfield in Switzerland. *Photogrammetrie, Fernerkundung, Geoinformation*, (1): 4154.

Crosetto M., Crippa B., 2000, Quality assessment of interferometric DEM. *International Archives of Photogrammetry and Remote Sensing*, 33(B1):146-153.

Felicísimo A.M., 1992, Digital Terrain Models and their Application to Environmental Sciences, *Ph.D. Thesis*, University of Oviedo, Spain, 235 p.

Gao J., 1995, Comparison of sampling schemes in constructing DTMs from topographic maps. *ITC Journal*, 1: 18-22.

Gao J., 1997, Impact Resolution and accuracy of terrain representation by grid DEMs at a micro-scale, *International Journal of Geographical Information Science*, 11(2): 199-212.

Gruen A. and Akca D., 2005, Least squares 3D surface and curve matching. *ISPRS Journal of Photogrammetry and Remote Sensing*, 59(3):151–174.

Haralick R.M., Shanmugam K., and Dinstein I., 1973, Textural features for image classification. *IEEE Transactions on Systems, Man and Cybernetics*, 3(6):610–621.

Li Z., 1992, Variation of the accuracy of digital terrain models with sampling interval. *Photogrammetric Record*, 14(79):113-128.

Pegase, 2009, http://dassault.ddo.net/pegase. Accessed, June 2009.

Toutin T., 2002, Impact of terrain slope and aspect on radargrammetric DEM accuracy. *ISPRS Journal of Photogrammetry and Remote Sensing*, 57(3): 228-240.

Weng Q., 2002, Quantifying uncertainty of digital elevation models derived from topographic maps, Advances in Spatial Data Handling (D. Richardson and P. van Oosterom, editors), Springer-Verlag, New York, pp. 403–418.