A QUALITY ASSESSMENT OF AIRBORNE LASER SCANNER DATA

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ABSTRACT:

A Toposys-1 airborne laser scanner (ALS or LIDAR) measurement campaign was arranged in June 2000 (Kalkkinen) and another campaign with helicopter-borne TopEye laser scanner was arranged in September 2002 in southern Finland (Masala, Otaniemi). The Toposys flying altitudes were about 400 and 800 m above ground and for the TopEye, 100, 200, 400 and 550 m flying altitudes were used. Reference measurements on the ground were made with a RTK GPS and a tachymeter. Points on asphalt, grass, gravel and forest ground were measured. Height errors for different surfaces were calculated. The higher the flying altitude, the larger is the height error. All the three comparison methods (ALS mean height in the test circle, height of the nearest laser point and interpolated height) seem to give the similar results for the mean of differences (reference height – ALS height) in the same flight line. There were also quality differences between flight lines. Also height errors as a function of observation angle were determined. Observation angle had an effect on the height accuracy. A systematic error of typically 10 cm was observed due to observation angle changes. Different R-squared values (coefficient of determination in the regression analysis) were obtained for the same surface material at different flying altitudes.

1. INTRODUCTION

The quality of laser scanning has been studied extensively during the last few years (e.g. Crombaghs et al., 2002; Gomes Pereira and Wicherson, 1999, Kraus and Pfeiffer, 1998, Maas, 2002, Ahokas et al., 2003). It has been shown that the terrain height can be typically collected within 15 cm. However, there are large number of factors affecting the quality and accuracy obtained, e.g. the surface material, flight altitude, applied sensor and platform, GPS/INS and observation angle, to name but a few.

In this paper, the elevation accuracy of digital evelation models and original laser points is studied in different test sites, with different surface types (forest, gravel, asphalt, grass), with two different sensors (Toposys-1 and TopEye), with different flying heights, as a function of observation angle and using different kinds of means to derive the elevation from the cloud of point.

2. MATERIAL AND METHODS

2.1 Airborne laser scanner data

2.1.1 Toposys: A German Toposys-1 airborne laser scanner is a pulsed fibre scanner. This system has a scan angle of 14° (±7°). Pulse length is 5 ns and the repetition rate is 83 kHz. Toposys uses 1.54 µm wavelength (www.toposys.com). Both the first and the last pulse modes were used in the Kalkkinen test area. Flying heights were 400 and 800 m above ground**.** Point densities were 7-8 points/m^2 from 400 m flying height and 4-5 points/m^2 from 800 m flying height. The Kalkkinen test area consisted of 14 flight lines (c.f. Table 1).

2.1.2 TopEye: A Swedish TopEye airborne laser scanner has a wavelength of 1.064 µm. Pulse rate is less than 6 kHz. Pulse length is 7 ns. This ALS uses oscillating mirrors and the resulting scan pattern is Z-shaped. Scan angle is 0-20° when a helicopter is used (www.topeye.com). Flying heights were 100 and 400 m in Masala and 200 and 550 m above ground in Otaniemi. Point densities were 4-7 (H=100m), 2-3 (H=200m), 1-1.5 (H=400m) and 0.8-1 points/m^2 (H=550m).

Test area	Flying altitude (m)	Number of flight lines (pulse)	
Kalkkinen	400	4 (First)	4 (Last)
	800	3 (First)	3 (Last)
Masala	100	4	
	400	1	
Otaniemi	200	9/18	
	550	5	

Table 1. Analysed flight lines for different test areas.

2.2 Ground truth data

Ground truth data were measured in three different areas, namely in Masala, Otaniemi and Kalkkinen. In Otaniemi reference points were measured with Leica SR530 Real-Time-Kinematic (RTK) GPS. Horizontal accuracy of the RTK measurements was verified to be about 0.015 m and vertical accuracy 0.02 m in another study (Bilker et al. 2001). Altogether 1659 points were measured from different targets and surfaces. Asphalt, grass and gravel were of interest.

In the Kalkkinen test area, tachymeter measurements were made in October 2002 at eight different test plots. Plots were chosen so that they represented different types of forest and ground. Heights were measured also under the trees on the location of the trunk. Each test plot was about 30 m by 30 m in size and the measured points were distributed evenly inside the plot. Altogether 2119 points were measured in the Kalkkinen test area.

In the Masala test area 3439 ground points were measured with a tachymeter. This forest area is a small one, about 50 m by 100 m in size.

2.3 Comparison of laser points with reference points

Elevations of ALS derived points were compared with RTK-derived reference points in Otaniemi area or tachymeter reference points in Masala and Kalkkinen areas. A circle with a radius of 2 m using a reference point as a centre point of the circle was created for every reference point. Statistics of the ALS points were calculated inside the circles if there were more than 5 laser points included. Mean value, median, minimum, maximum and standard deviation, nearest laser point to the reference point and an interpolated height value from the laser points were calculated. A 10 cm by 10 cm grid and a cubic method was used in the height interpolation calculations. The above mentioned statistical values were calculated to find out if there were a difference between mean value, nearest laser point to the reference point and an interpolated height value in the comparison process. A maximum value of 0.2 m for standard deviation inside the circle was used as a homogeneity measure for asphalt, grass and gravel. Otherwise there could be laser points e.g. on the tree branches inside a 2 m radius circle disturbing the results.

In Kalkkinen and Masala test areas, laser point clouds were first classified to separate ground points from all other points, because we wanted to study the accuracy of ground surface points. Applied algorithm selects local low points that are on the ground and makes an initial triangulated model (www.terrasolid.fi). Triangles are at first below the ground and only vertices are at the ground level. Then new laser points are added iteratively to the model and it describes the actual ground surface more and more precisely. Maximum building size, iteration angle and distance parameters determine which points are accepted. Trees and houses are filtered out in this method. When the ground points are selected we can use them for comparison with the RTK or tachymeter reference points.

3. RESULTS

Heights of the reference points were compared to the calculated laser point height levels. Results for different surfaces are in the following tables.

Kalkkinen, Toposys-1, H=800m, Forest ground			
First pulse	Mean and std of differences (m)		
Flight line	7	8	9
Mean z	-0.38±0.21	-0.40±0.23	-0.36±0.13
Nearest point z	-0.38±0.21	-0.40±0.23	-0.34±0.11
Interpolated z	-0.36±0.16	-0.38±0.18	-0.35±0.08
Last pulse			
Flight line *)	19	20	21
Mean z	-0.27±0.20	-0.28±0.19	-0.24±0.11
Nearest point z	-0.24±0.22	-0.25±0.22	-0.22±0.14
Interpolated z	-0.24±0.18	-0.25±0.16	-0.21±0.12

Table 2. Height errors (Tachymeter-Laser) and standard deviations for forest ground in Kalkkinen. *) indicates statistically significant (α=0.05) differences in mean values between flight lines.

Kalkkinen, Toposys-1, H=400m, Forest ground				
First pulse	Mean and std of differences (m)			
Flight line *)	4	5	6	7
Mean z	-0.16 ±0.15	-0.18 ±0.24	-0.24 ±0.25	-0.16 ±0.11
Nearest point z	-0.17 ±0.16	-0.18 ±0.23	-0.26 ±0.23	-0.16 ±0.11
Interpolated z	-0.17 ±0.13	-0.15 ±0.17	-0.19 ±0.12	-0.14 ±0.07
Last pulse				
Flight line *)	8	9	10	12
Mean z	0.02 ±0.11	0.05 ±0.20	0.04 ±0.18	0.02 ±0.20
Nearest point z	0.05 ±0.15	0.07 ±0.22	0.06 ±0.18	0.04 ±0.17
Interpolated z	0.06 ±0.12	0.08 ±0.17	0.06 ±0.13	0.05 ±0.15

Table 3. Height errors (Tachymeter-Laser) and standard deviations for forest ground in Kalkkinen. *) c.f. caption in Table 2.

The Toposys-1 first pulse flight from H=800m in Kalkkinen was on June 14, 2000 and all the other Toposys-1 flights were on June 15. This is the reason for similar flight line numbering 7, 8 and 9 (c.f. Tables 2 and 3).

Mean of differences describes the bias or systematic error of the laser measurements. The one-way analysis of variance showed that there are statistically significant differences in mean values between flight lines. Line 6 has larger height errors (mean of differences between the reference and the ALS-derived heights) than others in the forest ground areas. The last pulse mode Toposys-1 observations from H=400m are exceptional; because only these laser observations are below the actual ground surface (positive means of differences).

Masala, TopEye, Forest ground				
	Mean and std of differences (m)			
H=400m				
Flight line	4f2			
Mean z	-0.14±0.17			
Nearest point z	-0.14±0.18			
Interpolated z	-0.14±0.16			
H=100m				
Flight line *)	3f1	4f1	7f1	8f1
Mean z	-0.08 ±0.20	-0.05 ±0.19	-0.09 ±0.17	-0.10 ±0.17
Nearest point z	-0.08 ±0.19	-0.05 ±0.18	-0.08 ±0.17	-0.09 ±0.16
Interpolated z	-0.07 ±0.16	-0.05 ±0.16	-0.08 ±0.15	-0.09 ±0.14

Table 4. Height errors (Tachymeter-Laser) and standard deviations for forest ground in Masala. *) c.f. caption in Table 2.

The standard deviation of differences describes random error. The std of differences for forest ground are the same for 400m and 800m flying altitudes for Toposys-1 (0.11-0.25m). TopEye has the same behaviour for 100m and 400m flying altitudes. The flying altitude does not seem to significantly affect the standard deviation of differences in the forest ground in Masala test area. Only one flight line from the flying altitude of 400 m was available for comparison in this case.

When we look at the more planar test areas like grass and asphalt, flying altitude and the target material has effect on the standard deviation of differences. If we compare the standard deviations from the same flying altitude (200 or 550m) grass has larger standard deviation of differences than asphalt (Tables 6 and 7).

Otaniemi, TopEye, Gravel	
	Mean and std of differences (m)
H=550m	
Flight line	1f4
Mean z	-0.17±0.04
Nearest point z	-0.17±0.05
Interpolated z	-0.16±0.05
H=200m	
Flight line	4f3
Mean z	-0.10±0.04
Nearest point z	-0.10±0.05
Interpolated z	-0.10±0.05

Table 5. Height errors (RTK-Laser) and standard deviations for gravel in Otaniemi.

Otaniemi, TopEye, Grass			
	Mean and std of differences (m)		
H=550m			
Flight line	1f4	2f4	
Mean z	-0.24±0.13	-0.21±0.11	
Nearest point z	-0.24±0.13	-0.22±0.14	
Interpolated z	-0.24±0.11	-0.21±0.12	
H=200m			
Flight line *)	3f3	4f3	5f3
Mean z	-0.25±0.08	-0.14±0.11	-0.04±0.10
Nearest point z	-0.23±0.12	-0.13±0.11	-0.05±0.11
Interpolated z	-0.23±0.10	-0.13±0.11	-0.03±0.06

Table 6. Height errors (RTK-Laser) and standard deviations for grass in Otaniemi. *) c.f. caption in Table 2.

Otaniemi, TopEye, Asphalt					
	Mean and std of differences (m)				
H=550m					
Flight line *)	1f4	2f4	3f4	4f4	
Mean z	-0.13 ±0.06	-0.15 ±0.10	-0.21 ±0.10	-0.15 ±0.05	
Nearest point z	-0.14 ±0.06	-0.15 ±0.10	-0.21 ±0.10	-0.15 ±0.06	
Interpolated z	-0.14 ±0.06	-0.15 ±0.07	-0.21 ±0.10	-0.16 ±0.06	
H=200m					
Flight line *)	4f3	5f3	6f3	9f3	11f3
Mean z	-0.05 ±0.04	-0.06 ±0.05	-0.10 ±0.05	-0.08 ±0.05	-0.12 ±0.04
Nearest point z	-0.06 ±0.04	-0.06 ±0.04	-0.09 ±0.04	-0.08 ±0.04	-0.11 ±0.05
Interpolated z	-0.06 ±0.04	-0.06 ±0.04	-0.10 ±0.04	-0.08 ±0.04	-0.12 ±0.05

Table 7. Height errors (RTK-Laser) and standard deviations for asphalt in Otaniemi. *) c.f. caption in Table 2.

All the three comparison methods (ALS mean height in the test circle, height of the nearest laser point and interpolated height) seem to give the similar results for the mean of differences (reference height – ALS height) in the same flight line. Analysed test targets were planar, because the maximum value of 0.2m for the standard deviation inside the test circle was used. An exception was the forest ground where no limit for the test circle standard deviation was used.

The flying altitude has an impact for height errors. The higher flying altitudes resulted in larger errors. There are also differences between flight lines. Means of differences and standard deviations vary between lines (c.f. flight lines 8 and 9 in Table 3 and height errors between lines 3f3 and 5f3 in Table 6). This phenomenon leads to problems in the DEM production without flight line adjustment.

Height differences as a function of observation angle are depicted in the Figures 1 to 16. These are examples of different flying altitudes and surface materials in Kalkkinen, Masala and Otaniemi. Each point describes height difference between the reference point and the ALS mean height in the corresponding test circle.

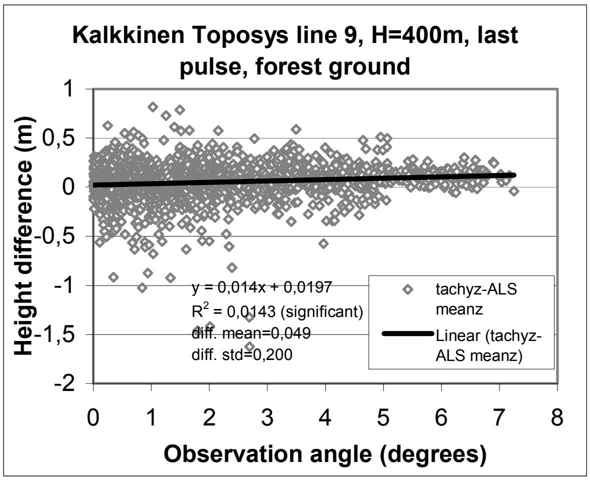

Figure 1. Height differences as a function of observation angle for forest ground in Kalkkinen.

Height differences were calculated also so that means and standard deviations are in one or two-degree bins. Random error variability will be visible.

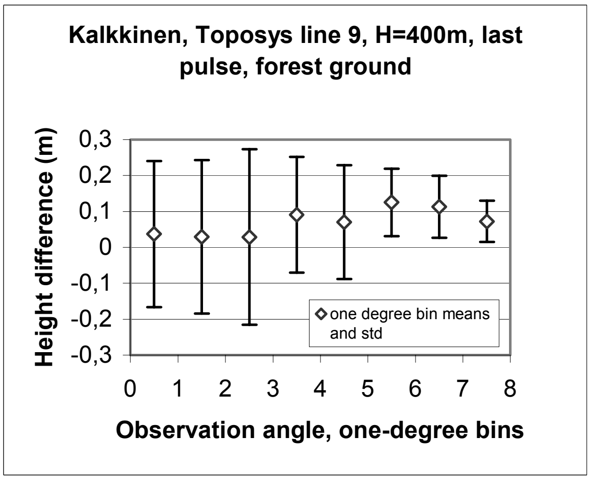

Figure 2. Height differences as a function of observation angle. Means and standard deviations calculated in one-degree bins.

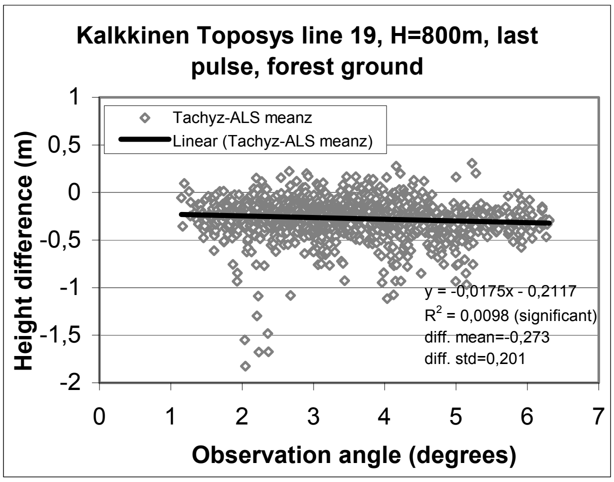

Figure 3. Height differences as a function of observation angle for forest ground in Kalkkinen.

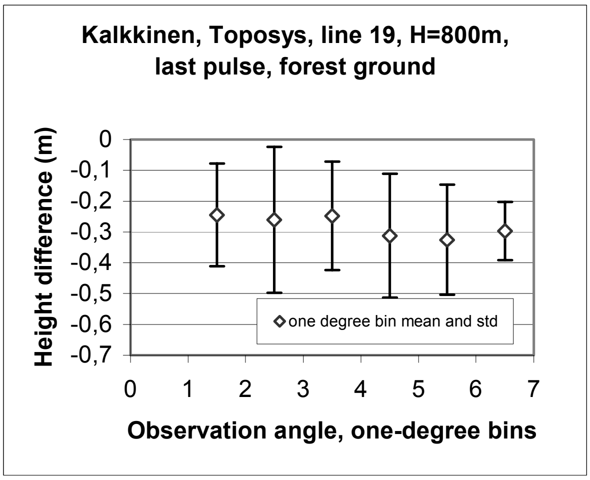

Figure 4. Height differences as a function of observation angle. Means and standard deviations calculated in one-degree bins.

The analysis of the impact of the observation angle on the results showed that the systematic level of the laser-derived values changes as a function of the observation angle. The fluctuation is clearly seen in the Figure 8 (Masala, TopEye, line 3f01, H=100m, last pulse). The systematic errors did not show any clear trend whether they grow and decrease as the observation angle increases. Both phenomena occurred. It was, however, rather typical that the systematic level of laser-based terrain heights were 10 cm shifted in the other side of the strip. The maximum error found was 17 cm and the smallest was 2 cm. Both these errors are due to the errors of direct georeferencing, and also due to changes in the targets (since the same target was not measured from different observation angles). However, the results implies that improvement is needed in direct georeferenceing and flight strip adjustment is recommended. Generally, the random errors should increase as the observation angle increases. That was not clearly demonstrated. E.g. in Kalkkinen using Toposys-1 and 400 m flight altitude (Figure 2.), the random errors seem to decrease as a function of observation angle. The reason for such phenomena is not yet known. It was also noticed that the random errors seem to fluctuate as a function of observation angle. That can be explained by the variability of targets but also by the inaccuracy of the direct georeferencing.

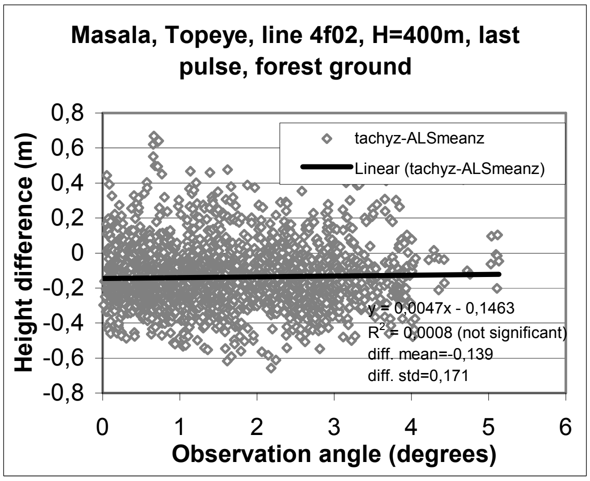

Figure 5. Height differences as a function of observation angle for forest ground in Masala.

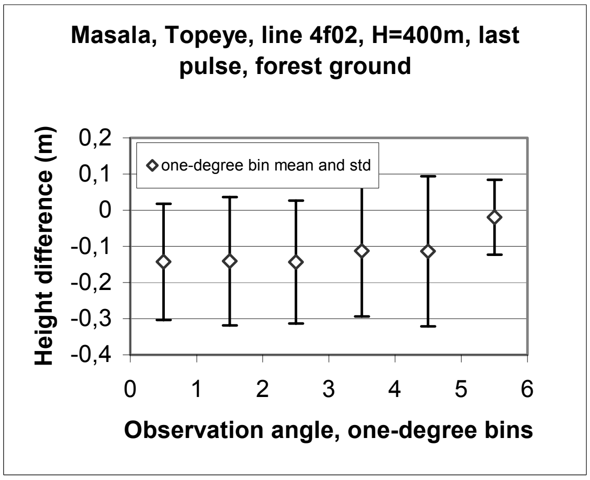

Figure 6. Height differences as a function of observation angle for forest ground in Masala. Means and standard deviations calculated in one-degree bins.

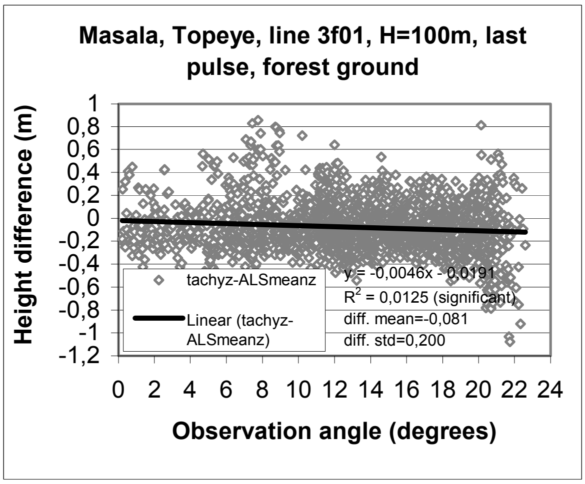

Figure 7. Height differences as a function of observation angle for forest ground in Masala.

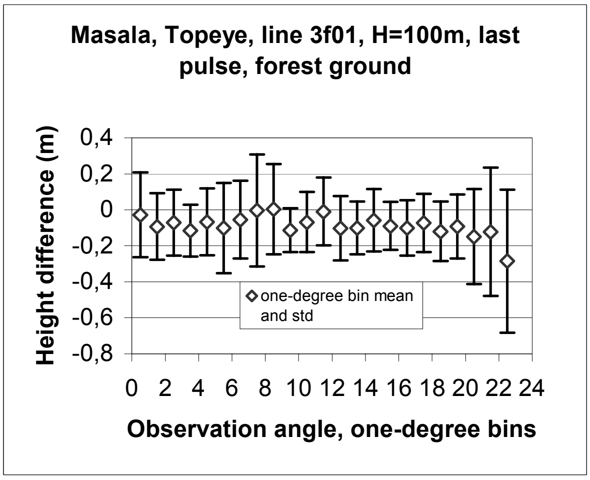

Figure 8. Height differences as a function of observation angle for forest ground in Masala. Means and standard deviations calculated in one-degree bins.

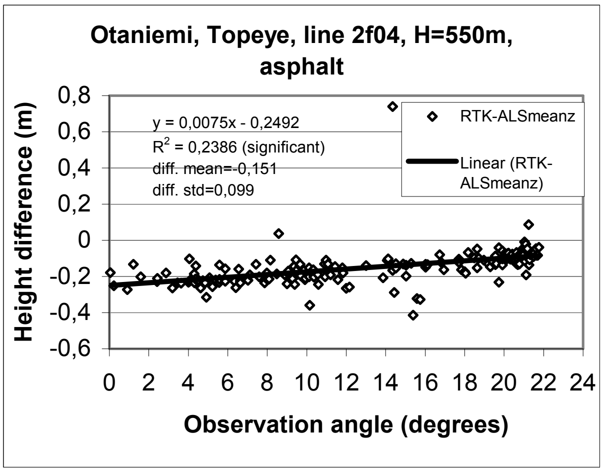

Figure 9. Height differences as a function of observation angle for asphalt surface in Otaniemi.

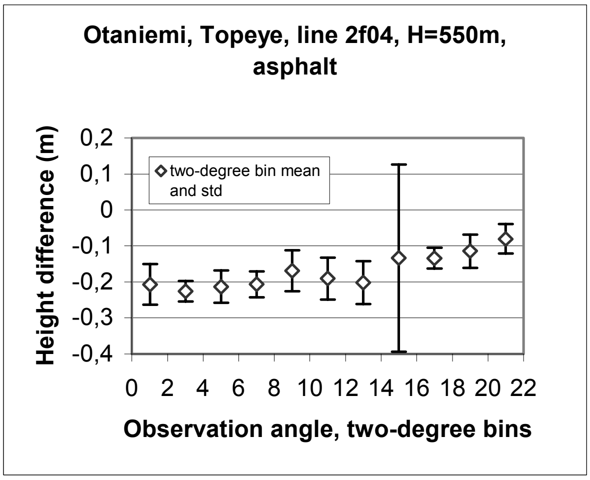

Figure 10. Height differences as a function of observation angle for asphalt in Otaniemi. Means and standard deviations calculated in two-degree bins.

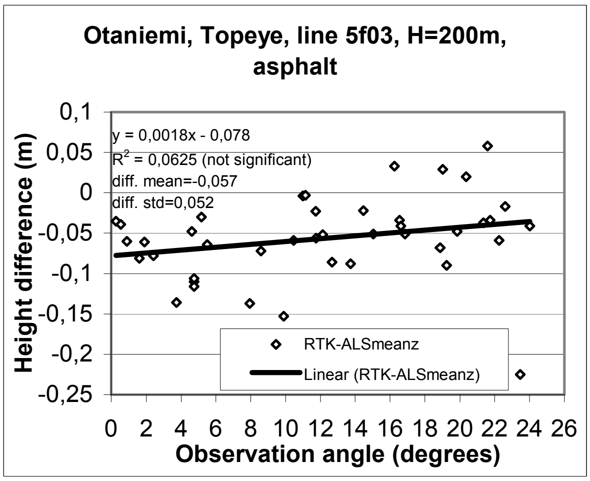

Figure 11. Height differences as a function of observation angle for asphalt surface in Otaniemi.

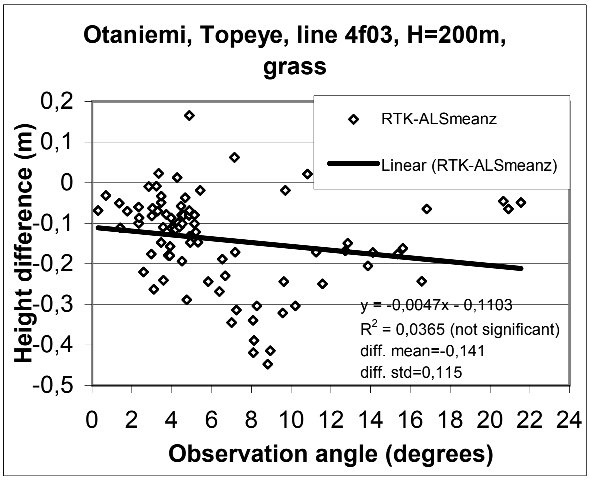

Figure 12. Height differences as a function of observation angle for grass in Otaniemi.

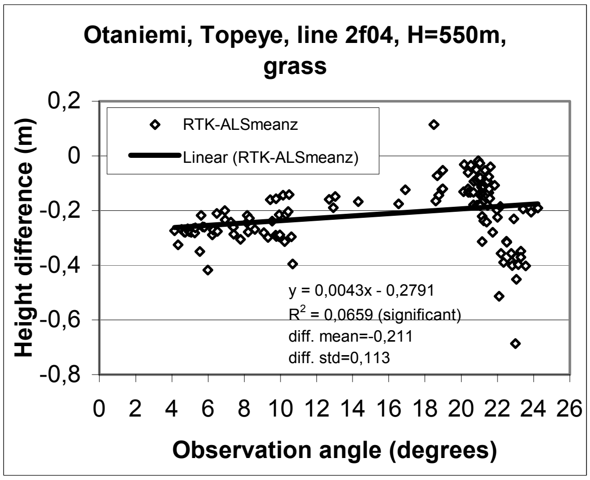

Figure 13. Height differences as a function of observation angle for grass in Otaniemi.

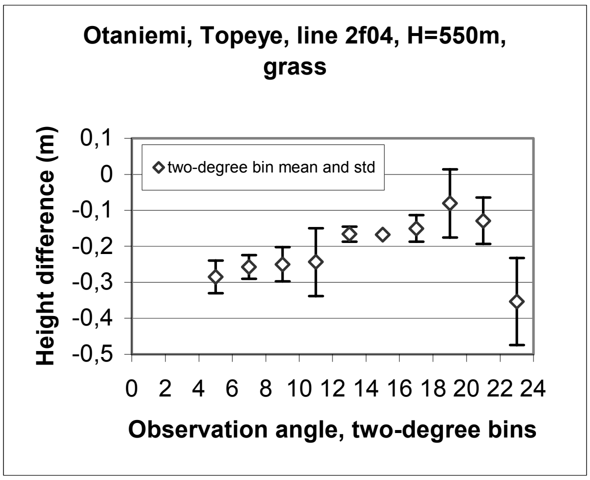

Figure 14. Height differences as a function of observation angle for grass in Otaniemi. Means and standard deviations calculated in two-degree bins.

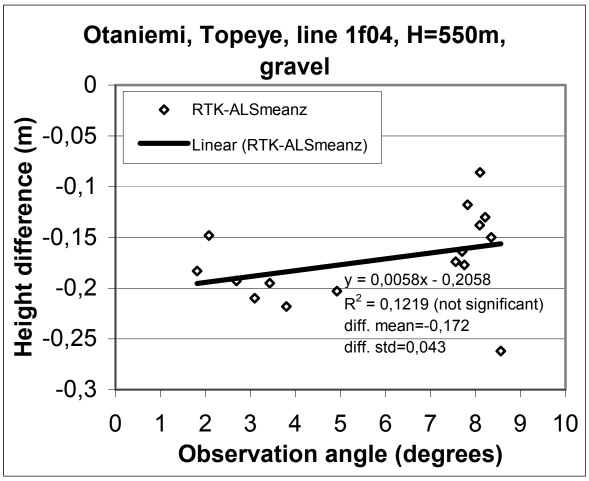

Figure 15. Height differences as a function of observation angle for gravel in Otaniemi.

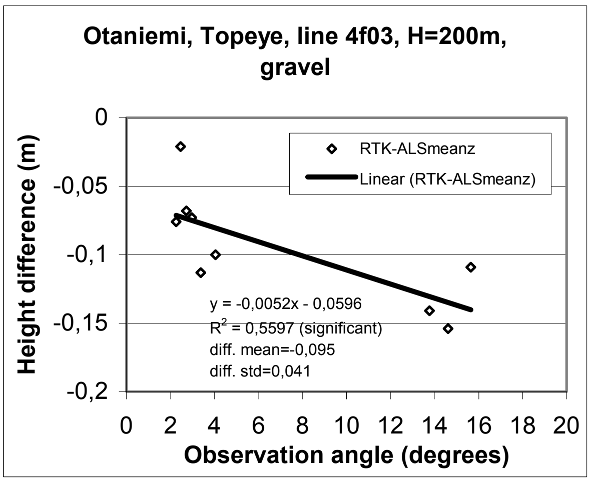

Figure 16. Height differences as a function of observation angle for gravel in Otaniemi.

The coefficient of determination in the regression analysis, R-squared value, 0.56 for gravel (H=200m) is the largest statistically significant value obtained at 95% confidence level. Only 9 points are included here so very strict conclusions should not be drawn in this case.

We got different R-squared values for the same surface material at different flying altitudes. In general the statistically significant R-squared values are very small (<0.05).

4. CONCLUSIONS

The quality of airborne laser scanner data has been studied from the flying altitude, surface material and the observation angle point of view.

The analysis of the factors affecting the total accuracy of the laser scanning is not as simple and as straightforward as it was thought. It seems that there is a reasonable amount of changes between flight lines, with flight altitudes, and observation angles, and sometimes the conclusions are not evident.

It was observed that there is a flight line-dependent systematic and random error affecting on the total accuracy obtained. Use of different flight lines resulted in different accuracies. For quality checking it is important to have control points distributed over the test area. Flight line adjustment is requisite for high quality products.

It was observed that the higher the flight altitude, the higher is the random error of terrain models. 800m flying altitude gives poorer results than 100m flying altitude. Laser measured heights are in general above the real ground surface. For asphalt surfaces a standard deviation of 10cm is obtainable from H=550m and from lower altitudes the results are even better.

A systematic error of typically 10 cm was observed due to observation angle changes.

All the three comparison methods seem to give similar results. This means that even the nearest laser point to the reference point could be used for quality control and the mean heights of laser points are not necessary for comparison.

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