PRACTICAL METHODS FOR THE VERIFICATION OF COUNTRYWIDE TERRAIN AND SURFACE MODELS

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ABSTRACT:

The Swiss Federal Office of Topography is leading a project for the determination of correct agricultural surfaces. As a part of this project, a Digital Terrain Model and a Digital Surface Model is being generated using airborne laser scanning methods. These two models must achieve a height accuracy of 50cm and a mean density of 1 point per m^2. One of the main tasks of swisstopo is to control the quality of the two models. To fulfil this task, a combined strategy using global and local control techniques has been established. This paper will focus on the philosophy and the tools swisstopo uses for the verification of a countrywide produced elevation model. Our investigations showed that quality control is mandatory when generating models by means of airborne laser scanning.

1. INTRODUCTION

1.1 The project LWN

Under the title "LWN" the Swiss Federal Office of Topography (swisstopo), on behalf of the Swiss Federal Office for Agriculture (BLW), leads a project for the determination of correct agricultural surfaces.
In many areas of Switzerland, particularly in the areas with extensive agricultural use, a significant number of objects represented in the cadastral maps, e.g. dynamic natural borders (forests, watercourses etc...) are out of date or only partly up-to-date. This situation is primarily due to the lack of suitable technical and economical procedures.

Wrong ground cover surfaces in the official cadastral surveying has led to

- Large uncertainties (in legal transactions)
- False evaluations (e.g. in the official evaluation of properties)
- Paying surface-dependent subsidies to the farmers for agricultural areas which have in reality became forest surfaces.

As the direct payments to farmers are mainly based on a surface value which is determined using the out of data cadastral data, a large scale project for the updating of cadastral maps is required.

The project is realized in two phases:

- Phase A, which takes place under the leadership of swisstopo. The production of an orthophoto mosaic (SWISSIMAGE), a digital terrain model (DTM-AV), a digital surface model (DOM-AV) and automatically extracted forest boundaries (AWG) are performed.
- Phase B, which takes place under the lead of each local region (canton) respectively. The digitization and the updating of the land registration maps as well as the calculation of the new agricultural areas, using the orthophoto mosaics.

1.2 The production of DTM-AV and DOM-AV

For the production of the required DTM-AV and the DOM-AV, swisstopo makes use of the airborne laser scanning technology. The production of these countrywide digital elevation models was assigned to private engineering companies as subcontractors. However, the project management, the verification and the examination of the quality requirements of the DTM-AV, DOM-AV, AWG and SWISSIMAGE remained a task of swisstopo.

The data acquisition and production of DTM-AV and DOM-AV will take place over a period of five years. The first period started in 2000 and the last period will end in 2005 (s. Figure 1).

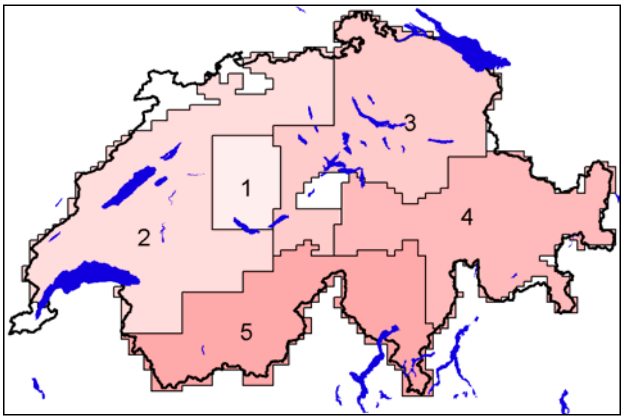

Figure1. The spatial distribution of the five data acquisition periods

The technical characteristics of DTM-AV and DOM-AV are:

- A height accuracy of ± 0.50 cm (1σ)
- A point density better than 1 Point / 2 m^2
- The permitted flight period extends from November to March, in order to be able to determine forest areas with sufficient reliability.

The elevation models are available in two formats. A raw data format, containing each filtered point observed point on the terrain or surface, and a "grid" format, containing a 2m grid derived from the filtered raw data.

The delivery of the elevation models takes place in blocks. A block consists of an approximate surface of 1'000 km^2. These blocks are delivered monthly by the subcontractors.

The verification of the data at swisstopo must take place within a two month time period. In the case of no re-flights being necessary, the correction on part of the subcontractors must take place in the same period.

This paper will focus on the philosophy and tools swisstopo uses for the verification of the countrywide produced airborne laser digital elevation model.

2. TASK OF VERIFICATION

A couple of organizations/countries have already experience in the production of countrywide terrain models by means of airborne laser scanning ([Scherer-Hertz, 2002], [Schleyer, 2002], [Wouters and Bollweg, 1998]). However, the quality of the produced terrain and surface models is the major factor for success and for the extensive use of the elevation models later on. The present state of the art shows that the derivation of terrain and surface models from filtered raw laser data is still subject to many sources of error (e.g. [Schenk, 2001], [Vosselman and Maas, 2001]).

In addition it has to be noted, that the experience of most of the airborne laser scanning data providers using Swiss type topography (mix of high mountains, hills and dense forest.) is limited. The flight and the derivation of terrain and surface models require special skills and can't be made solely with standard procedures. An independent control of the data to assure the homogenous production of the countrywide models is an absolute necessity.

Compared with the existing countrywide terrain model of Switzerland, DHM25 (a from the National Map 1:25'000 contour line based. terrain model over all Switzerland, with a height accuracy of 5 m for the Swiss Plateau and the Jura Mountains, 2 m for the Pre-Alps and the Ticino, and 3 m for the Alps) the new elevation models describe a new quality standard in terms of point density as well as height accuracy. Assuming that these new elevation models will be used for a long time as a basis for a lot of further applications and for continuous updating; swisstopo decided to invest time and money in a detailed verification of the DTM-AV and DOM-AV.

Quality control is done systematically and over the whole extent of the surface model and not in a random way as is commonly done. The controls had to be done mainly in the office, for reasons time, of efficiency, as well as for financial considerations. Field controls (field visits and GPS) had to be kept to a minimum and carried out only because of uncertainties with the office methods. All the test procedures had to be possible and displayable in the already existing GIS and PC environment. The quality checks are performed on the "raw" data sets and on the "grid" data.

3. THE VERIFICATION PROCEDURE

The initial question was: "How do you verify the most precise DTM and DSM of Switzerland?" After having tried different ways, the chosen solution is to perform checks directly on the new DTM-AV and DOM-AV data themselves in comparison and combinations with:

- Precise countrywide available topographic data (DHM25, 1:25'000 Pixel Map, the Orthophoto "SWISSIMAGE")
- Locally available precise single topographic fixed points (geodetic fix points, GPS measurements…)

Due of the characteristics of the input data, the controls are split in two classes: blanket coverage (global) and point wise (local) verification.

The controls of the elevation models are not an automatic procedure. The check of the data is under the responsibility of skilled operators. To support the operators several analysis tools have been developed. These instruments give clues to the quality of the models. The real job of the operator is to analyse all clues, to mark the suspicious areas and finally to discuss and transmit the problems to the subcontractors, so that they can be solved.

3.1 Global verification

In order to monitor and assure and standard quality of the data on all are of the new elevation models are checked in global verifications procedures.

3.1.1 Formal aspects: The first check carried out on the models is the control of the format and completeness of delivered data. The deliveries are checked manually by an operator and than saved on a server. The correctness of the format is than done automatically by a special script, which controls the integrity of the delivered files. Obviously, this seems to be a trivial task, but for an efficient procedure for the production and verification of a countrywide model this issue is critical. In case of non corresponding format a new delivery is requested from the subcontractor.

3.1.2 Density of the laser points: The quality of the final model is mainly defined by the accuracy of the single points, and by the density and the spatial distribution of these points. Based on the delivered "filtered raw" data the point density is calculated using a reference grid of 2 and 10 meters. The results of the calculations are represented with the help of two digital images (s. Figures 2 + 3). The colours of the pixel (1 pixel = 2 m or 1 pixel = 10 m) representing the amount of laser points falling in the 2 meter or 10 meter georeferenced squares. Figure 2 shows an example for a 10 x 10 m point density map calculated on a DTM-AV extract (black pixel= no point, white pixel = the point density is as expected, other pixel colours= the point density is less as expected). Figure 3 shows an example for a 2 x 2 m point density map calculated on the same DTM-AV extract as Figure 2. Hence, for the operator it becomes an easy interpretation task to check the quality of the point distribution.

Fig 2: 10 x 10 m laser point density calculated on a DTM-AV extract (1 pixel = 10 x 10 m)

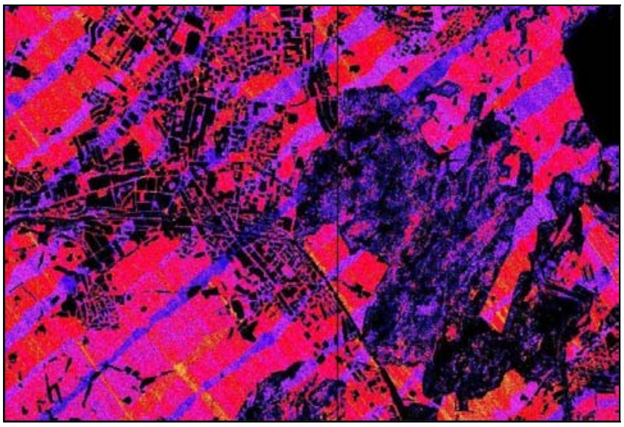

Fig 3: 2 x 2 m laser point density calculated on a DTM-AV extract (1 pixel = 2 x 2 m)

If the local distribution of the existing laser data has a significant impact then the data is rejected. The subcontractor has to analyse the cause of the bad point density and in a worst case scenario, has to re-fly the problem area again.

3.1.3 Height accuracy of DTM-AV and DOM-AV: The vertical accuracy of the terrain and surface model is checked in two different ways. First by analyzing the area surrounding a specific laser point (computing of gradients) and secondly by comparing the global trend of the terrain model with the existing DHM25.

Gradient:

Based on the delivered "filtered raw" data, a gradient is computed with a 3x3 Sobel kernel. The output is a grey scale digital image. The maximum slope, which is 2.5 [m/m], is represented by black pixels and the minimum slope of 0 [m/m] is represented by white pixels. The slopes over 2.5[m/m] are represented in blue. Figure 4 shows an example of a gradient calculated on a DTM-AV extract. The gradient gives a first representation of the topography and highlights the homogeneity of the objects, such as roads or groups of buildings.

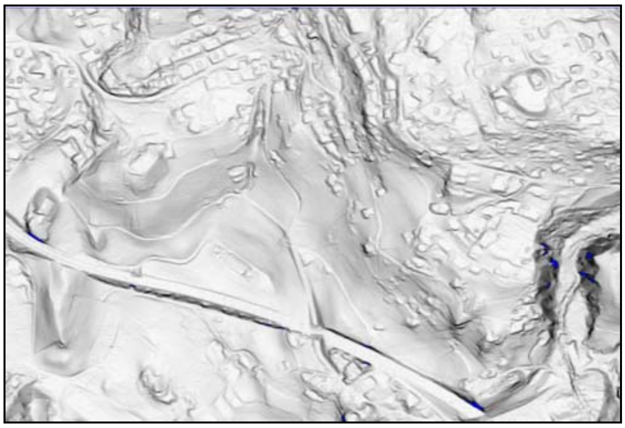

Fig 4: Gradient computed on a DTM-AV extract

Difference with the DHM25:

Using the DHM25 as a reference model, the height difference between this contour map (1:25 000) based digital terrain model and the new DTM-AV and DOM-AV is calculated (delta Z = new elevation models– DHM25). The result is represented in a digital image, where the colours of the pixel express the height difference. Fig 5 explains how the pixel colour is allotted in relationship to the height difference. Fig. 6 shows an example of a height differences map between a DTM-AV extract and the DHM25 and the colour legend. Height differences greater than 2 meters are considered as suspicious and analyzed in detail with the help of the gradient and the orthophoto mosaic. Smaller differences are due to the height accuracy of the DHM25 and are considered as insignificant. This test makes it possible to quickly highlight filtering faults in the DTM-AV data, for example points on roofs, or non eliminated points on vegetation such as trees. The problem areas are marked and delivered to the subcontractors.

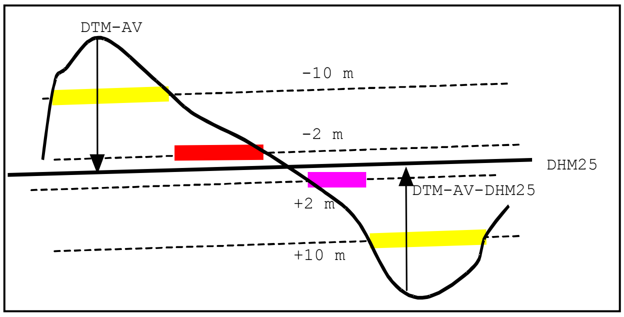

Fig 5: Diff. DTM-AV-DHM25: principle of the pixel colouring

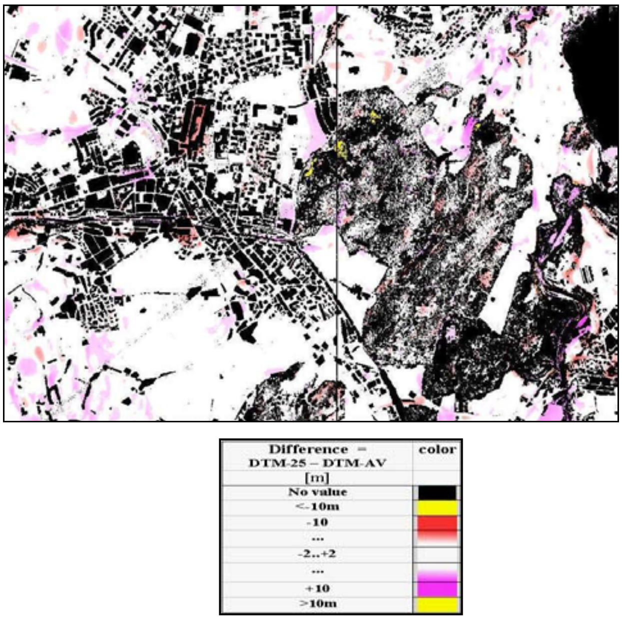

Fig 6: Diff. DTM-AV-DHM25 and colour legend

3.1.4 Consistency of DTM-AV and DOM-AV: This test takes into account that the terrain models and the surface models are per definition identical in open areas. To check the height accuracy and the homogeneity of the DTM-AV and DOM-AV, the height difference between the two elevation models is calculated (Delta Z = DOM-AV – DTM-AV). The result is represented in a digital image, the colour of the pixel expressing the height difference. Figure 7 explains how the pixel colour is allotted in relationship to the height differences. Note, that due to the different point locations of the two models and the underlying triangulation assumption for the DTM-AV, it is mathematically possible that the difference between the surface model and the terrain model is slightly increased to a certain extend. Each difference higher than ±1.5 meters (3σ) in open area is suspicious and examined in detail. This allows the detection of errors in both models such as snow areas, non-eliminated corn fields, non-eliminated cars, etc.

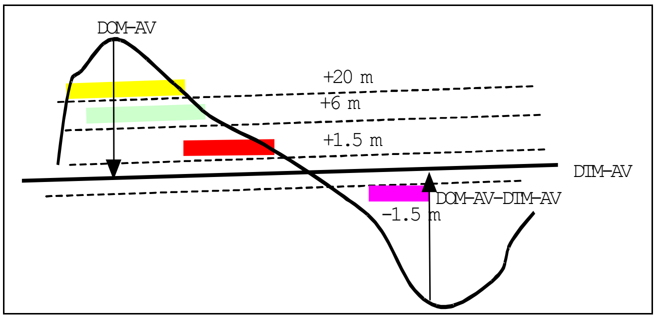

Fig 7: Difference DOM-AV and DTM-AV, principle of pixel colouring

3.1.5 Slope filtering: In order to find erroneous or non filtered laser points in the elevation models a slope filtering using mathematical morphology is run on the DTM-AV and DOM-AV laser data. The points identified as non-ground point are expressed as coloured pixels (1 Pixel = 1 m x 1 m) in a digital image. Figure 8 shows non eliminated laser data on trees in a DTM-AV extract. The slope filtering helps to localize these suspicious non-filtered points. With the help of the gradient, the orthophoto and the difference to the DHM25 the points are analyzed and classified as correct and incorrect points. A list of the incorrect points is transmitted to the production.

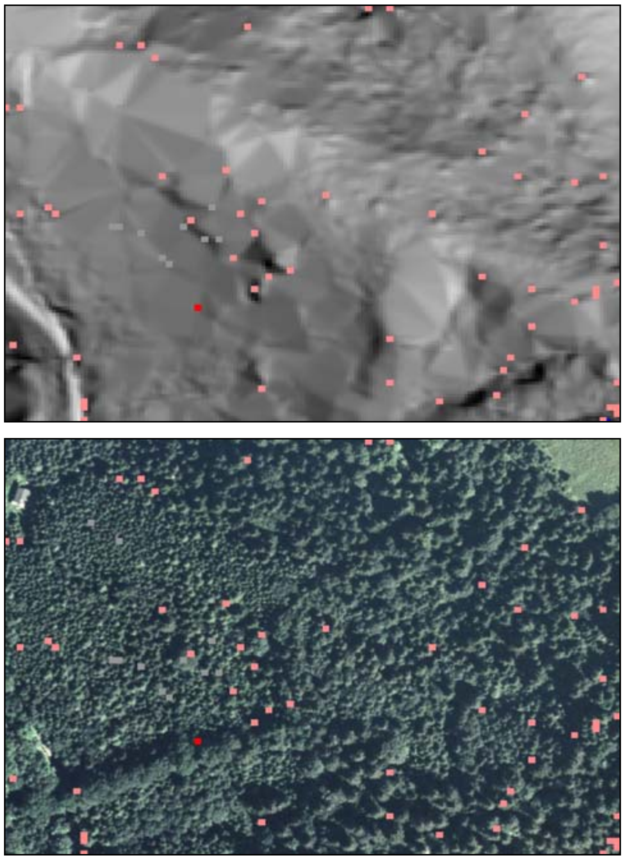

Fig 8: Result of the slope filtering. Top: Gradient and suspicious laser points. Bottom: orthophoto and suspicious laser

3.2 Local verification

In order to judge the absolute height quality of the elevation models and to check Results of the global verification local verification are achieved.

3.2.1 Height accuracy of the DTM-AV and DOM-AV: To check the height accuracy of the DTM-AV and DOM-AV, precise topographic data like GPS measurement and geodetic fixed points are used. The height difference between this data and the interpolated DTM-AV and DOM-AV is calculated and interpreted visually in a GIS. In Figure 9 the combination of an orthophoto and the height differences between the DTM-AV and geodetic fixpoints is shown. Each coloured point representing a geodetic fix point and a height difference compared to the DTM-AV. Height differences greater than 1.5 m (3σ) are analyzed and error are transmitted to the production.

Fig 9: Difference between geodetic fixpoints and DTM-AV

3.2.2 Plausibility of the elevation models: To check the plausibility of the morphology of the elevation models and to check suspicious laser points, the data can be analyzed directly with the help of a point editor software. Figure 10 shows a DOM-AV extract loaded in the point editor GVE. In order to check the plausibility, contour lines have been generated and compared with the orthophoto. Each single point can be displayed and edited. The amount of dots on the screen and the computer capacities are limiting factors to this kind of procedure. This is one of the reasons why most of the controls are performed with our own software "LWN Check" (see chapter 3.4), who ensure the operator a fluent interpretation on the screen. The point editor is used only in uncertain situations.

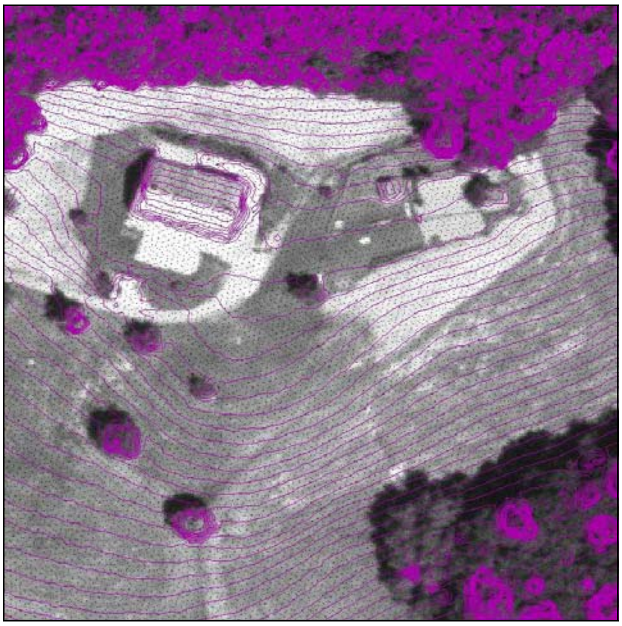

Figure 10: Laser point of a DOM-AV and calculated contour lines (Inpho GVE 5.43)

3.2.3 Field controls: Another way to check the plausibility of the elevation models is field visits. These field visits are very time consuming and carried out only if the office tools do not deliver clear results. However, these field visits are a unique source for the verification of the elevation models as these models should describe reality. These two methods are used mostly to confirm errors found using the other tools.

3.3 Combination of global and local verification: All of the above presented tools and representations of the laser scanning data are very helpful in order to the find errors in the DTM-AV and DOM-AV data. However these tools do not extract and judge the error by themselves. They only give clues and have to be interpreted by an experienced operator. Hence only the combination of these different data sets and representations enables a human operator to make relevant statements about the quality of the DTM-AV and DOM-AV data sets. Often the operator has only clues as to the reasons for the errors, but only a detailed discussion with the subcontractor can provide answers to the problems**.**

3.4 Used software

To perform all the checks, swisstopo developed his own software routine called "LWNcheck". This software simultaneously treats both "grid" and "filtered raw" DTM-DOM formats and automatically processes a number of tasks such as those described above. The majority of the results are expressed in TIFF image format to improve their legibility in a GIS environment.

This software consists of a main program managing the whole processing (Perl) and a package of optimised programs (C) carrying out the controls. The use of the software package is made as simple as possible by the use of a single description file which contains all the system parameters and a "log" file which indicates the test status.

4. CONCLUSION AND OUTLOOK

From the first experiences made in two and a half years of the verification procedure at swisstopo with approximately 13,000 km^2 of verified data (DTM-AV and DOM-AV respectively), we can draw the following conclusions:

- Global verification is essential

The experience from the achieved verification showed, that a systematic global control of the produced DTM-AV and DOM-AV is absolutely necessary. Despite the experiences and the quality management of the laser scanner data provider, the delivered data still contains substantial errors. The types of errors were multiple, varying from less problematic filtering problems to serious calibration and mistakes such as gaps in the data. The geographical location of these errors showed up to be distributed in random way.

- The verification contributed substantially to the quality of the final products

The experience of the achieved verification showed that a verification independent from the production contributes substantially to the quality of the products.

The relatively limited experience of airborne laser scanner data providers with the specific topography of Switzerland led in the initial phase of the project to the delivery of bad and useless DTM-AV and DOM-AV.

Only an open communication with the subcontractor on the methods and the clear results of the verification led to a better mutual comprehension and finally to better products.

- The verification expenditure is significant

The verification of countrywide produced models is rather demanding. The administration of the large datasets, the time expenditure for the compilation of the test routines, the time expenditure to check the data on a computer screen are not insignificant. On the average an experienced operator needs for the verification of 200 km^2 of DTM-AV and DOM-AV approx. 4 working days. At the moment swisstopo employs 4 persons only for the verification of these new data sets.

In order to assure the production of a high quality countrywide airborne laser product, independent blanket coverage verification is a necessity. In a procedure combining the new DTM-AV and DOM-AV data with other topographic data, the verification can be done efficiently in the office. Meanwhile it is a demanding work, where know-how is essential.

For the moment the production was restricted to the mainly flat parts of Switzerland. New production will take place in the Alps, and it is expected that new types of problems will appear and that the verification routines will have to be improved and adapted.

5. REFERENCES

Schenk T., 2001. Modelling and Recovering Systematic Errors in Airborne Laser Scanner, Proceedings of OEEPE workshop on Airborne Laserscanning and Interferometric SAR for detailed Digital Elevation Models 1-3 March 2001. Royal Institute of Geodesy and Photogrammetry, 100 Stockholm, Sweden, March 2001.

Scherer-Hertz, J., 2002. Digitale Geländemodelle in Bayern. DGM-Anwenderseminar. Landesvermessungsamt Baden-Württemberg, Germany, September 2002.

Schleyer, A., 2002. Baden-Württemberg auf dem Weg zu einem digitalen Geländemodell. DGM-Anwenderseminar. Landesvermessungsamt Baden-Württemberg, Germany, September 2002.

Vosselman, G and Maas, H.G., 2001. Adjustment and Filtering of Raw Laser Data Altimetry Data. Proceedings of OEEPE workshop on Airborne Laserscanning and Interferometric SAR for detailed Digital Elevation Models 1-3 March 2001. Royal Institute of Geodesy and Ph0togrammetry, 100 Stockholm, Sweden, March 2001.

Wouters, W. and Bollweg, A., 1998. AHN: Actual height model of The Netherlands – a detailed elevation model using airborne laser altimetry. GeoInformatics, vol. 1, September 1998.