3D MAPPING OF SWITZERLAND –CHALLENGES AND EXPERIENCES

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KEY WORDS: Airborne Laser scanning, High Resolution, DEM/DSM, Large Datasets, Project, Quality Management

ABSTRACT:

Airborne Laser Scanning was used to map Switzerland. Large parts of the project area are in mountainous terrain and all processes had to be adjusted to this challenging terrain to obtain the desired product quality. The required vertical accuracy on hard surfaces was 0.5 m, the achieved vertical accuracy is approximately 0.3 m (1 Sigma). The required point density in the open area was 0.44 Pts/m^2, the resulting one is almost 1 Pt/m^2.

Among others following factors were critical for the success of the project: optimized flight planning for the data collection in the Alps, adjusted automated filtering algorithms, both impossible without a profound knowledge of the topography. Finally the huge amount of data must be managed carefully and the project management must be supported with appropriate software tools.

1. INTRODUCTION

Airborne Laser-Scanning became more and more mature over the last years and it replaced traditional methods like stereo Photogrammetry for the creation of Digital Terrain and Surface Models (DTM, DSM). Once the technique was established and widely accepted it was used in larger projects and also in more challenging topography (Ruiz, 2004). In this paper we describe the experiences from a large mapping project in Switzerland where Airborne Laserscanning (ALS) was used to produce DTM and DSM. Compared to other ALS projects which are similar in size, like for the Duch AHN (Crombaghs, 2002) or for the new DGM in Baden-Wuettemberg (Schleyer, 2001), the main differences with respect to the requirements can be explained by the different topography:

- In flat areas the accuracy of the single point is critical for water management and/or flood risk modeling. Introduction of break lines might be useful.
- The automated filtering of the point cloud in *difficult* topography is less reliable and more manual editing is needed, see also (Sithole, 2003).
- The point density has to be higher in mountainous areas to describe the landform better.

After a description of the project in section 2 we discuss the main issues on data acquisition (section 3) and on post-processing and filtering (section 4). In section 5 impacts on the data management are studied.

2. DESCRIPTION OF THE PROJECT

2.1 Background

In 1999 the Swiss Federal Office of Topography ("swisstopo") started a project together with the Federal Office of Agriculture to update the land use data in the Swiss Cadastre (see also Artuso, 2003). It has been observed that in many areas of the country - especially in remote ones – dynamically changing, natural objects like forest boundaries or creeks are often not up to date in the surveying cadastre. The main purpose of the project was to resurvey the agricultural (non-) productive areas, because the government subsidies ("direct payments") distributed to the farmers depend directly on the farmed area. swisstopo decided to use Airborne Laser-Scanning (ALS) and Airborne Imaging with the object to produce a directly measured digital terrain and surface model, thereof automatically derived forest boundaries and a digital color orthophoto mosaic over an area of approximately 31'000 km^2 (see figure 1). Not included in the project perimeter are areas above the forest limit (2000 m respectively 2100 m above mean sea level) and some areas where a DEM has already been produced (like Canton of Geneva or Canton of Jura). The data acquisition part is divided in five lots (L1-L5). Where not stated otherwise the experiences refer to lot 2 to lot 4.

2.2 Requirements

In the Terms of Reference (TOR) different high level requirements for data acquisition and products are defined. Most important requirements and specifications from the TOR are listed below:

Data acquisition: The flights must be conducted in leaf off conditions (high penetration in forested areas) and the snow height shall not to exceed 10 cm. The flight season is limited from December to June.

Digital Terrain Model - DTM: The DTM is defined by single points on the ground surface, any vegetation or vertical constructions must be filtered out from the original point cloud. The vertical accuracy (RMSE) at any location must be better

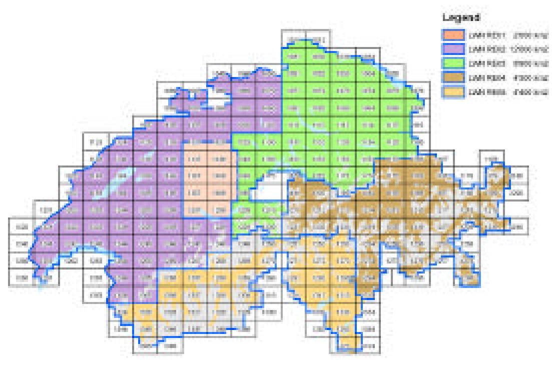

Figure 1. Project perimeter and the five lots

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than 50 cm (1 Sigma). The point density should not be less than 0.44 points/m^2 in open areas or 0.14 points/m^2 in forested areas. The points spacing in open areas should not exceed 2 m.

Digital Surface Model - DSM: The DSM contains the enduringly visible surface, including perennial vegetation and vertical construction. Annually changing vegetation like crop or corn is not part of the model. Moving objects like car, boats, trains, or small vertical structures like stop lights, towers or overhead lines have to be removed from the data set. The points belonging to the DSM must be classified into *ground points*, *vegetation* and *construction*. The vertical accuracy defined as root mean-square error (RMSE) at any location on ground or hard surfaces must be better than 50 cm (1 Sigma).

2.3 Perimeter

The first lot of 2'000 km^2 started in 1999 and served as a pilot project to ensure that ALS is the right technology for this task. An overview of the project extent can be found in figure 1. The Swiss topography can be simplified as following:

a) Central midland between Lake Geneva and Lake Constance; densely populated, but moderate topographic changes ("rolling hills"). It covers approximately 40 % of the entire project area.

b) Jurassic mountains; steep cliffs, mainly dominated by coniferous forests. Approximately. 10 % of the area.

c) Main valleys of the Alps – Aare, Rhone, Rhine, Reuss, Ticino and side-valleys; formed by glaciers and streams, moderately populated on the flat ground. Lots of steep edges, cliffs, many turns and large height differences to surrounding mountains. Approximately 20 % of the area.

d) Alpine; beautiful for hiking or skiing but a nightmare for airborne data acquisition! Approximately 30 % of the project area.

In table 2 one can find more details on the topography for each lot. These values are derived from an intersection of a 10 m digital height model with the deliverables tiling schema. Average height, slope and range refer to the entire project area where highest average slope and highest range are based on statistics on the single tiles (3 by 4.375 km) to give an impression about local varieties.

	L1	L2	L3	L4	L5
Average elevation (m)	850	892	885	1720	1483
Average slope (degree)	13	13	14	25	27
Average elevation range (m)	474	509	562	714	876
Highest average slope in a tile (degree)	32	38	45	47	41
Highest elevation range in a tile (m)	1'467	1'686	1'688	1'858	1'813

Table 2. Statistics on the topography within each lot.

3. AIRBORNE DATA ACQUISITION

3.1 Sensor

Two different sensor models have been used during data acquisition over five year (L2 – L5). TerraPoints ALTMS 2536 was employed in three projects and an Optech ALTM3100 in the last one. Due to the long period of the project the technology of scanners evolved and some of the developments were directly influenced by this project. Table 3 shows some important system settings we used in the projects. Note: the beam divergence of the ALTMS 2536 has been reduced several times to increase the number of returns for longer ranges.

	Lots 2-4	Lot5
Manufacture	TerraPoint	Optech
ALS model	ALTMS2536	ALTM3100
Inertial measurement unit	Honeywell H-764G	Applanix POS AV 510
Scan pattern	Parallel Lines	Saw tooth
Maximum returns	4	3 plus last
Roll compensation (degree)	-	maximum 7
Beam divergence (mrad)	1.2/0.9/0.8	0.3
Scan rate (Hz)	43	22
Scan angle (degree)	± 18	± 23
Pulse rate (kHz)	20/25/25	50
Ground Speed (KT)	110	110
Flying height above ground (FT)	3000	4900
Foot print (m)	1.10/0.82/0.73	0.41
Strip overlap (%)	40 – 50	50
Spacing across (m)	1.31	1.11
Spacing along (m)	1.31	1.28

Table 3. ALS characteristics and parameters of data acquisition

3.2 Flight planning

The planning of the flights was influenced by the characteristics of the deployed unit, the project requirements, the performance of the aircraft and most important by the topography. To avoid many, but short lines we decided to fly contour lines instead of at a constant flight level. The main flight direction for each block was given by the main valleys and the mountain chains. For mid-sized valleys separate flight lines were planned. Cross lines were added after initial flights where the local topography impeded the successful data collection. This happened typically where the air-ground distance over crossing valleys was longer than the maximum range of the ALS. Due to the overlap of the mid-sized respectively the cross lines with the main flight pattern we received a stable data base for strip adjustment. Figure 4 gives a good impression on the complexity of the flight planning for the Reuss valley in the Canton of Uri. The north-south extent is 23 km. White areas are above 2100 m and thus not part of the area of interest. Figure 5 gives an impression on the challenges in the data acquisition: the trajectory of four lines in the Reuss valley is overlaid with a DEM.

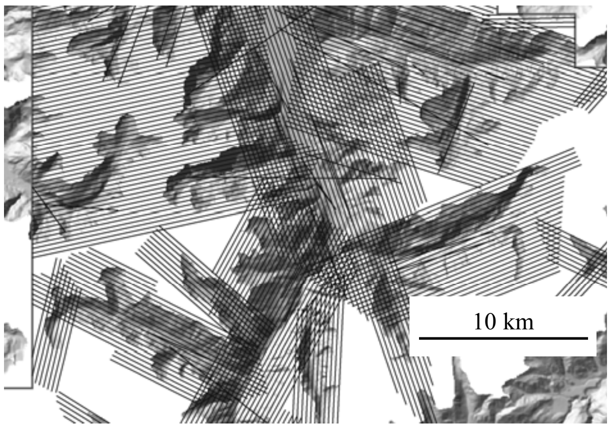

Figure 4. Planned flight lines for the area of the Canton of

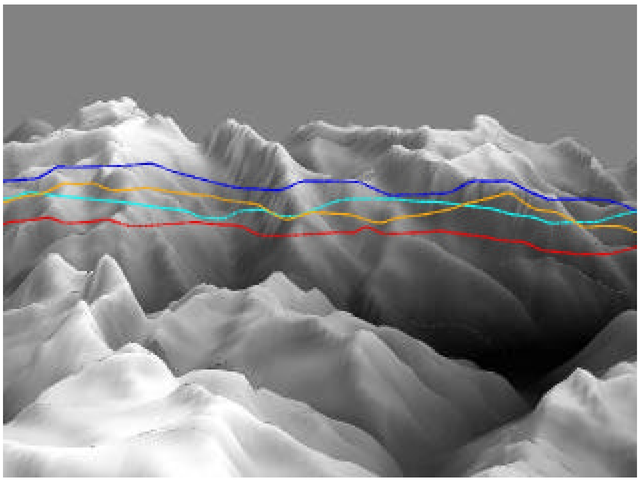

Figure 5 Processed trajectory of four flight lines over the Reuss valley

3.3 Data collection

The ALS was installed on a Pilatus Porter PC6 because of the performance and flexibility of this aircraft. Originally we planned to fly one lot per flight season (December until June), but due to weather and quality impacts on the data, lot 2 and 3 were flown over a period of 3 years and lot 4 over two years. Two ALS units and aircrafts were assigned for several months to speed up the data collection.
Compared with a project in a similar topography (Rieger 2005) the area covered by one flight line is here larger by a factor of 1.5. Therefore we could prove that the decision to fly contour is more efficient than flying on fixed flight levels.

	Number of missions	Number of flight lines	Total length of flight lines (km)	Average length of flight line (km)
Lot 2	211	2'988	59139	19.8
Lot 3	185	2'035	34'061	16.7
Lot 4	165	2'720	29'540	10.8
Lot 5*	75	1'000	18'000	17.0

Table 6 Statistics from data acquisition. Numbers from lot 5 are estimated based on 70 % of the flights done

3.4 GPS reference station

For each mission we run one GPS reference station at our own. Additional reference stations were provided by swisstopo through their Automated GPS Network of Switzerland (AGNES). For the operation we had to consider the distance between the reference station and the area where we had planned to fly, but also satellite availability and elevation masks. Special attention had to be put on the location of the reference station in order to keep the visibility to the satellites high. Even by following this, the operators were forced several times interrupting a flight due to a high PDOP. To ensure the requested accuracy, we decided to keep the baseline distance typically < 30 km and PDOP < 5. When the weather condition did not allow flying where planned or when the baseline exceeded the 30 km we first flew into that area and set up a GPS station.
Thanks to enhancements in the software for GPS post processing (POSPac 4.2 respectively GrafNav) several reference stations could be used now during one mission. This allows reacting more flexibly in the field operation of the last lot. Thanks to the excellent coverage of AGNES stations throughout the country (swisstopo, 2005) different regions can be covered within one mission by using the closest AGNES station as GPS reference.
Initially we logged the GPS data with 1 Hz frequency in the last lot we increased the rate to 2 Hz, AGNES data is provided at a rate of 1 Hz.

3.5 Sensor calibration and strip adjustment

The steep terrain reveals any misalignment of the strips and we decided to fly over a control site at the beginning and at the end of each mission to verify roll, pitch and heading drift compensation. Still the differences between adjacent strips were too often not within the tolerance. TerraPoint as the operator of the ALTMS 2536 equipment developed a strip analysis where additional installation parameters were gained to compensate for some misalignments in the optics and also to improve the reliability of the drift modeling (Latypov, 2002). This tool solved for most areas the problems. Nevertheless we observed some cases where local differences between strips reached locally up to 2 m which had to be cleaned manually. The reasons for these steps were not researched in detail but we found them typically in step terrain where the pilots tried to follow the terrain flying sharp tilts. Furthermore the effect of horizontal errors and different ranges from two adjacent spots collected from different flight lines were not included in the strip analysis.
For the current lot 5 we are using the Optech ALTM3100 and the first results show significantly less problems. We explain that with the higher acquisition rate of the Inertial Measuring Unit, more channels of the GPS receiver and the roll compensation (up to ± 7) degree.

3.6 Remarks on data acquisition

It became very quick evident, that a high flexibility in the logistics are required in the data acquisition. The weather conditions in the Alps may change very quickly and the local variations are often unpredictable.
After the first winter with few snow and large non mountainous areas it turned out during the following flight seasons that some requirements on the data acquisition are contradictory: less than 10 cm of snow and leaf-off conditions are for large parts of the projects can be found only in late fall. But since up to 50 % of the area of Lot 4 and 5 are above 1500 m with corresponding long winters, a certain amount of snow in higher regions had to be accepted. Especially because many of the flight lines cover regions from 800 m up to 1800 m, and therefore having sometimes winter and spring conditions along the same line. It was also the clients preference, to have some level of snow compared to leaf-on conditions, because according to the Swiss cadastre the accuracy requirement is less rigid in higher, less populated areas.

4. DATA POST PROCESSING

After the calibration of the mission the range measurements were processed to points (ellipsoidal coordinates). Then the points were transformed to the Swiss projection and the geoid undulation was applied. Even though commercial applications are available for this task we integrated the projection formulas in our own software tool to increase the performance. In the following section we want to discuss some details and

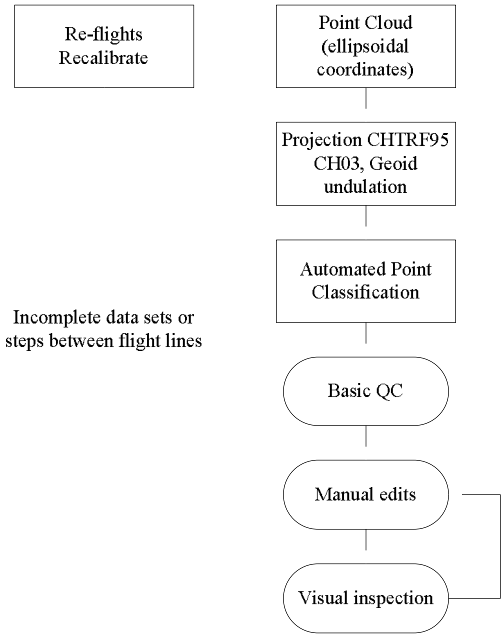

Figure 7. Flow chart of data post processing

experiences in the filtering and classifying of point clouds in mountainous terrain. Figure 7 shows the process steps in the data post processing. Irregularities in the data were found at latest in the Basic Quality Control (QC). In some cases several iterations were necessary for manual editing/visual inspection.

4.1 Automated classification - filtering of ground points

For the filtering of ground points we relied on the software TerraScan from the Finnish company TerraSolid (Soininen, 2004). It offers various algorithms to filter points and also various tools for manual classification. The filtering of ground points is based on the adaptive triangulation algorithm (Axelsson, 1999). Several parameters can be used to adjust the algorithm to the current topography. In combination with other TerraScan filtering algorithms (especially to remove low points) and classification functions (like using only the last return as potential ground measurement) we put together our own routines. Over the time we refined these routines to optimize the classification to the used sensors and the local topography. The error rate in the classification was between 0 and 10 % of all points, where zero defects was only achieved in tiles with flat and moderate rolling terrain. The percentage of point misclassification is not directly related with the manual corrective action. Groups of erroneous points caused by sensor faults (see section 3.5) could not be eliminated during the automated classification process and caused a lot of manual editing. Taking into account only the *correct* measurements the misclassifications can be characterized as follows (see also Ruiz, 2004).

Points *not recognized* as ground points,

- On steep mountain tops or ridges;
- in trenches with sloping walls (steep valleys);
- on (overhanging) cliffs;
- where the density of ground points is low because of dense vegetation (young coniferous forest or flying under leaf on conditions).

Points *wrongly classified* as ground points,

- on bridges (especially footbridges);
- on very large industrial buildings;
- on construction attached to the ground;
- on shrubs and bushes where the density of ground points is low.

The ISPRS report (Sithole, 2003) and also newer publications on that topic, for example (Crosilla, 2004) showed clearly, that every filter algorithm has its weaknesses. To reduce the editing time we tried to minimize the numbers of single misclassified points but accepted to have large objects entirely wrong, because these are easier to detect and correct.

The most time consuming tasks in the manual editing were:

- Removing erroneous points like clusters of low points or even complete scan lines vertically shifted;
- local steps between strips, either due to different snow levels or due to the abovementioned issues on the calibration;
- determine ground in forested areas with low point density;
- detect small objects attached to the ground;
- forested areas in steep and rough terrain.

Since some of these problems are not caused by the filter algorithm to reduce the work and increase the quality the focus has to be put on the data acquisition.

4.2 Classification of DSM points

The DSM point had to consist per requirement of the first returns which needed to be classified into ground points, vegetation and construction. To increase the efficiency of the production we decided to process the DSM together with the DTM. The degree of manual editing for the DSM was significant higher than the DTM: due to the specification only permanent objects were allowed in the data set which meant that wherever recognizable objects like trains or annually changing vegetation etc had to be removed. From the remaining point cloud the ground points were classified according to section 4.1. For the building points we referred to the algorithm provided by TerraScan but we had also for part of the area building footprints from cadastral surveying available which were used for the classification. Lots of discussion arose how well one can determine correctly from which kind of object a laser impulse has been returned. It became evident that only a pragmatic approach allowed completing the project in time.

4.3 Quality inspection

Quality management played a central role in these projects (Luethy, 2004). Before starting the first lot it was requested to develop a quality plan which included all work flows and relevant quality check (QC) procedures. In this paper we want to focus on the QC of DTM and DSM because of its impact on the data management.

For the **Basic QC** the point cloud was automatically classified according to the mentioned procedure. The goal of the Basic QC was to detect data gaps or slivers between strips, to check the overall accuracy of the data and to verify the goodness of the strip adjustment. The completeness was checked visually with density grids which we derived for different cell sizes and almost any issue was easily detected. The overall accuracy was determined by elevation fix points and ground control points (GCP). Strip misalignments were more difficult to identify on a large scale; we achieved best results by calculating the difference between the DSM and the DSM. Since the classification algorithm classifies the lower surface as ground and the upper surface as DSM, the difference grid shows a

pattern which could not be explained by topographic features. If the Basic QC failed, appropriate corrective action was taken.
For the **Visual Inspection** of the classification various data sets were generated out of the point cloud. Additional data sets like Pixelmap or Orthophoto were provided and used as reference. To check the DTM we used: point density (2m, 10m and 100m cell size), hillshaded DTM, slope grid, contour (2m, 5m or 10m interval, depending on the elevation range), difference to GCP and fix points and the DSM-DTM difference. For the DSM we used also point densities grids, hillshaded DSM, vegetation grid (i.e. a grid which was interpolated from vegetation points only), hillshaded building grid and DSM-DTM grid. Obviously these data sets are only one aspect of a reliable inspection. Due to the limited statistical tests it was necessary that all editors and inspectors had a good understanding of the requirements, the landscape and the imagination for 3D geo-data sets. Field trips can be a helpful to familiarize with region specific geomorphologic, architectural and topographic features.

4.4 Education

Since manual correction and visual inspection have to do a lot with experience, interpretation and know how, the training is a central element in the production. The work flows were taught with written documentation and were accessible on the intranet. Depending on the project progress and therefore changing topography and/or geomorphology refresh courses were held to ensure that everyone learned the particularities and followed the same policy. Also new sensor techniques or new problems from data acquisition required an update of the training. Despite all these trainings everyone had their favored tool which was accepted as long as the results fulfilled the specification and the process was efficient.

5. DATA MANAGEMENT

5.1 Data sets

Over the last four years a huge amount of data has been collected, processed and temporary data sets have been generated. For the considerations on data management the data sets can be simplified as follows:

- Laser data
- Data sets for Quality Control
- Production Meta data
- Deliverables

While some of the above-mentioned data sets need special attention because of their size, others need to be treated carefully because of their importance for subsequent processes and some are both huge and essential. Yet it is evident that the data management is also a key factor for such projects. In other fields of data processing a standardized data model and a database with secured transactions are used. But the efficiency of these systems is not yet considered to be appropriate for large laser data sets. Typically the laser data is stored on a file base while auxiliary data may be stored in a GIS database (Hug, 2004).

5.1.1 Laser Data: The laser data run through various stages from the data acquisition to the final deliverable. Some intermediate stages need only processing time and are therefore less vulnerable but others are essential and critical for the processing. Processing out the strips to the point cloud in ellipsoidal coordinates, the transformation into the local coordinate system and splitting the points into tiles is time consuming but in case of failures the steps can be redone without loss of data.
We decided to process the tile with a buffer of 30 to 50 m to reduce artifacts along the tile borders. The buffer was generated on the fly, so no points were stored redundantly. The fact that the data was organized as flat files implied careful handling and organizational aspects (rules and roles) were important.

5.1.2 Data to support Quality Control: After every iteration of classification in TerraScan a visual inspection was performed. The data sets used for that have already been mentioned before. *Temporary data sets* were derived in an automated procedure and loaded into ArcView. Management of these temporary data sets was not so critical because the processing time per tile was less than five minutes. In case of failures or corruption of the files we were able to reconstruct them in short time.
The *additional basic data* for visual inspection were made available partly as raster and partly as vector data sets. The management of these data required only minimal interaction, mainly to conform to naming convention and to keep the data volume as low as needed.

5.1.3 Production Meta Data: Besides the data sets which were needed directly to process or inspect the required products there were obviously many other data sets involved. We subsumed these as production Meta data. Herein fall for example the information from the calibration site and the control fields, but also the tiling schema. We used the tiles to link the progress status: For each tile we wanted to know which processing step already happened and which ones were still outstanding. This was achieved by developing a Monitoring Database (MDB): each editor updated the MDB after each completed step for every tile. The following automated process was able to as well check the start-status (precondition fulfilled to run the process) as to change the status after the process had run successfully. Visual reports generated from the MDB helped the production manager to determine which co-worker was ahead or behind the schedule and therefore to optimize the resources. Finally the project

Lot	Number of tiles	Average number of DTM points per file	Total points in DTM	Average DTM point spacing (m)	Total points in DSM	Average DSM point spacing (m)	Average data file size (MB)	Total size ALS data only (GB)	Temp. data for QC (GB)
2	3780	2'457'500	9.22E+09	1.15	1.45E+10	1.10	92	346	1’360
3	3000	2'865'500	8.38E+09	1.03	1.15E+10	0.88	94	276	1’080
4	2660	2'378'800	5.35E+09	0.91	7.52E+09	0.77	80	180	960
Overall	*9440*		*2.23E+10*		*3.35E+10*			*802*	*3’400*

Table 8. Points statistics and data volume for each lot and the grand total over three lots.

manager used these reports also to decide when to bring new data on-line and to initialize the production processes.

5.1.4 Deliverable: For the delivery of the data to the client the data had to be merged from processing unit to the deliverables unit. Again this process was fully automated and could be started from the MDB as soon as every tile was marked as "Passed QC".

5.2 Data Volume

A strict management of the different data set was indispensable to handle the huge data volume we generated and processed over the years. Table 8 gives a good idea about the data volume: the specifications regarding point spacing were overall exceeded and only in few areas not met completely. The volume of the data is not impressive when talking about single files with the laser points. But when considering the number of tiles and the temporary data sets which had to be generated or used for visual inspection then the volume becomes more impressive.

5.3 Data organization

Having the data volume in mind it becomes evident that the data organization is also a deciding factor for these projects. We must ensure that we have enough space on the data server to run the current processes without adding new disk space every other month! Therefore all processing tools were elaborated to minimize the volume of the data sets and to automatically delete obsolete data. Nevertheless it is important to assign a person to scan the data server for any irregularly created files and to clean up after completing the production for a certain region.

The linking and automation of the tools allowed processing large amounts of data sets overnight or over the weekend. Thus we were able to react quickly on the progress in the production. After the delivery of a region the data was archived in a tape library. Almost all on-line available data was thereby actually in production.

6. CONCLUSION AND OUTLOOK

With this project we could prove that Airborne Laser Scanning technique is mature for high quality DTM and DSM even under very difficulty mountainous conditions. The challenges started with the flight planning where the decision to fly contour reduced the costs for data acquisition without significant loss of quality. The point density exceeds the specification with the exception of some small areas. The vertical accuracy – i.e. the RMSE (1 Sigma) determined by the difference between ground control points and the DTM – is 31 cm (lot 2), 25 cm (lot 3) respectively 34 cm (lot 4). The largest differences were measured close to artificial features (roads, bridges and buildings) and in forested areas. In both cases the visual inspection showed that the error arose because of the interpolation of the model, not because of false filtering or erroneous coordinates.

Due to the size of the project the rigid management of the production is crucial. The project management must be supported by a tool to track of the progress and to plan the allocation of resources. Several tools have been used to automate as many processes as possible but manual editing of the data, visual inspection and continuous training are inevitable.

Obviously there are several different actions we had to take for a successful production. We see room for improvement by differentiating the raw points according to a quality estimate. We can approximate the accuracy for each point, using the system characteristics, the trajectory quality estimate, range and scan angle values. With this measure only the best points could be used in further processing and reducing some of the problems mentioned in section 4.1 seem to be achievable.

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