The influence of DEM characteristics on preprocessing of DAIS/ROSIS data in high altitude alpine terrain

Daniel Schläpfer, Benjamin Koetz, Stephan Gruber, Felix Morsdorf

Remote Sensing Laboratories (RSL), Department of Geography, University of Zurich
CH-8057 Zurich, Switzerland
dschlapf@geo.unizh.ch

Key Words: Geocoding, Ortho-Rectification, DEM, DSM, DTM, Preprocessing, PARGE, ATCOR

ABSTRACT

In summer 2003, an unique imaging spectrometry data set has been recorded in the Swiss Engadin Valley regionin the framework of the European HySens project using the imaging spectrometers DAIS-7915 and ROSIS. This paper deals with specific issues in the geo-atmospheric preprocessing of this topographically challenging data sets, investigating the influence of digital representation of the terrain. For both geometric and radiometric preprocessing, an accurate digital elevation model (DEM) has to be provided. For the test area, several sources of DEMs are available: a standard DEM from national cartography, a DEM derived from digital photogrammetry, and a LIDAR DEM acquired within 3 months of the scanner data acquisition. Practical recommendations are finally given on the best suited DEM data source and on generic rules for its preprocessing in view of geometric and radiometric preprocessing.

1 INTRODUCTION

Geometric and radiometric effects are the major distortions inherent to airborne imaging spectrometry data and need to be corrected for physically-based validation of the imagery and quantitative extraction of surface characteristics. The prerequisite for the preprocessing is an accurate description of the image image geometry on a pixel level. This includes the geometric surface characterisitics given by a digital elevation model (DEM). The elevation data is usually given as Digital Terrain model (DTM) or as digital surface model (DSM), wherefrom the latter is considered as the optically relevant data.

An integrated geo-atmospheric correction chain is applied to the DAIS (Chang et al, 1993) and ROSIS (Doerffer et al, 1989) imagery. The orthorectification of the imagery is done using the parametric geocoding procedure PARGE (Schläpfer and Richter, 2002; Schläpfer, 2002). The methodology allows for the correction of sensor movement dependent distortions in airborne imagery with direct intersection to a the elevation model. Theoretically, a DSM at a resolution of the sensor geometric instantaneous field of view (IFOV) would be the best basis for this type of processing. If uncertainties in the position knowledge persist, the DSM has to be degraded to the theoretical accuracy achievable based on the provided sensor attribute data (i.e. geometric sensor model and navigation parameters).

The radiometric processing is done using the ATCOR 4 method (Richter and Schläpfer, 2002). This program simultaneously corrects for topographic illumination influences and atmospheric radiative transfer effects. Its method uses a co-registered digital elevation model and DEM-derivates such as terrain slope, aspect, cast shadow, and skyview factor to calculate the complete radiometrically relevant geometry for each pixel. The preprocessing of the DEM is therefore an important task prior to the application of the ATCOR4 method.

2 DATA BASIS

Three distinct campaigns were carried out in summer 2003 in the Swiss Engadin valley. The first two campaigns were carried out under the hood of the European HySens activities. Some details of the acquired and the used imagery and of the respective terrain data are given in Table 1. DAIS and ROSIS imagery were taken at two test sites on August 8th and 14th 2003. A total number of 7 flight strips was available for each site. Two extensive ground campaigns were carried out for the topics of alpine forest mapping as well as energy balance and permafrost distribution modeling, respectively. A third campaign in late fall 2003 focused on the measurement of the vertical structure of forest parameters in the Swiss National Park area using a laser scanner systems (see below). For both test sites, multiple terrain representations are available (compare Baltsavias, 1999b). The best suited source of terrain model shall be investigated for each data set separately in this short analysis, since the requirements highly depend on the distinct topics of interest.

Table 1. Hysens alpine imagery in engadin valley.

Source	Date	Description	Spatial Sampling	Site[a]
DAIS	(8.8.2003) 14.8.2003	Digital Airborne Imaging Spectrometer 7915	5-15 m	C / P
ROSIS	(8.8.2003) 14.8.2003	Reflective Optics Spectral Imaging System	0.8 -1.6 m	P / (C)
Swisstopo	1998	Swiss Topographic Elevation Model from classical Cartography	25 m	P / C
Conventional RC-30	2002	Photogrammetric DSM Corvatsch, Leica Helava Station	10 m	C
Falcon LIDAR	29.10.2003	TopoSys Airborne Laser Scanner (DTM/DSM)	0.5 m	P

a. C: Corvatsch site, P: Swiss National Park site

The first test area is situated in a high alpine terrain of the Corvatsch area close to St.Moritz, Switzerland. The terrain altitude varies between 1800 and 3300 m.a.s.l. with rocky slopes as steep as 70 degrees. The goal of the related imaging spectrometry campaign was the derivation of geophysical parameters such as albedo suited for modeling the permafrost distribution of the area. Two partially overlapping DAIS strips have been taken as main data set in order to investigate the stability of albedo retrieval methods in alpine terrain. For the critical area of interest, a photogrammetric surface model processed to 10 m resolution was available, created at the Dept. of Geography of the University of Zurich. Its vertical accuracy is better than 3 m while its horizontal resolution was resampled to a 10 m grid. A standard swiss federal topography DEM was used for test purposes and as backup solutions for areas of low coverage.

At the second site in Swiss National Park (close to Zernez/Ofenpass) one ROSIS strip has been selected as main data set of interest. The topography of this site was mapped using the Falcon II LIDAR Sensor, developed and maintained by the company Toposys, Germany[1] (Baltsavias, 1999a). The system is a push-broom laser altimeter recording both first and last reflection from the laser signal on the ground (first/last pulse). The flight was conducted at nominal height over ground of 850 m, leading to an average point density of more than 20 (first and last pulse) points per square meter (p/m^2). A smaller subset of the area (0.5 km^2) was overflown at a height of 500 m above ground, resulting in a point density of more than 40 p/m^2, thus combining the two datasets yields a point density of more than 60 p/m^2. The footprint sizes were about 30 cm in diameter for 850 m flight height and about 20 cm in diameter for 500 m flight height, resulting in an oversampling of the area (oversampling factor ~ 1.4) in the smaller subset.

3 ELEVATION DATA PROCESSING

As mentioned before, the preprocessing of a DEM has to be in accordance to the optical resolution and spatial accuracy of the optical sensor data to be processed on the DEM. For the described case, the standard DSM/DTM resolutions are in the same order of magnitude as an average optical resolution for both the ROSIS and the DAIS data sets, respectively. It is yet to be thought about how this original data have to be degraded to achieve radiometrically useful representations. In non-forested areas, the same rules of thumb can usually be applied for the spatial preprocessing of a DSM for both radiometric an geometric preprocessing while a forest canopy causes specific problems as described below.

1 http://www.toposys.com

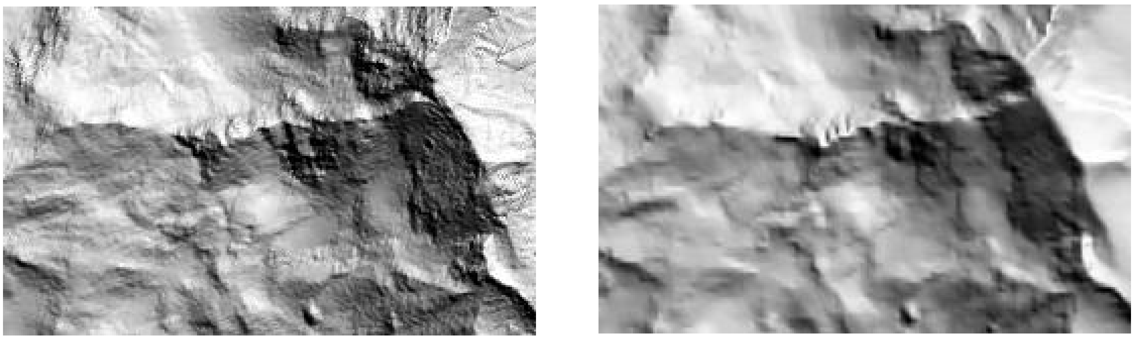

Figure 1: Illumination shaded view of photogrammetric DSM at original and degraded resolution in the Corvatsch area.

The creation of the photogrammetric DSM over the Corvatsch area is done using a LEICA Helava workstation and the SOCET SET software product[2]. The stereo matching process is calculated on a 10 m spatial resolution level, leading to horizontal and vertical accuracies better than 2 m. The illumination shaded view of the resulting DSM product is shown in Figure 1. A crisp appearance is visible in this DSM product, which partially may be attributed to the relative error in the data.

The raw LIDAR data delivered by the sensor (x,y,z - triples) is processed into gridded elevation models by the data provider (Toposys GmbH). The DSM is constructred from first pulse reflections while the DTM was calculated using the last pulse LIDAR, with subsequent Delauney triangulation interpolation and a 9x9 low pass filtering algorithms. An illumination shaded subset of the derived products is shown in Figure 2. The forest signature is almost completely removed in the DTM product. The grid spacing is at 1 m with the height resolution being 0.1 m. The quality of the LIDAR models was assessed using 6 geometric reference targets being 3 by 3 meter in size. The absolut positional accuracy of the DSM was determined to be less than 0.5 m and the height accuracy is better than 0.15 m. Internal positional accuracy was found to be better than ± 0.5 m, and the internal height accuracy is better than ±0.15 m.

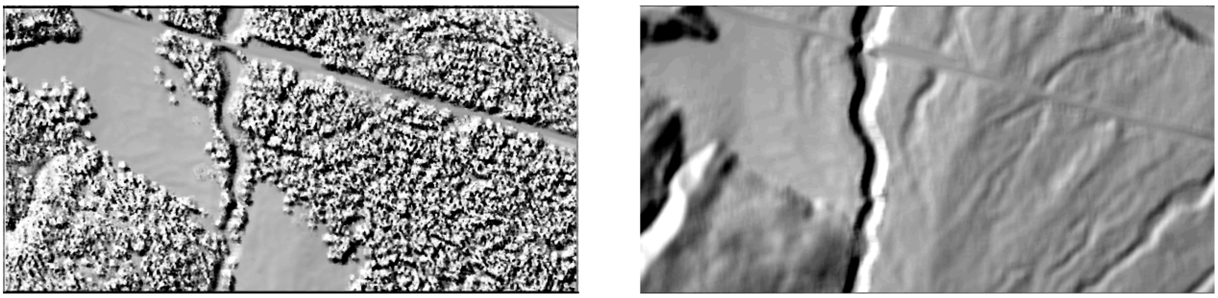

Figure 2: Digital surface model and digital terrain model derived from the TopoSys laser scanner system in a forest area (illumination shading as used for topographic correction).

4 PROCESSING RESULTS FOR HYPERSPECTRAL IMAGERY

The above-mentioned data sets have been processed on the given various DEM types and a variety of DEM resolutions and processing states. The most interesting effects and results are given in this section for each test site.

4.1 DAIS Corvatsch

The preprocessing of the DAIS data is mainly done on the photogrammetric surface model. The achieved geometric accuracy is on a sub-pixel level if compared to the basis orthophoto imagery. An RMS error of 5 m (0.5 pixels) can be reported on ground control point data. If a less accurate DSM (i.e. the standard DEM) is chosen for the geometric processor, the RMS error increases from 4.9 to 5.6 meters by 0.7 meters in across track direction , while the along track error remains at 4.6 meters. The difference in accuracy is more obvious, if the resampled pixel positions are compared. Figure 3 shows the distribution of pixels which changed in position between the two compared terrain models. If nearest

2 http://www.gis.leica-geosystems.com

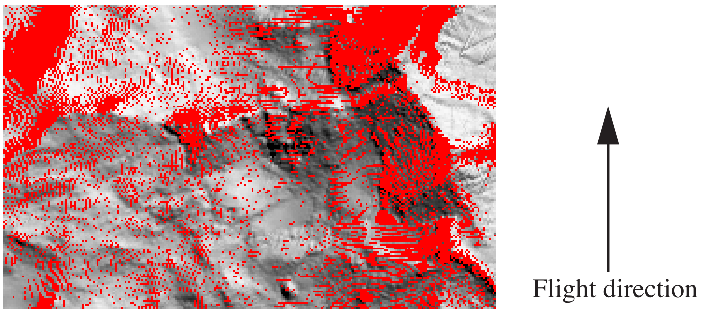

Figure 3: Distribution of shifted pixels between correction on photogrammetric DSM and topographic DEM (displayed on top of shaded relief).

neighbor technique is used for resampling as much as 30% of all pixels change their position. As expected, the number of shifted pixels increases with steeper slopes, specifally in rocky areas, and towards the off-nadir positions of the imagery.

Some example results of topographic correction (radiometric nadir normalization of the surface HDRF data) using the ATCOR4 topographic correction scheme are given in Figure 4. The correction is done both on the topographic elevation model and the photogrammetric surface model. Additionally, the terrain parameters (terrain slope and aspect) are calculated on the photogrammetric surface model using a 2-pixel distance operator (Corripio, 2003). The correction using the DSM parameters derived on a highest accuracy surface model introduces obvious noisy artefacts, visible in the upper right image. Three potential reasons are identified: first, the data acquisition by the DAIS system does not resolve the imagery to the high resolution given in the photogrammetric model. Second, the geometric accuracy of the processing is knowingly at 1-2 pixels, and third the DSM uncertainty may lead to such pixel-effects. Only a low pass degradation of the photogrammetric model appropriate to the DAIS optical resolution and filtering noisy DSM artefacts leads to more adequate results. The spatial structure of these results are comparable to the processing on the basis of the standard Swisstopo DEM. This leads to a conclusion, that radiometric processing not necessarily requires the highest accuracy DSM as long as the data to be processed are affected by positional and optical inaccuracies.

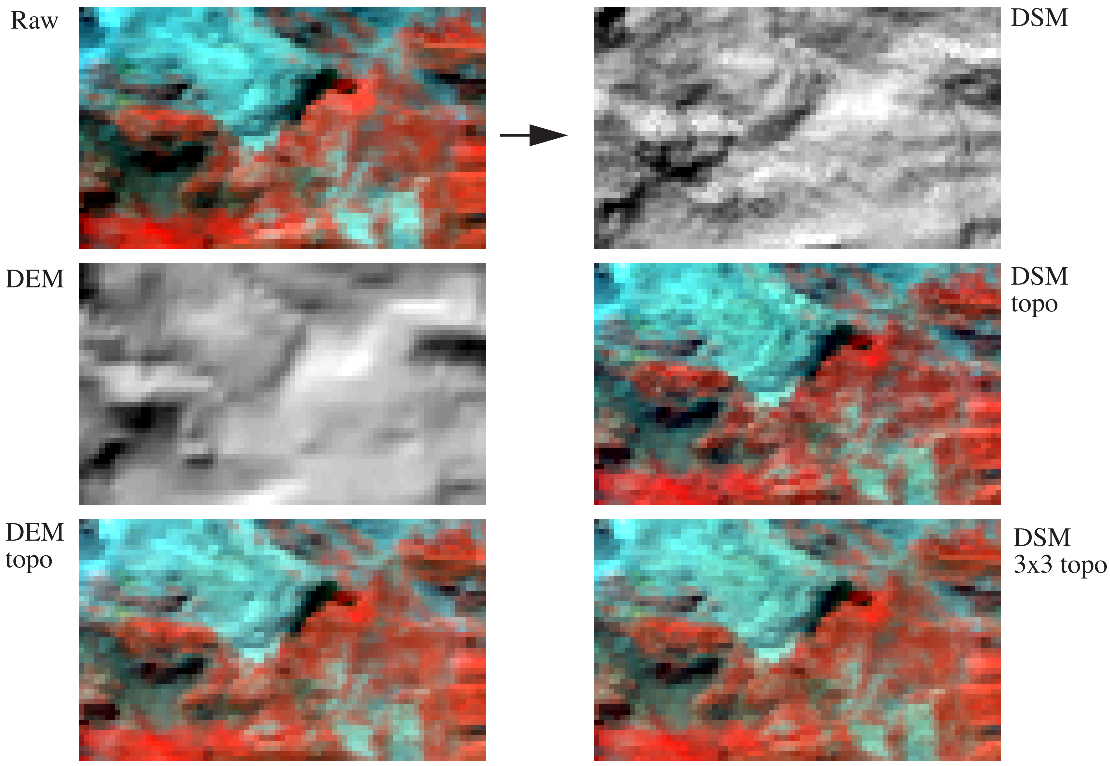

Figure 4: Terrain correction processing results of DAIS data on Swisstopo DEM and photogrammetric DSM. Upper left: raw image, upper right: illumination shaded DSM; middle right: illumination shaded DEM; middle right: correction using the photogrammetric DSM; lower left: correction using Swisstopo DEM, lower right: correction using degraded photogrammetric DSM.

4.2 ROSIS Swiss National Park

The ROSIS imagery first is orthorectified on the available DSM/DTM. A scanner system failure required the application of new methods for post-synchronization of aircraft movement parameters to the image lines. The PARGE preprocessing system is adapted for that purpose.

The optically most obvious distortion in airborne imagery are usually roll-induced across track line shifts. This distortion can be derived from the imagery itself by systematic line-by-line correlation analysis. The offset between the lines in across track direction is attributed to the roll movements and finally filtered using a high pass filter set to 250 image lines. The resulting synchronization is accurate within a range of ±10 image lines as depicted in Figure 5. The synchronization of the ROSIS imagery was further improved using a set of 39 GCPs taken from orthophoto reference images. The RMS of the ground control points was systematically decreased by adjusting the synchronization on a 1-image line level within the range given by the first automatic synchronization step. The resulting RMS derived from GCP's was at 1.00 m across track and 0.87 m along track. This error is confirmed if comparing a digital orthophoto to the orthorecified ROSIS image (see Figure 5, right). This is definitively not the maximum accuracy achievable with the ROSIS system and would certainly be better for perfectly synchronized data. Anyhow, it is a satisfying accuracy for forest parameter mapping applications.

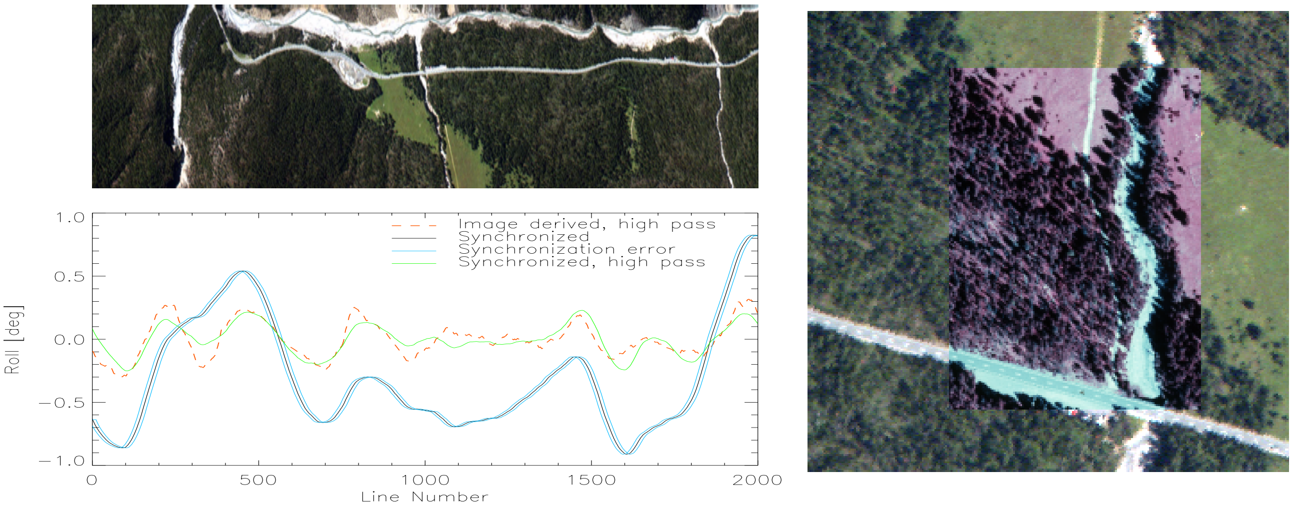

Figure 5: Synchronization of ROSIS roll parameter (dashed) to the image based roll estimate, raw image given at upper left. Best correlation is found within ±10 image lines (given by the added additional lines). Right: Geometric accuracy in comparison to photogrammetric orthophoto.

The optical resolution of the ROSIS instrument is approximative at 1 m. Thus a DSM resolution of 1 m would be appropriate for geometric processing. However, the synchronization problems found in the system led to geometric inaccuracies in the range of 1-2 pixels. A spatial smoothing of the DSM to this limit is thus applied to take this inaccuracy into account. Figure 6 shows the difference between the geometric processing results on a 3x3 low pass filtered DSM in comparison to the use of the raw DSM. Less than 10% of all pixels have been shifted in the nearest neighbour resampling by 1 pixel distance. In forests and off-nadir (top and bottom of image), the number of shifted pixel obviously increases.

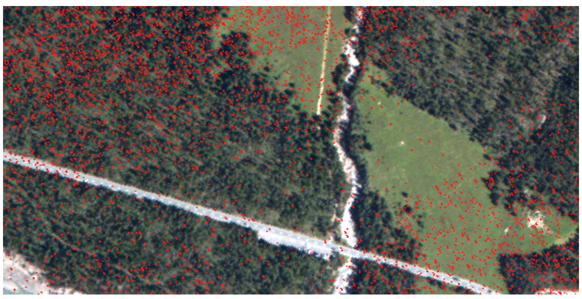

Figure 6: Influence of surface model preprocessing on geometric accuracy: red pixels are shifted in position if a 3x3 smoothing filter is applied to the DSM before geometric processing.

The rugged structure of the boreal canopy surface model leads to this effects. For the given FOV of view of approximately ± 9˚, a vertical offset in the DSM 5 m leads to horizontal shifts in the range of 0.7 meters. This is larger than half a pixel as required to cause a pixel-shift in the nearest neighbour resampling.

The radiometric preprocessing of the ROSIS data over the forested area proves to be a very challenging endeavour. The underlying problem is that the exact surface characteristics for the optical response of a forest canopy can not easily be related to the laser scanner derived topographic DSM products. The multiple scattering processes within the volume of a plant canopy and the geometrical shape of the tree crowns lead to surface characteristics which can not be completely described by any 2.5-dimensional surface model. The vertical forest structure rather requires a true 3-dimensional view of the problem. Figure 7 tries to illustrate how the shape of a virtual 'crown-surface' may vary significantly depending on spatial resolution, sampling characteristics, and the shape of the crowns. An artificial optical reference surface could be defined on a top-crown level, on an average optical response basis within the canopy, or on the terrain surface. All these approaches are no satisfying solutions. Ideally, an illumination-equivalent layer would be calculated using a ray tracer combined with the 3D structure of the forest canopy. In such a way, the radiometric behaviour might be parametrized to a level suitable for further radiometric correction. Note, that any reference surface is a model far from the realistic 3D structure and may be useful only for specific and limited processing steps.

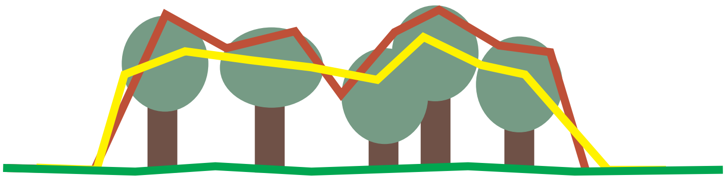

Figure 7: Digital surface description within a forest canopy.

For our data set, the orginal laser DSM is taken for radiometric processing in a first experiment. The above considerations can be confirmed: strong overcorrection artefacts are observed in the topographically corrected images (see Figure 8). In a further test, the original DSM is filtered with a 5x5 low pass filter to change the spatial structure to a more appropriate appearance (the typical diameter of a tree crown in this area is about 5 meters). This test still results in obvious artefacts and even with further filtering approaches no appropriate respresentation could be found on the basis of the DSM. The overcorrection using a DSM becomes obvious if statistics in a NIR band at 802 nm are calculated: the mean values increase by as much as 30% while the standard deviation almost doubles on a forest canopy. In contrast, the statistical values are affected by less than 3% on a meadow surface. The situation does not change if larger DSM filter windows are selected – the numerous small forest clearings are still not appropriately treated and false corrections on forest borders occur.

Only using a terrain model for radiometric correction leads to constant statistics within ± 1%. We conclude that not a tree crown model should be used but rather the terrain model. Consequently, we use for the correction large scale radiometric effects the LIDAR DTM instad of any DSM product (while the DSM is still used for geometry). Any radiometric variability within the forest is to be handled by three dimensional radiative transfer modeling rather than applying DSM-based correction approaches.

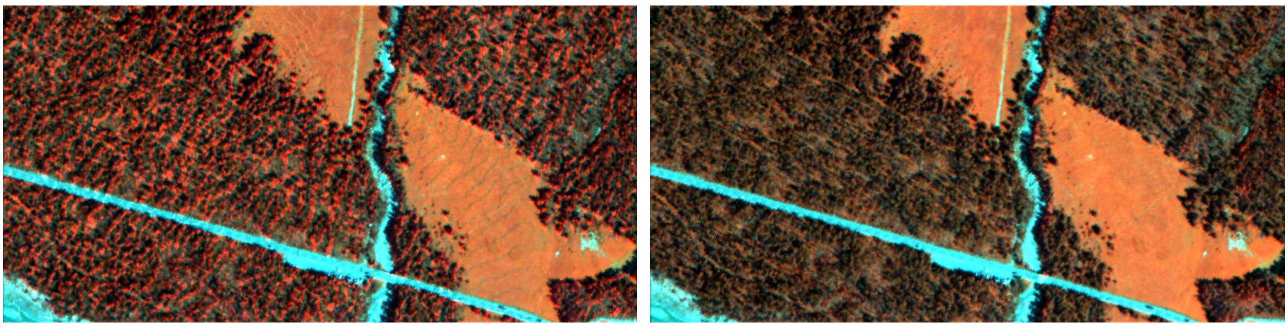

Figure 8: Topographic correction results over forest using a DSM (left) and a DTM (right) surface representation (RGB at 802, 660, and 502 nm).

5 CONCLUSIONS

A parametric orthorectification methodolgy has been applied to two sets of imaging spectroscopy data in high alpine terrain. It allows for correction of attitude and flightpath dependent distortion and includes GCP based data re-calibration capabilities. A new method of image-based parameter synchronization was invented and applied to the ROSIS imagery. A relative accuracy of 1-2 meters could be achieved for ROSIS, while sub-pixel accuracy of ±5 m was reported for the DAIS data. The topographic correction applied with the atmospheric correction package ATCOR4 proved to be very sensitive to the DSM resolution and preprocessing. For high alpine terrain, the DSM proved to be ideally suited for this correction and its use is recommended if high spatial accuracy is of importance.

In rocky and sparsely vegetated areas, the digital surface model proved to be suited for radiometric processing and nadir normalization of the measured data. Anyhow, moderate low pass filtering improves the radiometric results significantly. The influences of relative DSM accuracy, orthorectification accuracy, and true optical sensor resolution have to be accounted for to derive the appropriate filter size. For the employed DAIS imagery, a filter size of 3x3 pixels proved to be adequate.

For forest investigations, it is shown that for spatial resolutions below 5 meters, the heterogeneous 3-dimensional canopy structure of the surface cover becomes more and more important. The radiometry of the objects, especially of trees, can no longer be represented by a continuous and opaque surface with lambertian reflectance characteristics. Only large scale radiometric effects as represented in a DEM or in a low-pass filtered DSM can be corrected by such standard assumptions. The limitations in accuracy of radiometric preprocessing no longer can be attributed to inaccuracies of the used DEMs but rather to inappropriate use of the available digital surface data. Further investigations thus have to focus on the development of radiation models of vegetation canopies which may be directly coupled to the high resolution DSM data or even to a true 3D representation of the canopy taking the distribution of foliage elements into account, as available from current LIDAR sources.

6 ACKNOWLEDGEMENTS

This study has been funded by the Swiss National Science Foundation and the European SPREAD forest fire mapping project. We also specially thank for the great collaboration and support by Andreas Müller, Steffi Holzwarth, and Rolf Richter from the German Aerospace Agency (DLR).

7 REFERENCES

Baltsavias E.P., 1999a: Airborne laser scanning: existing systems and firms and other resources. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(2-3): 164-198.

Baltsavias E.P., 1999b: A comparison between photogrammetry and laser scanning. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(2-3): 83-94.

Corripio J.G., 2003: Vectorial algebra algorithms for calculating terrain parameters from DEMs and solar radiation modelling in mountainous terrain. *International Journal of Geographical Information Science*, 17(1): 1-23.

Chang S.-H., Westfield M.J., Lehmann F., Oertel D. and Richter R., 1993: 79-Channel Airborne Imaging Spectrometer. Im. Spec. of the Terr. Env., *SPIE Vol. 1937*: 164-172.

Doerffer R., Kunkel B. and Van Der Piepen H., 1989: ROSIS - An imaging spectrometer for remote sensing of chlrophyll fluorescence, Proc. *SPIE Conference 1070*, Los Angeles, pp. 9 (separatum).

Richter R. and Schläpfer D., 2002: Geo-atmospheric processing of airborne imaging spectrometry data. Part 2: Atmospheric/Topographic Correction. *International Journal of Remote Sensing*, 23(13): 2631-2649.

Schläpfer D. and Richter R., 2002: Geo-atmospheric processing of airborne imaging spectrometry data. Part 1: Parametric Ortho-Rectification Process. *International Journal of Remote Sensing*, 23(13): 2609-2630.

Schläpfer D., 2002: Parametric Geocoding (PARGE), User Guide, Version 2.0. ReSe Applications Schläpfer, Wil SG & Remote Sensing Laboratories University of Zurich, Wil SG, pp. 166 (CDROM).