ATMOSPHERIC AND TERRAIN CORRECTION OF IKONOS IMAGERY USING ATCOR3

M. Neubert*, G. Meinel

Leibniz Institute of Ecological and Regional Development (IOER), Weberplatz 1, D-01217 Dresden, Germany - M.Neubert@ioer.de, G.Meinel@ioer.de

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ABSTRACT:

When ordering very high resolution (VHR) imagery of IKONOS or QuickBird a cloud coverage up to 20 % within the scenes has to be accepted. This indicates the high impact of atmospheric conditions to VHR imagery. Beside clouds the images are influenced by haze oftentimes. This haze could be removed using new atmospheric correction algorithms, which were not available for VHR data so far. Furthermore, effects caused by the terrain are influencing the classification quality of VHR imagery in particular in areas of high relief energy. These effects can be eliminated using a high resolution digital elevation model (DEM) within the correction process. The main reason for atmospheric correction is that multi-temporal scenes become comparable, because digital numbers are substituted by surface reflectances. Thus, classification schemes developed once can easily be applied to other subsequent recorded scenes. The haze removal and atmospheric-topographic correction algorithms are implemented in the software ATCOR3 which is available as an extension of standard remote sensing software, like ERDAS IMAGINE 8.7 or PCI Geomatica, and as stand-alone software based on IDL as well. The software was tested and improved in cooperation between users and the developers using IKONOS data, but it is also applicable to other VHR data (QuickBird etc.). Within the paper the procedure and the results of correcting two hazy IKONOS scenes will be demonstrated and evaluated from an end-user's point of view. On the other hand the terrain correction of this imagery using a VHR laser scanning DEM is in the focus of the investigation.

1. INTRODUCTION

Atmospheric and topographic effects influence radiometry as well as the analysis of optical remote sensing data negatively. Especially when ordering very high resolution (VHR) imagery of IKONOS or QuickBird a cloud coverage up to 20 % within the scenes has to be accepted. This indicates the high impact of atmospheric conditions to VHR imagery. Beside clouds the images are influenced by haze oftentimes. On the other hand the appearance of haze in VHR data is different, clearer, than from lower resolution sensors. Thus, other algorithms for corrections are necessary. The new atmospheric correction algorithms implemented in ATCOR for the herein used ERDAS IMAGINE 8.7 offer a solution. Such algorithms were not available for VHR data so far.

An atmospheric or haze correction eliminates the effects caused by scattering and absorption of the earth's atmosphere. Aerosols, haze, clouds or fog result in a deflection of electromagnetic radiation in diverse directions, whereby the signal is alleviated. An additional reduction of radiation intensity comes from absorption processes, by which some wavelengths are intercepted by molecules and changed into other forms of energy (e.g. thermal). The algorithms for correcting such effects are based on knowledge of the meteorological parameters, which are characterising the current state of the atmosphere at the time of image recording. Such information is provided within the correction softwares by data bases. In addition some parameters have to be set by the user (e.g. visibility).

By a topographic or terrain correction disturbing illumination effects caused by the relief – in particular in areas of high relief energy – like sunny and shadowy hill sides as well as terrain and adjacency radiation (radiation reflected by the neighbourhood) can be compensated. Thus, the use of a high resolution digital elevation model (DEM) is necessary. As result of an atmospheric and terrain correction the per-pixel digital numbers recorded by the sensor are transformed into surface reflectance values.

The main reason for atmospheric-topographic correction as data pre-processing is that multi-temporal scenes become comparable, because digital numbers are substituted by surface reflectances. Effects of the sun position due to the recording time of day as well as seasonal differences are equalised. In addition variances comparing to spectral ground or laboratory measurements are minimised. Due to the quantitative analysis of the imagery, classification schemes developed once can easily be applied to other subsequent recorded scenes because the reduced range of spectral object values. Thus, also the results of change detection analysis will be improved. Furthermore the comparability between imagery of different sensors with equal spectral bands is reached. Last but not least an optical appealing image is produced which allows better interpretation results.

The current algorithms for correcting atmospheric influences available on the market and implemented into remote sensing software packages are not suitable for VHR data (0.5 - 1 m resolution; Neer 1999) – the only exception is ATCOR. This ERDAS IMAGINE 8.7 add-on module was released in March 2004. This software is announced to be suitable for IKONOS, QuickBird or OrbView data. Thus, the application of ATCOR (and also a pre-version) was tested using IKONOS data and improved in co-operation between users and the developers. The results of correcting IKONOS data will be demonstrated and evaluated from an end-user's point of view.

* Corresponding author.

2. ATCOR SPECIFICATIONS

The algorithms used for haze removal and topographic correction within ATCOR were developed originally by Dr. Rudolf Richter (German Aerospace Center, Wessling, Germany, www.op.dlr.de/atcor; Richter 1996, 1997, 2005). The company Geosystems (Germering, Germany, www.atcor.de; Geosystems 2004a) adopted the algorithms to an ERDAS IMAGINE add-on module, but the software is available for PCI Geomatica and as stand-alone software based on IDL too.

For processing two variants are selectable: ATCOR2 allows a two-dimensional atmospheric correction, ATCOR3 permits an additional three-dimensional topographic correction including the use of a DEM. Furthermore a version for the correction of air-borne sensors is available (ATCOR4), which takes the scanning angle into account additionally.

ATCOR permits the correction of optical remote sensing imagery in the spectral range between 0.4 and 2.5 µm as well as in the thermal range between 8 and 14 µm. It is among others convenient for the imagery of Landsat, SPOT, IRS, ASTER, IKONOS and QuickBird. The software uses a data base which rests upon the MODRAN-4-Code for the radiative transfer from measured digital numbers to the radiance at the sensor.

The following limititations are announced by Geosystems (2004a, 2005): For the application of ATCOR claer image areas (arround 40 %) are needed beneth hazy parts. Only hazy areas could be corrected but not clouds which make the surface invisible completely. The blue and red image bands must have a high correlation to reach good results. If the blue band is missing the correction is still possible but leads to non-perfect results. The algorithm is not suitable for haze over water, this will result to more noise in such areas.

3. INPUT DATA AND PRE-PROCESSING

The process of haze and terrain correction was tested using two hazy IKONOS scenes (4 m multi-spectral, 1 m panchromatic) – one from the city of Dresden, Germany, and one from the Saxon Switzerland, a national park area south-east of Dresden. Both scenes are influenced by clouds and haze explicitly. As the Dresden area is relatively flat, the scene was only haze corrected using ATCOR2. In contrast the Saxon Switzerland shows a very mountainous and rocky area with steep slopes. To reduce illumination effects caused by the terrain this scene was not only de-hazed but also topographic corrected (ATCOR3), which is a more complex process. Thus, the procedure is explained by this scene.

Suitable IKONOS data should be purchased unconditionally without the dynamic range adjust option (DRA). This pre-processing by the data provider can make the correction impossible.

As a prerequisite for using ATCOR3 the imagery should be ortho-rectified and geo-referenced. The reason for this is that ATCOR calculates the topographic correction depending on an accurate fit between the required DEM and the imagery. The average position accuracy of the used IKONOS scenes is about 2 - 3 m (RMSE).

Concerning the quality of the used DEM a comparable spatial resolution regarding to the image resolution is sufficient for most applications. With a higher DEM resolution than the image resolution a clearer reduction of topographic illumination effects is achievable. An optimal DEM has a quarter of the image resolution (Geosystems 2004a), what is not possible in the most cases even when using VHR imagery. In high resolution DEM's (typically 1-10 m) for steep slope gradients artefacts occur from one pixel to the neighbouring pixel. This causes the slope pattern to be visible in the processed image as artefacts. To avoid this a mean filter should be used to smooth the gradients. In this investigation a last pulse laser scanner DEM with a ground resolution of 1 m was used (position accuracy 1 m, height accuracy 0.5 m). Due to visible artefacts it was mean filtered using a 7x7 window before (see figure 1).

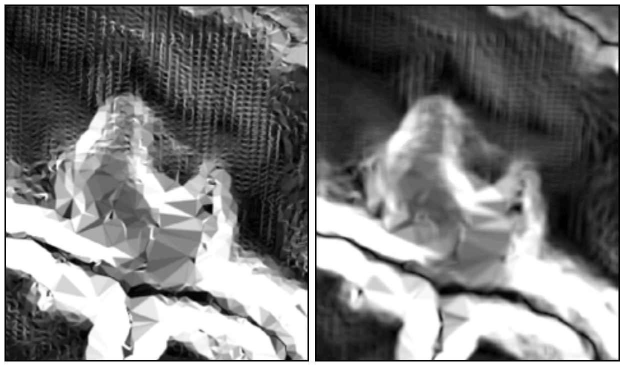

Figure 1. Calculation of slope based on a subset of the original laser scanner DEM data containing explicit artefacts (left) and smoothed DEM with reduced artefacts (right).

4. ATCOR3 PROCEDURE

The atmospheric and terrain correction precedure is structured in sequential steps which are displayed in the scheme of figure 2. The processing is described by means of the more comprehensive ATCOR3 procedure.

Before processing some terrain files have to be derived from the DEM. The calculated slope, aspect, skyview and shadow files will be used afterwards during the topographic correction process (see figure 3). Especially the processing of the skyview, which is an expendable ray tracing analysis, is time intensive (around three hours) and needs a lot of hardware resources.

The first step in atmospheric correction using ATCOR is to set up some principle scene parameters, as there are the acquisition date, the sensors name, the scene visibility and the solar zenith and azimuth. The last two parameters could be calculated by the acquisition date and time (available from the header file) as well as the geographic coordinates of the scene centre using the provided sun position calculator tool. A query dialogue ensures the input of all relevant parameters and data (see figure 4). To preserve the 16-bit range of IKONOS data the default factor for reflectance has to be set from 4 (8-bit) to 10 in the scale factor settings. As type of atmosphere the option “midlat_summer_ rural” was used. This corresponds with the model of solar region for mid latitudes at summer season with a rural type of aerosols. The scene visibility was set to 25 km based on metrological information at the time of image recording.

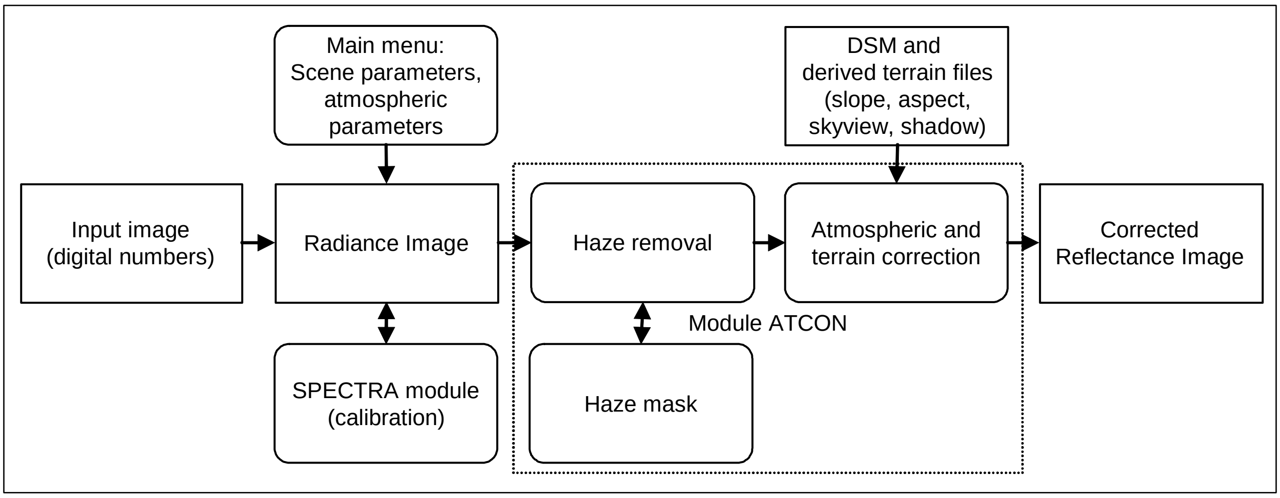

Figure 2. ATCOR3 procedure.

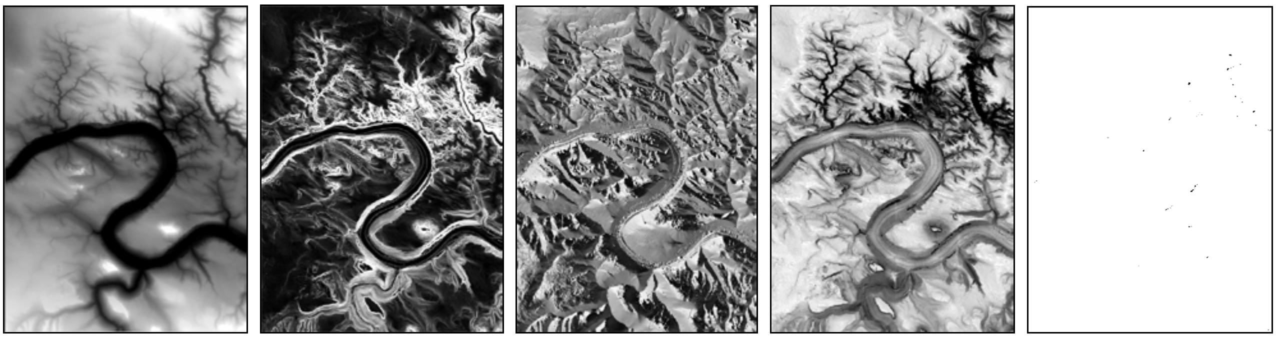

Figure 3. DEM and derived terrain files slope, aspect, skyview and shadow (from left to right).

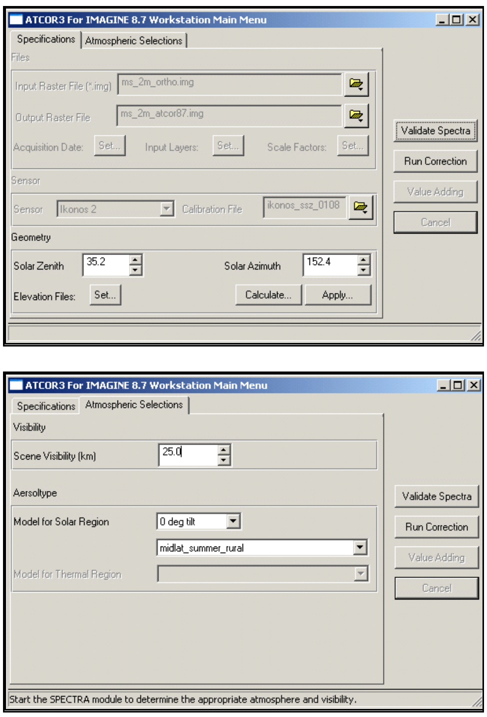

Figure 4. Starting dialogue of ATCOR.

Furthermore the sensors off-nadir tilt angle as well as the tilt direction of IKONOS can be considered. These settings are derivable by assignments of Geosystems (2004d) from the image header information. In this example the nominal collection azimuth is 71.4° what results a tilt of around 17°. Due to the rounded input possibilities in 10°-steps a tilt angle of 20° in eastern direction was used.

As calibration file for the image the included dummy file for IKONOS data can be used firstly. This file contains the calibration coefficients Bias [c0] and Gain [c1] for each band. Bias describes the spectral radiance immission at the sensor for a digital number of zero. Gain represents the calibration gradient. The unit of measurement for both coefficients is electromagnetic radiance [mW cm^{-2} sr^{-1} μm^{-1}]. By this factors ATCOR calculates the radiance at the sensor (Geosystems 2004b).

The ATCOR module Spectra is used next. Spectra enables a simple comparison of measured and given reference spectra. The measured spectra could be used to easily set up an accurate sensor calibration file (auto-calibration), which is needed for the atmospheric correction of the whole scene. Thus, dark objects (e.g. spruce forest) are selected by setting points and compared to a loaded reference spectrum (in this case spruce_tm, see figure 5). It is possible to use an auto-calibration option for automatic adoption of the calibration file (Geosystems 2004c).

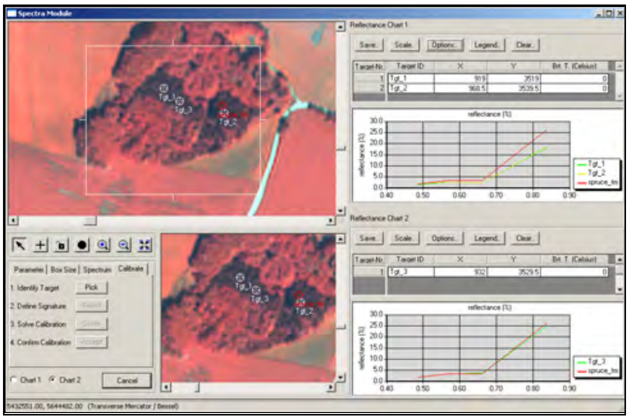

Figure 5. ATCOR module Spectra: The upper chart shows slight differences between measured and reference spectra. The chart below shows the result of the corrected calibration file.

After this the correction of haze starts using the Constant Atmosphere Module (ATCON). A fast de-haze preview shows the prospective result before the actual de-hazing operation is performed and considerably saves time when assessing the feasibility to actually perform a de-hazing and which parameters should be used (see figure 6). Different options of overlaying (e.g. haze mask) help to assess the results. All processing steps and results are stored in a report file.

Finally, the actual very time and performance consuming correction process starts and ends up with the atmospheric and topographic corrected result. The processing time was about six hours for the whole multi-spectral and two hours for the whole panchromatic IKONOS scene (using an Athlon 64 3500+ 1 GHz machine with 1 GB of memory).

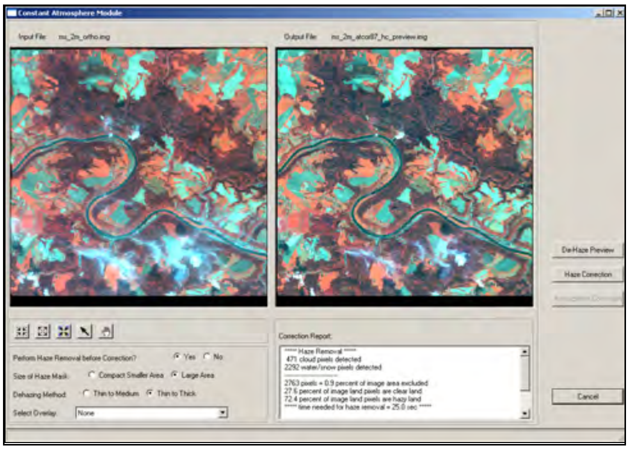

Figure 6. ATCOR module Constant Atmosphere: The input image is on the left, the de-haze preview on the right.

Subsequent to the atmospheric and terrain correction some value adding products can be calculated by ATCOR: the soil adjusted vegetation index (SAVI), the leaf area index (LAI), the absorbed photosynthetically active radiation (FPAR), the surface albedo and some radiance and thermal flux indices for sensors having a thermal band.

The correction of the panchromatic band has to be done separately. The procedure is the same like in the case of multispectral imagery stated above. Due to the fact that panchromatic imagery has no band for calculating haze, only a terrain correction is possible. Fortunately haze is often not that distinctive in panchromatic than in multi-spectral images.

5. RESULTS

For the very hazy IKONOS scene from the city of Dresden the only haze-corrected ATCOR2 result is shown in figure 7. The result is of a high visual quality. The thin to medium haze is corrected completely in the image. All in all, the image is much clearer and has a higher object contrast. Due to the absence of a DEM within the correction process no problems with artefacts occur. Only water areas (river Elbe) are less homogeneous than in the original just as it is advertised by Geosystems (2005).

Figure 8 represents the results of haze removal and atmospheric-topographic correction using ATCOR3 whose visible quality is convincing too. The areas of transparent haze are well corrected. Furthermore the illumination effects are minimised.

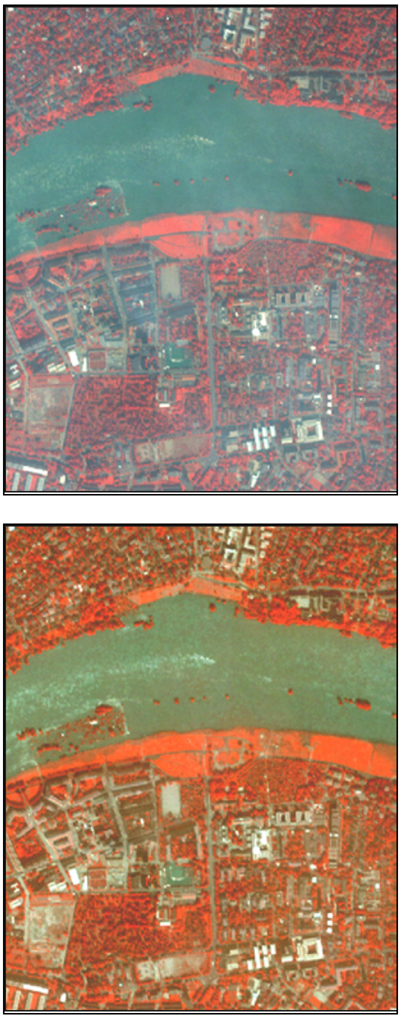

Figure 7. Subset of the haze reduction and atmospheric correction result processed with ATCOR2 for the IKONOS scene of Dresden.

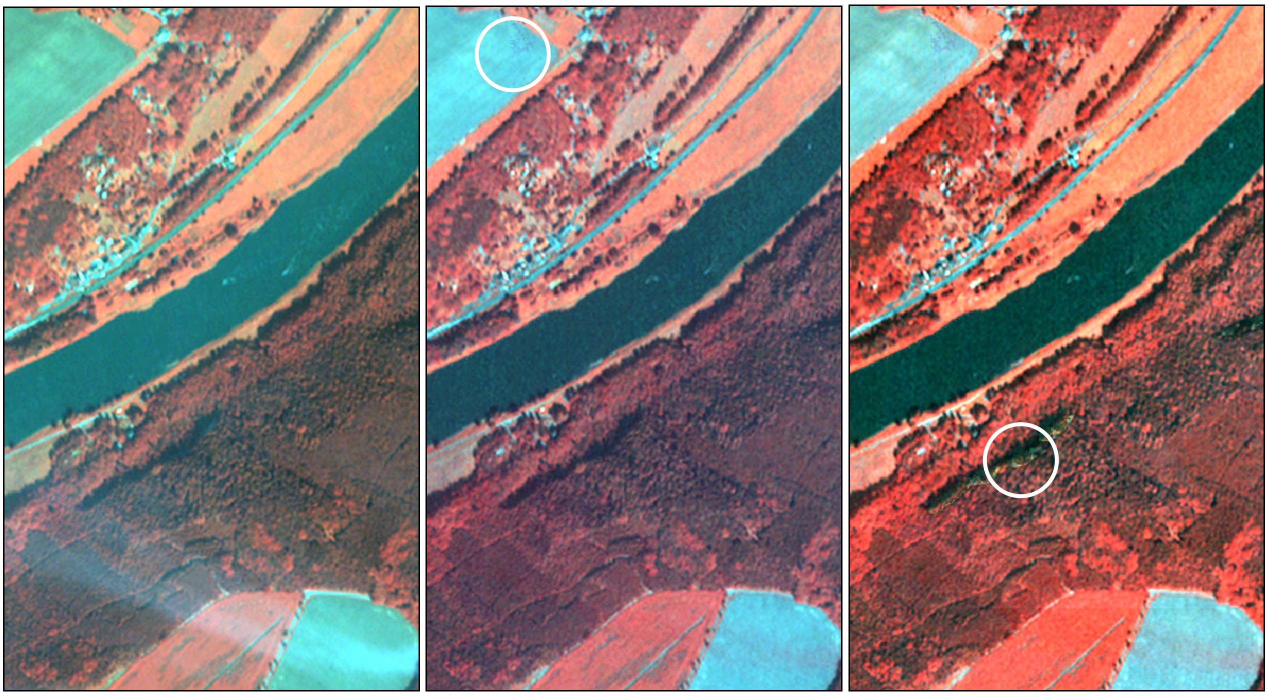

Figure 8. ATCOR3 results for the IKONOS scene of the Saxon Switzerland: original, de-hazed and atmospheric-topographic corrected imagery (from left to right). The markings indicate occurring artefacts in bright image areas due to haze correction and visible slope pattern within the final result.

At very steep slopes slope patterns from the DEM can affect the correction result. This is due to the DEM issues stated in chapter 3. But in the Saxon Switzerland rugged rocks, canyons and former sandstone quarries are common. Furthermore, at shadowed hill sides an over correction is possible. To prevent such effects the scene dependent thresholds for BRDF correction have to be adjusted interactively.

Additionally, the following problems were observed: In bright image areas sometimes artefacts occur after haze correction. In certain circumstances edges of masks used during the correction as well as edges of image processing tiles – maybe from the skyview analysis which is calculated in tiles – can be visible in the results.

The topographic correction result of the panchromatic band is also convincing (see figure 9). Although due to the higher contrast within the shadowed areas the image seems to be darker than the original. The increased contrast appears that the result is clearer and sharper. The DEM affects some small artefacts as in the multi-spectral correction result.

6. CONCLUSIONS

The results of the haze removal as well as the atmospheric and topographic correction using ATCOR leads to good visual results. In comparison to the pre-version ATCOR3 Ver. 2.1, which was not suitable for the correction of IKONOS data (Neubert 2005), some important improvements concerning the software handling as well as the processing were achieved. Some parts of the correction process are more automated and free of input parameters now. The new and powerful haze correction algorithm based on Zhang et al. (2002) was realized in the new version.

The huge amount of data due to VHR imagery and DEM in combination with the intensive computation processes makes the correction a challenge for hard and software at the moment. The handling of large datasets e.g. when using very high resolution DEM's can cause performance problems and temporary files larger than 2 GB.

Finally it could be stated that an atmospheric and terrain correction of VHR imagery using ATCOR3 for ERDAS IMAGINE 8.7 is technically mature and operational. In particular the results of haze removal are convincing. However, there are still some smaller problems but the software is under development permanently. As an example the correction of cloud shadow is planned in addition.

Some further tests will be done to evaluate the quality of the resulting image. Furthermore some classification tests should show if once developed classification schemes based on reflectance values could be easily applied to other subsequent recorded scenes. Furthermore the impact to image segmentation results will be tested.

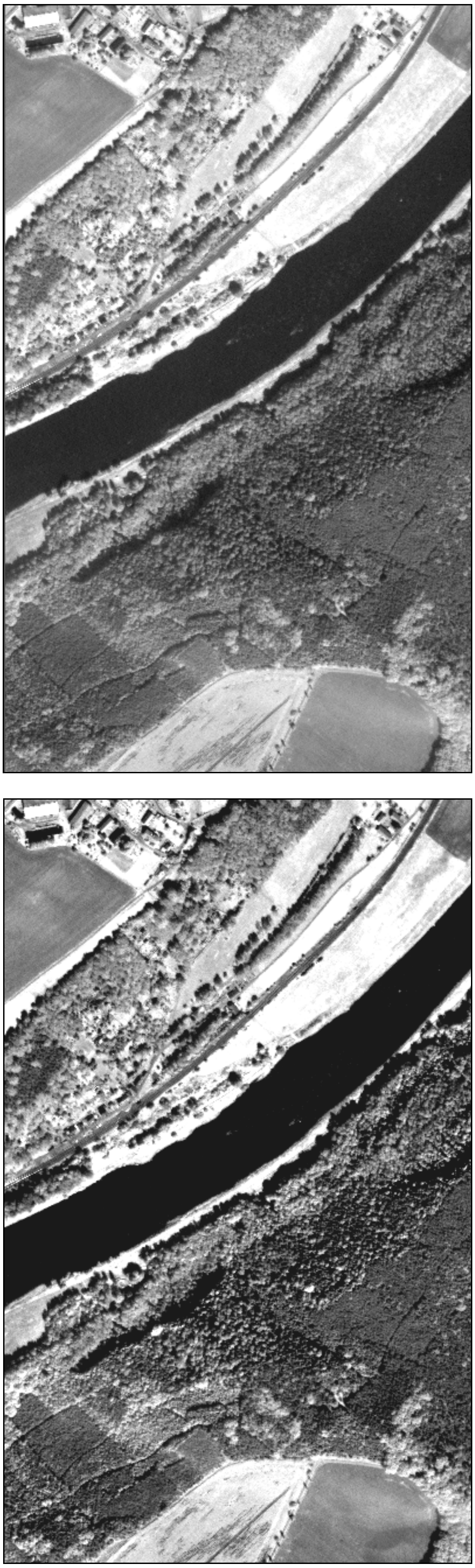

Figure 9. Topographic correction result of the panchromatic band of the IKONOS scene of the Saxon Switzerland: original (above) and topographic corrected imagery (below).

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