ATMOSPHERIC AND TOPOGRAPHIC CORRECTION OF PHOTOGRAMMETRIC AIRBORNE DIGITAL SCANNER DATA (ATCOR-ADS)

Daniel Schläpfer [a], Rudolf Richter[b], and Tobias Kellenberger[c]

[a]ReSe Applications Schläpfer, Langeggweg 3, CH-9500 Wil, Switzerland
http://www.rese.ch; daniel@rese.ch
[b]German Aerospace Center, DLR, Germanyl; rudolf.richter@dlr.de
[c]swisstopo, Bern, Switzerland; tobias.kellenberger@swisstopo.ch

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ABSTRACT:

Digital airborne photogrammetric cameras have evolved from imagers to well-calibrated radiometric measurement devices. As such, the radiative transfer based processing of the acquired data to surface reflectance products has become feasible. Such processing allows for automatic and consistent compensation of the effects of the atmosphere and the topography, which is known from remote sensing applications as the atmospheric correction task. The motivation is both, a qualitative improvement of the outputs of the automatic processing chains as well as the possibility to develop remote sensing data products from the imagery.
This paper presents the operational implementation of a radiative-transfer based radiometric correction method of the Leica's ADS-80 image products. The method is developed on the basis of the ATCOR-4 technology. The ATCOR-4 atmospheric correction software inverts the MODTRAN®-5 radiative transfer code for atmospheric compensation of trace gas and aerosol influences as well as for topographic correction of the illumination field. The focus of the processing is twofold: for image products, the correction of topographic dependency of atmospheric scattering, depending on flight altitude, terrain height, and viewing angle is envisaged. For remote sensing products, the output shall be optimized for automatic quantitative processing, including the correction of irradiance variations and cast shadow effects. The implementation of these two procedures have been successfully tested for both types of applications. Validation results in comparison to in-field measurements indicate a reliable accuracy of the such produced reflectance spectra.

1 INTRODUCTION

Airborne photogrammetry has gone all digital at various operational data acquisition facilities. However, the potential of this system change has not yet been explored as the data is hardly used for remote sensing - like data analysis. The are more and more well-calibrated radiometric measurement devices. As such, the radiative transfer based processing of the acquired data to surface reflectance products has become feasible (Honkavaara et al., 2009). Such correction has the advantage that inherent surface properties become available rather than the at-sensor measurement signals, which are biased by the state of the atmosphere and the illumination conditions. The Swiss federal office of topography (swisstopo) uses two ADS-80 (Sandau et al., 2000) systems for cartography and for the generation of its imaging products on a regular basis. The systems are calibrated by the system provider (Leica). This allows to apply a physically-based atmospheric compensation method to improve the imagey quality and to retrieve surface reflectance products. Thus, it was decided to develop a correction scheme on the basis of ATCOR-4 (Richter and Schläpfer, 2002) technology. The ATCOR-4 method relies on the MODTRAN®-5 radiative transfer code (Berk et al., 2004). The calibrated at sensor radiance values are inverted to (directional) ground reflectance values. Effects of aerosol and molecular scattering, gaseous transmittance and illumination are removed under consideration of the state of the atmosphere, the local view angle, and the terrain altitude and exposition. This method requires absolute physical calibration of the image data to the units $mW/(cm^2 sr \mu m)$ for fully automatic processing.

The goal of this development is to improve the quality of two major products in the processing chain:

- The *swissimage* product should be corrected for the topographic dependency of atmospheric scattering, depending on flight altitude, terrain height and viewing angle. The target resolution of the products is at 0.25m and 16bit TIFF files shall be generated as RGB and NRG composites. The focus of this product is the improved consistency between mountain areas and valleys, a correction of the across track scattering effect by the aerosol phase function, and an improved visual appearance with respect to colors and and contrast.
- The *remote sensing basis* product is optimized for use for quantitative thematic analysis using standard remote sensing methods. The result should be a surface reflectance product which is not biased by shadows and bidirectional reflectance effects. The target resolution is at 0.5m and the output is a 4-band NRGB TIFF image. A limited number of selectable options of radiometric correction should be possible depending on the type of application envisaged.

The development in view of these two products involves the setup of an automatic processing chain, including the preprocessing of digital elevation data for radiometric correction, automatic metadata handling, and ADS-80 data import. On the methodological side, the illumination field is to be calculated from terrain model information as well as using image-based algorithms for cast shadow detection. The correction is then implemented in two well defined standard workflows for both product. The software is an add-on to ATCOR-4 which we refer to as "ATCOR-ADS". This paper focuses on the implementation details and the workflow of the processing and shows some first validation results with respect to ground reference measurements.

2 PROCESSING SCHEME

The atmospheric compensation routine is implemented within the framework of the standard processing system for ADS-80 data at swisstopo. The goal is a fully automatic processing on an operational basis. This section gives an overview of the required inputs and interfaces, specific illumination-related add-ons, and the processing workflow.

2.1 Input Data

The input data are given in three entities: ADS imagery, a digital terrain model (DTM), and meta data. The ADS imagery is provided as the orthorectified data product, i.e. a NRGB TIFF image, accompanied by a *.tfw TIFF world file descriptor, 4 bands, 16 bit, cut to tiles with file sizes of 2GB maximum. No compression is applied and only the nadir viewing imagery is processed. The DTM is provided at a resolution of 1m or 2m in TIFF format, accompanied by a *.tfw descriptor format. The terrain model should cover the same area as the complete imagery of a full run (containing all adjacent image tiles). A digital surface model (DSM) may be available but it is not used in the radiometric processing for now. The meta data required for the processing is compiled in two XML files. The first summarizes the specific information of all flight lines available in the processing, i.e. the date and time of data acquisition, the starting point and the ending point, the flight altitude a.s.l., and the camera identification. A second files gives the information regarding the available cameras. Specifically, it contains the band configuration and calibration information for the four spectral bands.

2.2 Illumination and Cast Shadow Preparation

Illumination effects to be corrected for the *remote sensing basis* product, but not for the *swissimage* product. The illumination is first calculated on the basis of the terrain model using the standard approach implemented in ATCOR-4, i.e., using an efficient vector algebra based method (Corripio, 2003). Moreover, the skyview factor describing the amount of visible blue sky per pixel is calculated on a reduced resolution DTM. First tests had shown that the correction of cast shadows and illumination on the basis of a surface model does not lead to useful results as the surface representation with respect to the radiometry is never accurate enough; this leads to heavy over- and undercorrection artifacts in the resulting images.
The correction of cast shadows has been widely studies, specifically for space borne high resolution instruments (Asner, 2003, Shao et al., 2011). For the improvement of the cast shadow correction in ATCOR-ADS, a new method for cast shadow detection has been implemented which produces a continuous shadow field. It relies on the fact that all areas in cast shadows are illuminated by diffuse irradiance only. The diffuse illumination is caused by scattering and thus exhibits has a very specific spectral characteristics if compared to the direct illumination. Specifically, the signal in the blue spectral band is much higher. For the shadow quantification, the brightness as the root of the sum square of all 4 bands is first calculated. Secondly, a blue index is found as the relation between the green and blue spectral band, and a second one in relation between the red and the blue band. These three measures are combined such that a value equivalent to the illumination between 0 and 1 is created (0 being a cast shadow area). The output is continuous and may be used as such in the atmospheric correction directly as a side input to ATCOR-4. Note, that this illumination map does not consider the slope and aspect information for terrain correction yet. Our tests have shown that this algorithm detects the cast shadows definitely to a higher accuracy than the geometrical approach based on a DSM.

2.3 Processor Workflow

Two interfaces are foreseen for the ADS processing: at first, a simple ATCOR-ADS graphical user interface is developed which allows to select the input data files as described in 2.1 and to toggle the applicable options of the processing. This interface is used for testing purposes, but potentially may also be used for operational processes supervised by an operator. For automatic processing, a batch call is implemented where all necessary input parameters are provided by a single command line sequence. Both interfaces call first the interfacing routines specific to ADS and secondly, the atmospheric compensation process is called. The programs including ATCOR-4 are fully based on the IDL programming language (Exelis, 2011). Both, ATCOR-4 and and IDL are licensed standard products which are engaged for the batch processing by the end user.

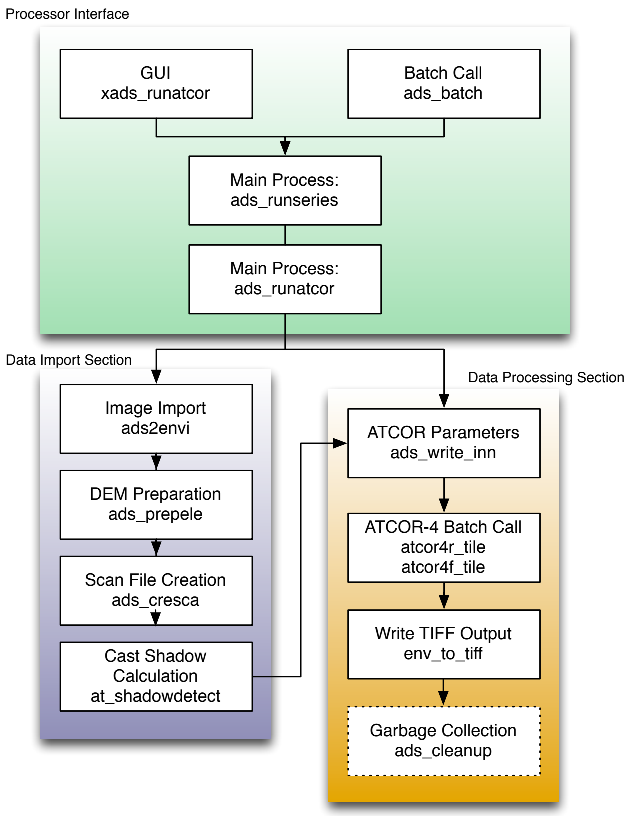


Figure 2: ATCOR-ADS processing workflow overview.

The processing workflow of ATCOR-ADS is defined as follows (compare Figure 2):

1. In the interfacing part, the names of all input files are defined, i.e. the image, the DEM, the sensor definition, the meta data XML. Furthermore, the output resolution and directory is given and options of the ATCOR-4 processing are defined, i.e. product type, shadow detection, illumination treatment, and output bands combination.

2. The series of image tiles is compiled to be processed for a full flight line in preparation to a sequential call of all tiles.

3. The image data is loaded from TIFF to ATCOR-4 compatible ENVI®-type formats and written to a temporary directory.

4. The meta data is read for sensor and image lines information.

5. The DEM is loaded and resampled to the image dimensions. All required DEM-related auxiliary layers (i.e., slope, aspect, skyview) are calculated and written as additional input files.

6. A scan angle file is created which stores the view zenith angle for each pixel using the flight path and the image geometric reference information.

7. The cast shadow detection routine is optionally run to create an input illumination field file.

8. The ATCOR-4 batch control *.inn-file is written, including the geometric information calculated from the meta data stream and the file names of all files created.

9. ATCOR-4 is started in batch mode using the set parameters. A log file is written during the processing.

10. The standard output is transformed to TIFF format and stored to the destination directory.

11. The process (points 3 to 10) is repeated if further tiles are in the queue.

12. An optional garbage collection routines cleans all files from the temporary directory location.

Currently supported processing options are the selection between flat terrain and rugged terrain, consideration of terrain slope illumination, cast shadow correction, empirical correction of the incidence BRDF effect, and the enhancement of cast shadow areas in combination with incidence BRDF correction. Any further options intrinsic to ATCOR-4 are to be treated externally to the streamlined processing workflow. Also note that the sensor definition for ADS-80 has to be done properly in advance within the standard ATCOR-4 framework. This includes the creation of the appropriately sampled LUTs and the calibration files (which normally are simply scaling factors to physical units with no offset).

2.4 Outputs

The standard output of ATCOR-4 atmospheric correction contains the following layers in ENVI format (raw binary with ASCII header). This includes two types of files: a series of files is created from DEM such as the elevation data, sky view factor, slope, and aspect angle. From imagery, the illumination map is optionally calculated as an input on the basis of the cast shadow classification routine and the scan angle file is created using the meta data information in conjunction with the georeferencing information of the imagery. For standard photogrammetric applications, most of these side layers may be deleted after processing. However, for remote sensing applications the archiving of this side information may be of interest. Only the image itself is transformed to TIFF whereas all side outputs remain in the standard ENVI® data formats.

3 RESULTS

The implemented software has been tested on three representative test data sets provided by swisstopo from Brunnen, Simplon and Thun areas (in Switzerland, years 2010 and 2011). The data were complete flight lines containing 3 to 7 tiles each. Both, the *swissimage* product and the *remote sensing basis* product has been created from these data sets. The data are accompanied by a Lidar DTM covering the whole area per flight and the XML meta data files as mentioned above. Furthermore, the Remote Sensing Laboratories of the University of Zurich provided atmospherically corrected APEX (Itten et al., 2008) test data and spectroradiometric ground reference measurements for cross comparison on the reflectance level for the THUN scenes. The spectroscopic reflectance data provided by University of Zurich is convolved to the spectral response characteristics of ADS-80 for the further evaluation.

3.1 Processor Performance

The processing is tested on a machine with 16GB Ram and a 2.2 GHz Intel Core i7 processor, with standard 5400 rpm hard discs. The processing of the 'Brunnen' image scenes, which is a series of 4 images and a total of 8.9 GB of data, takes 2 hours 20 minutes. The processing time scales linearly with the amount of data for large data sets. This results in a performance of 16 Minutes/GB data processing for the swisstopo case.
For the *remote sensing basis* product, the processing time decreases roughly by a factor of 4, as the resolution is down to 0.5m instead of 0.25m. The processing for 4.8 GB (reduced to 1.2GB) of the Thun dataset takes 20 minutes in this configuration, which results in a performance of roughly 4 Minutes/GB raw data. This result confirms the assumption, that the processing duration may be linearly scaled with the data amount. This speed may be further increased by sending parallel batch jobs for the individual scenes or by the use of SSD discs.
Some improvements to the underlying ATCOR-4 software were required to allow the fully automatic processing of the data. ATCOR-4 has been adapted in collaboration with the developer (R. Richter,

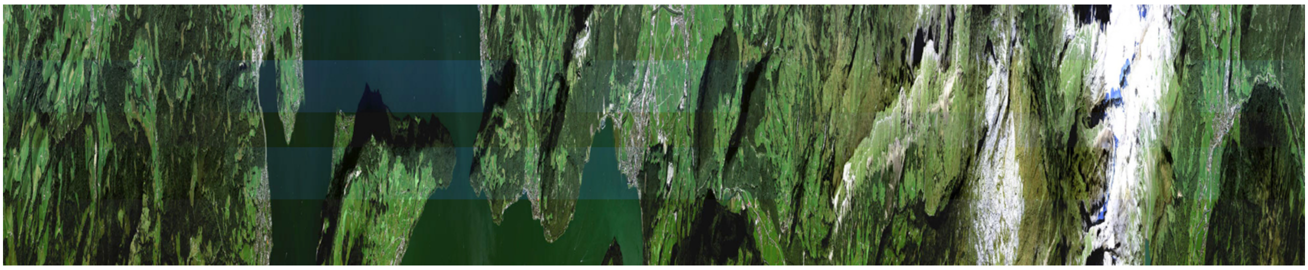


Figure 1: *Swissimage* correction output overlay with original imagery (2 stripes). The image is skewed in along track direction for better visibility of the correction effect.

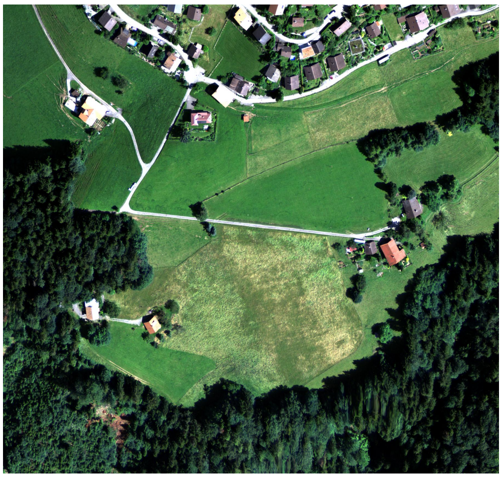
German Aerospace Center, DLR) to account for specific situations occurring for the ADS data sets. Specifically, images containing large portions of background are analyzed for the tile containing most of the information. This tile is used for aerosol detection and in the processing of a series of images (i.e., of a flight line), the aerosol amount is inherited from the first data set to all subsequent sets to allow for a seamless aerosol correction. Furthermore, logging is done to one log file only even if a series of files is processed and the console outputs are consistent to the outputs in the log file. The currently implemented options have been evaluated on all test data provided, however full operationality still requires more extensive testing of the procedure on a broader set of data.

3.2 Swissimage Product

All data has been processed to *swissimage* standard products in order to test the processor stability. First, the standard 0.25m products are generated for a subset of the imagery for test purposes. Secondly, products at an output resolution of 0.5 and 2m are created in order to allow large scale analysis of the imagery. The focus of the *swissimage* standard products is a natural visual appearance and consistency amongst data acquired at various dates throughout the year. Using the provided test data sets, the first criterion is hard to assess quantitatively, as no scenes acquired at the same location from various times of the year were available for this analysis.
The second criterion is analyzed twofold: first, the visual appearance is investigated. Secondly, the along track statistics are compared within the flight track with the highest expected variations (i.e., Brunnen). The major visible impact of the *swissimage* correction is the removal of the blue haze influence in low altitude regions. This also results in a greenish lake, which is its natural color (see Figure 1). At higher altitudes, the effect is no longer visible which leads to a better consistency between ground altitudes. A further removed effect is the across track variation of the atmospheric path scattering which is visible in the northern part of the images. However, some information within cast shadow areas may be lost by over-correction, specifically for the shorter wavelength bands. A special treatment of the cast shadow or an adaption of the calibration coefficients will be required to get better results.
A spectral analysis of the correction shows a reduction of the signal in the blue spectral band reflects the correction of the path scattered radiance. The green and the red spectral band signal are closer together, whereas the generally brighter near infrared band is less affected by the atmospheric compensation.

3.3 Remote Sensing Basis Product

The correction of the data to the *remote sensing basis* product is optimized with respect to the variation of the illumination and for the absolute accuracy of the derived reflectance data products (compare Figure 3). The results of the cast shadow correction show the improved accuracy of the correction: most shadows are detected and corrected at their correct locations. Artifacts appear at the edges of the cast shadows. The reasons for these artifacts are due to the way the atmospheric correction is implemented in ATCOR-4: a first artifact is seen between the core shadow areas and the partially shadowed areas. This appears because the core shadows are treated in a separate process of ATCOR-4 processing. A second artifact appears as a brightening at the borders of the cast shadows. The shadows have therefore been smoothed to avoid overcorrections and discontinuities at the edges. Still, a blue effect is seen at the borders only. This may stem from the circumsolar irradiation, which is a strongly forward scattered portion of the irradiance within a few degrees of the principal solar direction. This part of the irradiance is not accounted for separately in the radiometric correction scheme of ATCOR-4 yet. A further improvement of these observed artifacts will require a major rewrite of parts of the ATCOR-4 software.



(a) flat correction

(b) image based shadow correction

Figure 3: Automatic cast shadow removal on the basis of cast shadow classification.

4 VALIDATION

A first statistical validation has been done between the two ADS cameras of swisstopo. A very good agreement was found as shown in Table 1. Only a small offset in a range of up to 0.3% reflectance was found between the cameras. Linear regression analysis between the two cameras also suggests that camera 30030 has a slightly higher gain (about 2-3% more) than camera 1308. Thus, the relative calibration of the two cameras is considered being valid and sound.

	Mean-1	Stdev-1	Mean-2	Stdev-2
Blue	5.53	5.17	5.80	5.55
Green	9.11	6.53	8.98	6.76
Red	8.20	7.57	8.40	7.91
NIR	28.31	14.66	28.84	15.30

Table 1: Intercomparison of swisstopo ADS cameras 1308 (1) and 30030 (2) reflectance values [%] over same area.

For absolute validation, the data was compared agains ground reference spectra. The results show a good agreement between

ADS-spectra and the in-field measurements. Specifically, for the stable targets 'Asphalt' and 'Gravel', the agreement is good within 1% reflectance between the ADS 30030 (see Table 2) and the ground reference. The outputs of camera 1308 are slightly lower than for camera 30030 which is in agreement to the cross-comparison results. Results for the target 'Gravel' were on the same level of accuracy, whereas for a 'Meadow' target, the offsets where higher in the blue and red spectral bands. It has to be noted, that meadows should only be used with caution for such analyses, due to their strong bidirectional reflectance variation.

	In-Field	ADS-1308	ADS-30030
Blue	14.0	12.3	13.2
Green	15.0	15.0	14.8
Red	15.3	15.1	15.5
NIR	15.9	15.0	14.5

Table 2: Intercomparison of swisstopo ADS cameras 1308 and 30030 reflectance values [%] to a ground reference spectrum of asphalt.

Some validation with APEX data has also been performed and show a good comparability of the resulting reflectance values. Details about this validation will be published elsewhere.

5 CONCLUSIONS AND OUTLOOK

The presented analyses have shown that a radiative transfer based atmospheric compensation is feasible in an operational way for calibrated ADS-80 data. Two product types have been implemented for operational processing in a productive environment. The process has been implemented on the basis of three test data sets such that fully automatic interactive and batch processing is feasible.

For the *swissimage* data product, an improved terrain-dependent correction of the aerosol scattering effect could be achieved. It also reduces effects of the atmospheric scattering in across-track direction and increases the consistency of the data in mountainous areas. For the *remote sensing basis* product, substantial progress could be done by inclusion of a quantitative shadow detection routine into the radiometric processing. Some preliminary analyses on the basis of NDVI maps have shown a higher reliability of the therefrom derived remote sensing standard products.

ATCOR-ADS has been developed as an add-on to the ATCOR-4 software on the basis of the swisstopo processing system. However, it may be transferred to other systems as a generic approach is followed in the implementation.

Further developments and analyses from this state are required to consolidate this work. For the *swissimage* product, it has to be checked how dark areas are to be treated in order to avoid data loss by blackening. Furthermore, a reliable across track BRDF correction is still to be added and is investigated with high priority. For the *remote sensing basis* product, the new method for cast shadow detection and correction is to be further developed and tested in various environments. Specifically, the masking of water surfaces is required to avoid false-classifications as shadow areas.

For the reduction of the observed artifacts, it is to be checked, if the effect of the circumsolar scattering can be corrected within ATCOR-4 or as an external process. Also, the treatment of core shadow areas will have to be improved to allow for a smooth transition to partially shadowed areas.

The first validation has shown a good agreement between the corrected ADS data and ground reference reflectance values. The radiometric validation of the outputs with respect to ground reference data should be extended to further measurements and to the available APEX data.

The evaluation of the *remote sensing basis* product reflectance with respect to remote sensing standard products could be further elaborated, such that the quality of such products can be well quantified. Finally, a surface-cover dependent BRDF correction should be envisaged which accounts for the typical east-west flight pattern of swisstopo. The *remote sensing basis* product data bear a valuable potential for future products, and their further development is of high interest. However, it is yet to be shown if all the improvements can be achieved with reasonable efforts and some compromises may have to be taken in the course of potential further developments.

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