RADIOMETRIC PROCESSING OF ADS IMAGERY: USING ATMOSPHERIC AND BRDF CORRECTIONS IN PRODUCTION

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ABSTRACT

Leica XPro 4.0 for processing ADS imagery has introduced new radiometric correction models to reduce image bias created by atmospheric and ground reflections. Most notable is the availability of atmospheric corrections based on the equation of radiative transfer and a correction that deals with bidirectional reflectance effects on the ground (BRDF) based on a modified Walthall model. To obtain best results, it has been proven that land body masks determined by classification of the near infrared and red bands are required for the BRDF correction. The creation of such land masks is automated in the Leica XPro processing chain. The masks are embedded in the image statistics that are utilized by the image viewer and orthorectification process to apply the BRDF model. The atmospheric and BRDF corrections can be used in real-time in the Leica XPro QC Viewer, allowing the evaluation without the necessity of orthorectifying the imagery. This paper discusses the radiometric corrections in Leica XPro and presents the results of extensive testing of the atmospheric and BRDF corrections in a real world mapping production environment. It is shown that the application of the atmospheric and BRDF corrections at orthorectification time is a true enrichment of radiometric options and generates high quality deliverable image products. In most cases, corrected orthoimages show little radiometric difference throughout a block and only minor adaptation is needed for mosaic generation; respective research is described in a follow-up paper.

INTRODUCTION

Due to the inability to perform an absolute radiometric calibration with analog sensor technology, it was always a challenge for mapping companies to deliver homogeneous image products for very large projects. It is impossible to deliver reproducible radiometric responses with film due to many factors, e.g. film grain, laboratory processing, etc. With the advent of digital sensors like the Leica ADS line-scanner, which can be correctly radiometrically calibrated, it is now possible to effectively create a calibrated radiometric response for a sensor. Not only does this lead to results from the same sensor being comparable, but also from different sensors flown under varying illumination conditions. This allows mapping companies to acquire and process very large projects (such as a full US State at 1 foot resolution) and derive homogeneous image products. The absolute radiometric calibration, as discussed in the following, is the prerequisite for the ability to pursue geographically large projects that can be acquired with multiple digital sensors.

A sensor independent model also permits the application of higher level radiometric corrections that can adjust sun angle and physical disturbances of the image signal, i.e. light scattering and haze. These corrections are image based and are a function of physical properties such as sun angle, integration time, ground elevation, flying height and sensor orientation. In addition to the atmospheric correction, a second level of radiometric BRDF correction based on image statistics can be applied to normalize the image.

The ability to process large projects and create mosaics from many image strips acquired from multiple sensors opens new opportunities for mapping companies; but it also creates new challenges for radiometric quality control in the production work flow. Tools to apply the radiometric corrections in real time to the raw images have become necessary for production. Leica XPro provides a QC Viewer that can perform absolute radiometric calibration, atmospheric, and BRDF corrections in real time. It can also rectify the raw data to a plane surface and display this virtual image. This allows quality control and preview of multi-band products, such as 3 band images or 4 band images (RGB + infrared) that are prevalent, before the data is geometrically triangulated and orthorectified.

ABSOLUTE RADIOMETRIC CALIBRATION

The physical principle of radiance in a CCD sensor is defined by a linear response to the incoming amount of light (radiance). Secondary effects such as dark current, sensitivity variations, and lens falloff result in an inhomogeneous image. In order to allow the use of a linear radiometric model, Dark Signal Non-Uniformity (DSNU) and Photo Response Non-Uniformity corrections are performed during image acquisition on the sensor head. The resulting image's DNs can be accessed as level zero data and checked with the Leica XPro QC Viewer using a correction setting of "None". As a result of the system corrections, the following linear relationship can be used for each pixel of a CCD line to calculate the at-sensor radiance:

$$L = \frac{c_{CCD}}{t_{CCD}} DN$$

L – spectral radiance [W/m^2/sr/μm]
DN – measured intensity
c_{CCD} – specific radiometric calibration factor [Ws/m^2/sr/μm]
t_{CCD} – integration time of the CCD line [s]

In the Leica XPro QC Viewer and Rectifier for processing ADS image data, the standard setting for corrections is "Calibrated". This means that the resulting DNs are calibrated to radiance values and scaled with a factor of 50, i.e. 50 DN equal to a band averaged spectral at-sensor radiance of 1 W/m^2/sr/μm (Beisl, 2006b). This absolute radiometric calibration has already been available in previous software, GPro 3.0, and for all ADS40/50/80 sensor heads.

Absolutely calibrated radiances are the starting point for all further corrections since they provide a sensor independent data reference. This is extremely useful for data fusion with other sensors.

ATMOSPHERIC CORRECTIONS

Radiation Transfer

Considering the light path from the sun to the ground and reflected back to the sensor, Figure 1 shows several influences that determine the pixel brightness. The sun zenith angle θ (= 90 degrees - solar elevation) will account for an attenuation of the solar irradiance on the ground of cos(θ).

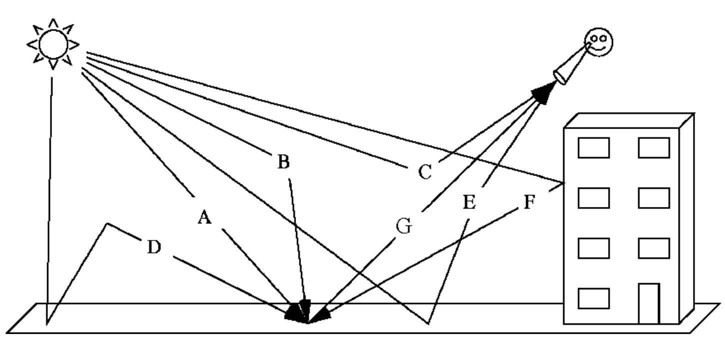

Figure 1. Radiation components reaching a sensor.

Furthermore, the direct downward transmissivity from sun to ground (A) will reduce the irradiance on the ground, which is partly compensated by diffusely scattered light from the atmosphere (B), which results in the total downward transmissivity. Also the upward transmissivity from ground to sensor (G) will attenuate the reflected signal. The path radiance (C) from atmospheric scattering reaching the sensor will enhance the signal by a viewing angle dependent amount, without carrying any target information. This component is the haze, found on aerial and satellite images; it increases with sensor height over ground. Finally, light reflected from bright surfaces adjacent to the pixel and finally reaching the sensor (contributions D, E, F) will cause an additional diffuse irradiance and, accordingly, a contrast reduction (adjacency effect).

Taking into account all of these influences allows the operator to perform a radiometric normalization such that "ground reflectance" (a surface property) can be calculated. Only this value enables comparing brightness within an image, from image to image in a block, from sensor to sensor and from block to block in a time series and/or a spatial layout. All atmospheric and BRDF corrections described in the following work on a per image basis. When it comes to mosaicking, final relative radiometric normalization is performed considering a whole block (Gehrke, 2010).

Dark Pixel Subtraction and the Modified Chavez Method

The first steps to atmospherically correct ADS data were made in GPro 3.1 with the introduction of the "Dark Pixel Subtraction" (DPS) and the "Modified Chavez" (MCh; Chavez, 1988) method, described in Beisl et al. (2006a). Both empirical methods correct the view angle dependent path radiance by column wise subtraction of the brightness of a dark pixel. This results in an atmospheric gradient correction and contrast enhancement. The dark pixel brightness value can be changed by the user by selecting the percentile that defines the dark pixel threshold.

While the DPS addresses each spectral band separately, MCh detects the haze value in the blue band and predicts the haze in the other bands by assuming a certain haze model. This is to prevent overcorrection of the RED and NIR bands in desert areas that have very few dark pixels. The automatically detected haze model can be manually overridden. In almost all cases, both methods produce the same result, i.e. ground reflected radiances. Those radiances are comparable between sensors, within one image and between adjacent images. Both methods are rather robust towards weather conditions and include the absolute radiance calibration.

Modified Song-Lu-Wesely Method

As shown above, the solar position and atmospheric properties also influence the irradiance on the ground, which in turn cause proportional changes in the ground reflected radiances. Only by dividing out the solar irradiance (an invariant property), ground reflectances can be obtained.

With Leica XPro a new method is available following Song et al. (2003) and explained in more detail in Beisl et al. (2008). The reflectance calculation is performed using the formula of Kaufman and Sendra (1988). The atmospheric modeling is done using a parameterized model based on the solar position, flying height, ground elevation, and sensor orientation as general inputs. The atmospheric haze is automatically determined by calculating the dark pixel radiance from the image histogram. Currently a uniform haze over the whole image is assumed and no elevation model is used. The solar irradiance is assumed to be constant over one flight line. When selecting "Atmospheric" in the QC Viewer or Rectifier, the DNs of an ADS image are calibrated to ground reflectances and scaled by a factor of 10,000. Thus, a DN of 10,000 is equal to a reflectance of 1, or 100%. This is the preferred method for good to moderate weather conditions and permits simplified mosaicking of data, even from different times and dates.

BRDF CORRECTION

After performing a view angle dependent haze correction, image anisotropy will still be observed in general. This is due to the so-called bidirectional reflection properties of all natural and artificial surfaces, described by the Bidirectional Reflectance Distribution Function (BRDF).

Modified Walthall Model

The BRDF correction is based on statistics for the land surface of the whole image (see below). In order to avoid boundary issues and have a fast algorithm, water parts are corrected as land surface and no classification is performed to correct for different BRDF types. For the BRDF modeling the empirical Walthall model (Walthall, 1985) is used which was extended by a hot spot term as described in Beisl et al. (2006a).

Classification to Detect Land

A non-classified BRDF approach allows for efficient processing but at the cost of not being able to accurately model certain terrain types. Specularly reflective surfaces can also adversely effect the correction and cause it to perform incorrect changes in the radiometry of the images. Large water bodies can be a major contributor of specular reflection and therefore need to be detected and removed from the statistical collection. Figures 2 and 3 show the effect that a large amount of specular reflection on water can have on the statistics used in the BRDF correction. The un-masked statistics (Figure 2) clearly show a large increase on the right side of the image, but after the masking of water the statistics show the opposite, land only gradient (Figure 3).

A preprocessing step is done to generate a mask that allows the statistical collection to ignore the water areas. The masking process uses the NDVI value of each location in the image to determine if it is land, i.e. NDVI > -0.1:

$$NDVI = \frac{DN_{NIR} - DN_{RED}}{DN_{NIR} + DN_{RED}}$$

Once the mask is generated, the statistics are collected for both masked and unmasked data. The masked statistics are then used to initialize the BRDF correction allowing it to properly correct the land areas of the image.

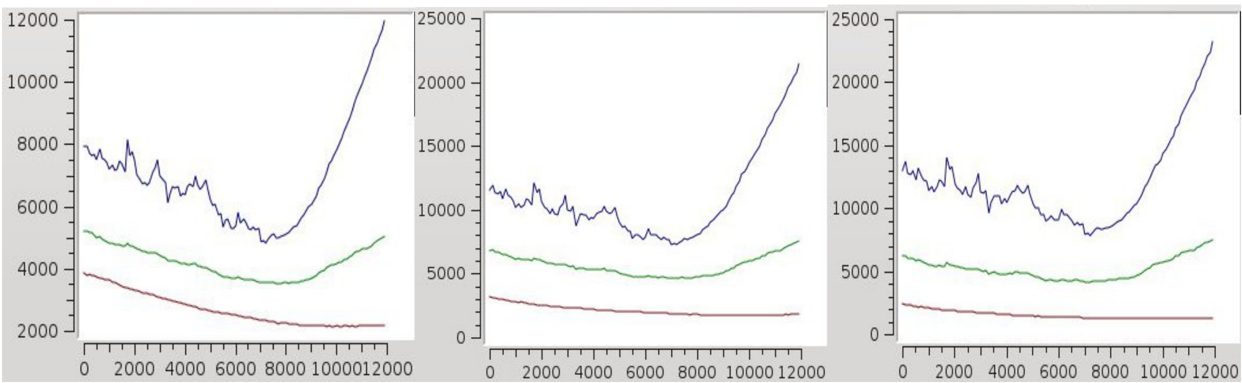

Figure 2. Unmasked Red, Green and Blue statistics showing the 95%, 50% and 0.1% values across the image, from top to bottom (histogram percentile at each image column).

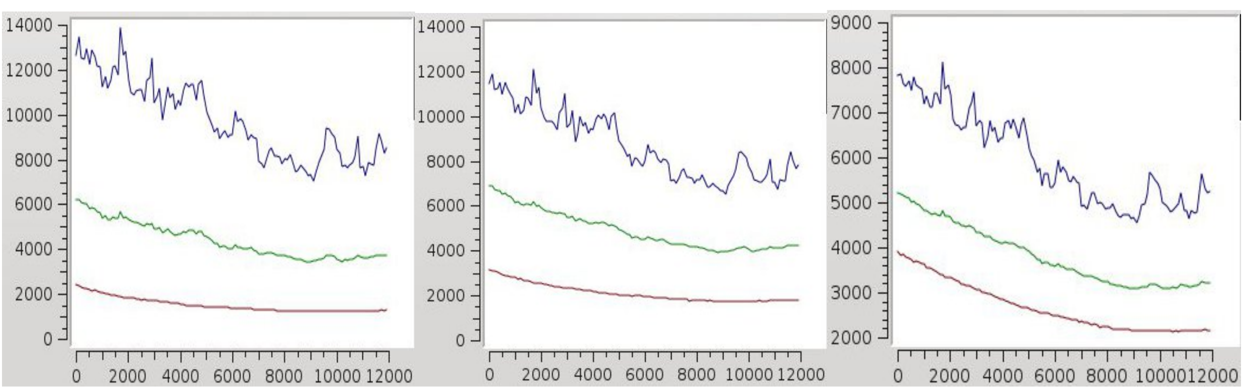

Figure 3. Masked Red, Green and Blue statistics showing the 95%, 50% and 0.1% values across the image, from top to bottom (histogram percentile at each image column)

Considerations

Since the BRDF correction is only intended for image normalization in mapping applications, for remote sensing applications it is recommended to perform the flight planning such that BRDF effects are minimized. This is done by aligning the flight direction with the sun-target direction (towards or opposite the sun). If the backward colors of an ADS SH82 are also used, the direction with the sun in the back is the recommended configuration. Flight times when the sun zenith angle is smaller than the maximum view angle of the sensor – 32 degrees, i.e. solar elevation larger than 58 degrees – should be avoided, since BRDF effects are increasing even in the recommended flight direction. But in contrast to frame images where there is always a hotspot in the images when sun zenith angle is smaller than the view angle, with the ADS a hot spot – or, respectively, hot streak in line-scanner images – can be avoided by sticking to the recommended flight direction.

The described atmospheric and BRDF corrections create a reasonably good and fast normalization of ADS imagery. The current implementation of these corrections in Leica XPro works well for flat terrain and homogeneous haze. For highest accuracy, the user is encouraged to apply custom methods.

XPRO WORKFLOW AND RESULTS

Generally, during the active flying season a busy company can generate many terabytes of input data that needs to be processed. Handling the volume of data and ensuring that all the processing steps are executed can be a difficult task. Making as many steps in the processing work flow automated is the key to ensure proper set up for incoming data. Minification, masking and statistics generation need to be run on all data. Submitting these processes out to a large cluster is critical to ensure that they get done in a timely manner.

Real-time QC

A number of problems occur when trying to apply reasonably complex corrections to a large set of image data. Incorrect sensor calibration, incorrect flight data and incorrect statistics can all cause large problems. It is important to catch these errors early in the processing workflow to prevent large delays. Ideally the checks need to be done at the very start of the workflow. To properly validate the corrections, a viewer is required that can rectify the four visible bands of the ADS to a constant height and apply the required corrections in real time. Each band needs to be corrected and rectified separately and then merged into a single multi-band image.

A processing chain was developed to provide the Leica XPro QC Viewer with the needed functionality. Full strips can be loaded, corrected, rectified and merged on the fly permitting quick viewing of corrected products. If problems are detected the user can easily switch between different correction levels to determine what correction is not properly set up. For example, if the wrong sensor calibration is being used, the operator can view the image with only the calibration correction applied and see from a color shift that the output imagery is not correct. Other possibilities would be to view just the atmospherically corrected output or just the BRDF corrected output – see examples in Figure 5 –, allowing the user to quickly find what is causing the issue.

Orthorectification and Mosaicking

The same processing chain is used for orthorectification, once the block is set up and the triangulation has been done, ensuring consistent radiometry throughout the workflow. For the subsequent step of orthoimage mosaicking, an additional, relative correction across the block might be necessary (Gehrke, 2010). Final radiometric adaptation, e.g. to customer specifications, is done outside of the processing chain because it is carried out (partly) manually.

Examples

The effect of atmospheric and BRDF corrections is demonstrated in Figure 5 for an individual flight line, which has been flown by North West Geomatics in April 2009 for USDA NAIP. The predominantly blue color in the radiometrically calibrated image is caused by the atmospheric haze, which results from flight altitudes of about 6.5 km above ground. In addition, there is a gradient across the flight line due to different illumination and viewing angles. While the atmospheric correction is able to significantly reduce the haze, the BRDF removes the gradient. Both corrections need to be applied to get a radiometrically uniform, natural image.

Viewing a single flight line doesn't show the major radiometric differences throughout a block. Figure 4 shows an example block, Texas South A, which covers the area from the Mexican border in the southeast to the Golf of Mexico, as far north as Baffin Bay; its largest extent is about 260 km x 190 km. In altogether five flights with three different ADS cameras, a total of 36 takes has been captured. This makes it a radiometrically challenging but, nonetheless, typical ADS block. In Figure 4, top, flights flown at different times of day are clearly visible and neighboring lines can appear significantly different. As shown in Figure 4, bottom, atmospheric and BRDF corrections greatly reduce the influence of haze as well as illumination differences, allowing for easier mosaicking – see Gehrke (2010) for the results of further radiometric normalization of this block.

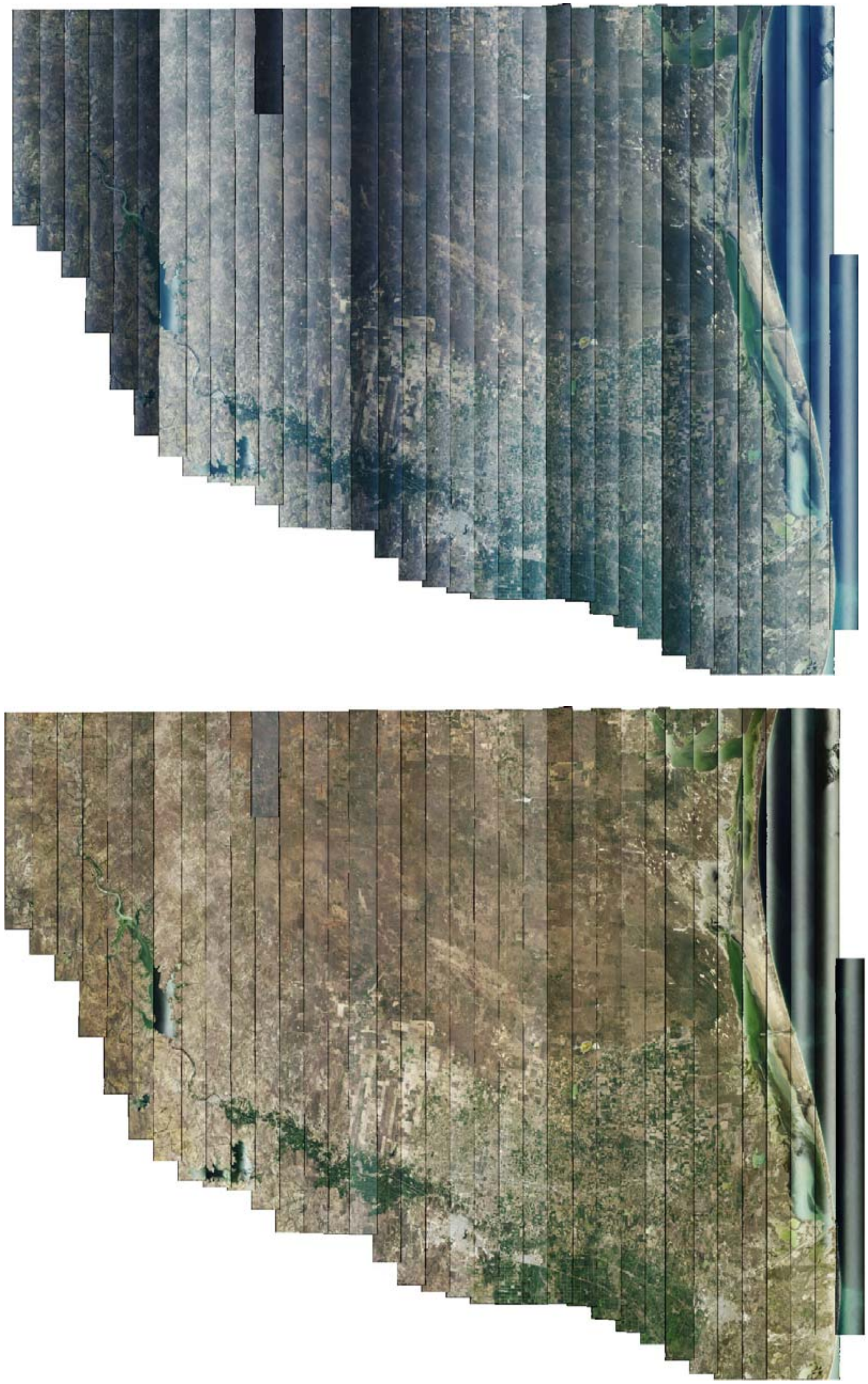

Figure 4. Block Texas South A with calibration (top) and atmospheric and BRDF (bottom) corrections applied.

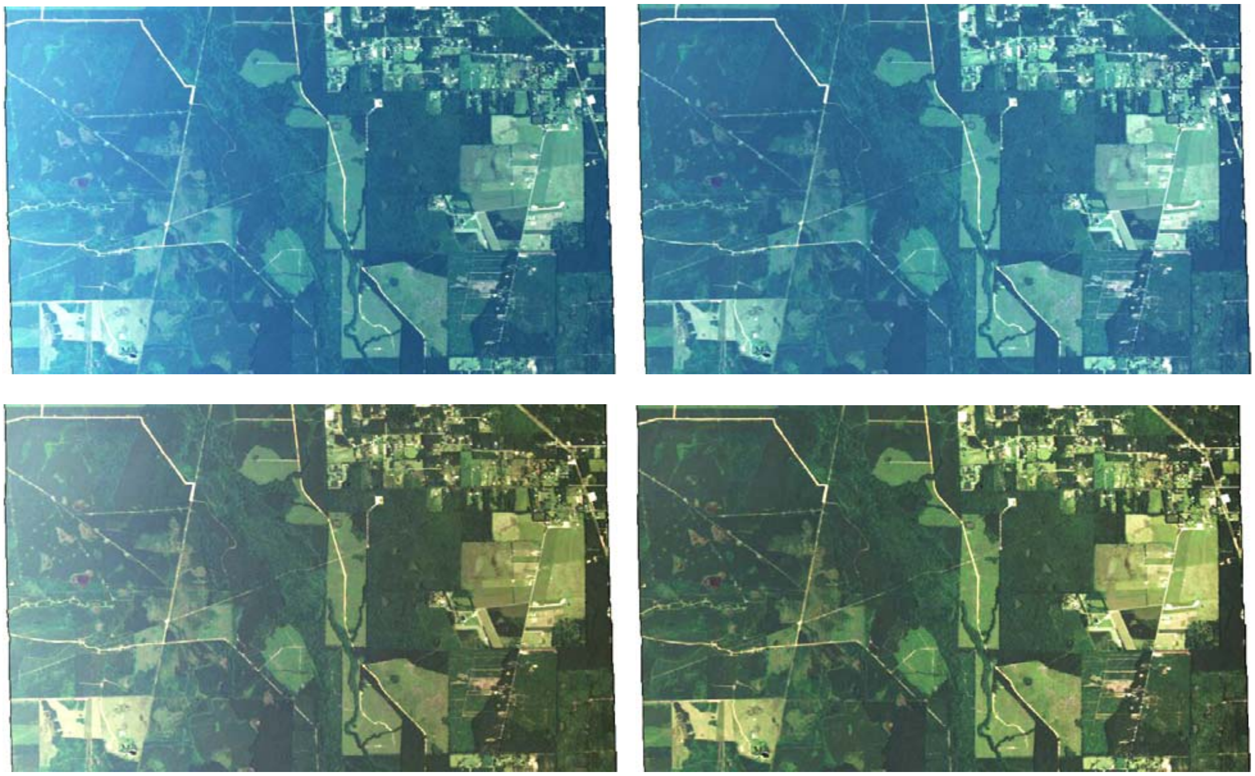

Figure 5. Examples of different radiometric corrections, applied to a Texas flight line (cross-sections). Upper-left: calibration; upper-right: calibration and BRDF; lower-left: atmospheric correction, inherently accounting for the calibration; lower-right: atmospheric and BRDF corrections.

CONCLUSIONS

This paper has outlined radiometric corrections for ADS imagery, in particular atmospheric and BRDF corrections, and their application in a production environment in the mapping industry. It has been empirically determined that the combination of atmospheric and BRDF corrections is the best solution for generating large homogeneous blocks of imagery.

With the advent of tools to apply atmospheric and BRDF corrections in real time in an image viewer – the Leica XPro QC Viewer – as well as in the orthorectification to disk, it is possible to process very large blocks of ADS image data in a short amount of time. In particular, the ability to preview the radiometric corrections in the QC Viewer before the time consuming rectification has been invaluable to production teams and amounts to large time savings. It should be noted that there are considerable IT requirements in regards to storage space and network speed to make this process feasible. The result from the QC process is the confirmation that the radiometric corrections improve the image homogeneity over a large block and provides the confidence that the orthorectification process will generate an output usable in the following mosaicking step. A relative radiometric normalization process, utilized to deliver final mosaic products, is described in a companion paper: "Radiometric Processing of ADS Imagery: Mosaicking Large Image Blocks" by Gehrke (2010).

REFERENCES

Beisl, U., Woodhouse, N., Lu, S., 2006a. Radiometric processing scheme for multispectral ADS40 data for mapping purposes. *Proc. ASPRS Annual Meeting, Reno, NV.*

Beisl, U., 2006b. Absolute spectroradiometric calibration of the ADS40 sensor. *Proc. ISPRS Commission 1 Symposium "From Sensors to Imagery", Paris - Marne-la-Vallee, France.*

Beisl, U., Telaar, J., Schoenermark, M., 2008. Atmospheric correction, reflectance calibration and BRDF correction for ADS40 image data. *Proc. XXIst congress ISPRS, Commission VII, Beijing, China*:7-12.
Chavez, P. S., Jr., 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sens. Environ., 24*:459-479.
Gehrke, S., 2010. Radiometric Processing of ADS Imagery: Mosaicking of large blocks, *Proc. ASPRS Annual Conference, San Diego, CA* (this issue).
Kaufman, J. Y., and Sendra, C, 1988. Algorithm for automatic atmospheric corrections to visible and near-IR satellite imagery, *Int. J. Remote Sensing, 9(8)*:1357- 1381.
Song, J., Lu, D., and Weseley, M. L., 2003. A simplified atmospheric correction procedure for the normalized difference vegetation index. *Photogramm. Eng. Remote Sens., 69(5)*:521-528.
Walthall, C. L., Norman, J. M., Welles, J. M., Campbell, G., and Blad, B. L., 1985. Simple equation to approximate the bidirectional reflectance from vegetative canopies and bare soil surfaces. *Appl. Opt., 24(3)*:383-387.