AEROSOL OPTICAL THICKNESS DETERMINATION AND COMPENSATION BASED ON ADVANCED CAST SHADOW DETECTION

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ABSTRACT

Aerosol optical thickness (AOT) retrieval is a critical parameter for atmospheric compensation of remote sensing imagery, but also for meteorological applications. This paper shows first results of a new aerosol detection method. The approach uses small scale shadow pixels for determination of the atmospheric scattering by inverting the ATCOR® atmospheric compensation method. In a first step, the shadow pixels have to be identified in the imagery. This is done by a blue to red ratio which is further adjusted by the near infrared band in order to take the vegetation bias into account. On high resolution instruments with resolutions below 5m, a decent amount of shaded pixels can be found by this method in a reliable way. Using this shadow mask, the aerosol inversion is done. The aerosol contents are varied in a way to retrieve a correction of shaded areas to a brightness comparable to non-shaded areas what leads to the best fitting aerosol amount. The method is tested on APEX airborne imaging spectroscopy data. The such derived aerosol contents are higher than expected if compared to AERONET station measurements. However, it can be shown that the atmospheric compensation using the such derived aerosol contents are significantly improved in comparison to standard aerosol estimation techniques.

KEYWORDS

atmospheric correction, radiometric compensation, haze and dust correction, atmospheric scattering, ATCOR.

INTRODUCTION

The aerosol optical thickness (AOT) is a key parameter for atmospheric compensation techniques as well as for micro- and macro-climate models. The retrieval and correction of AOT from optical remote sensing and spectroscopy data is a task which has been investigated for many years. The most prominent method currently used to compensate for aerosol effects in optical remote sensing data is the dense dark vegetation approaches (DDV, [1]). It relies on the presence of vegetated areas and uses an empirically found correlation between the visible and near or short wave infrared reflectance to find the signatures of aerosols in the visible bands. This method is limited to data containing dark vegetation such as forests. Recent experience by the authors has shown some limitations of this methods for high spatial resolution data. where numerous small scale shadows and dark objects are visible. Another approach for aerosol and haze detection and correction is the dark object analysis and subtraction method (DOS, 2). It is specifically suited for dense aerosol layers and haze. Using a moving window technique, this method can be used for statistical haze detection and removal [3]. However, the underlying reflectance signature does not allow for accurate aerosol optical thickness determination in relatively clear atmospheres.

To further advance the aerosol detection in support of atmospheric compensation, a new approach is investigated in this paper. Experience in atmospheric compensation of shadows by de-shadowing has shown a very high sensitivity of the de-shadowing process from the aerosol contents. This sensitivity can be used for aerosol contents derivation by optimization of the de-shadowing. Using shadows instead of dark vegetation bears the advantage that shaded pixels can

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be found in most high resolution imagery, unless it has been recorded with very small zenith angles or over completely flat areas such as salt lakes or extended agricultural fields.

METHOD

A precondition to the analysis of shadow signatures is knowledge about the location of shaded pixels. A shadow detection method is used, which exploits the difference of the spectral signatures of shaded pixels in comparison to the directly illuminated pixels to detect cast shadow areas. This shadow detection approach has been further developed from an idea presented in [4]. The method uses a red-blue shadow index which is calculated as:

$$Ind_{rb} = \frac{\rho_r}{\rho_b - c_n[(\rho_n - \rho_r) > 0]}$$

where ρ_r, ρ_b and ρ_n are the apparent reflectances in the red blue and near infrared bands, respectively and c_n is an empirical correction factor to account for vegetation influences.

This index is further adjusted to the ground altitude and aerosol regime by applying a correction factor which depends on minimum dark object signatures. Additionally, shadows on water are determined and brightness criteria are set to optimize the shadow distribution. Finally, thresholds are set on the combined index to derive a shading map with transition between full cast shadow and illuminated areas (compare Figure 1).

This cast shadow map is then used in conjunction with the ATCOR® atmospheric compensation approach [5] and the therein contained atmospheric look-up-table (LUT) for AOT determination. The LUTs are based on MODTRAN®5 [6], whereas the ATCOR model itself is described in detail in [5]. In an iterative procedure, the diffuse irradiance onto the cast shadow areas is tuned by varying the aerosol amount until the corrected reflectance statistics in originally shaded areas are at the same brightness level as the adjacent areas with direct irradiance regime. Using a moving window approach, AOT distribution maps can be derived by this technique at spectral bands in the visible wavelengths of the spectrum.

The complete retrieval procedure consists of the following steps:

1. prepare calibrated image, DEM, and ATCOR LUT,
2. transform image to at-sensor reflectance and find dark reference,
3. run shadow detection routine to create cast shadow and updated sky view factor layer,
4. start moving window on one selected image band (e.g., at 550 nm).
5. create image subsets including DEM, shadow mask, sky view factor, and LUT subset,
6. find bright reference mask for cast shadow correction iteration,
7. adjust aerosol content iteratively until the average reflectance in the corrected cast shadow areas match the bright reference areas, and
8. write aerosol optical thickness distribution and visibility index.

This shadow based aerosol optical thickness retrieval procedure (we name it SHAOT) has been implemented in the ATCOR atmospheric and topographic compensation environment, making use of the terrain-dependent modeling of irradiance for each image pixel. The model takes the adjacency radiance as well as the local sky view factor into account, which are both critical parameters for correct description of the diffuse irradiance on a pixel.

It has to be noted, that this method uses image statistics for its analysis. A minimum of 100 shaded pixels and 300 reference pixels per image patch have been set as limit to make the retrieval work with enough statistical viability.

RESULTS

First tests of this method had been successfully on the Leica ADS high resolution photogrammetric data and for high resolution satellite data. In this paper, we focus on the application to APEX imaging spectroscopy imagery. The investigated sample data was acquired on June 26th and 29th 2010 over the Laegern test site, Switzerland. Simultaneous AERONET [7] station measurements of aerosol optical thickness have been available from within the image scene for both days of data acquisition.

An example of the shadow detection routine output is given in Figure 1. Most small scale shadows are well detected and the discrimination with water is sufficient. Misinterpretations can be found for some bluish roofs in the image. The shown image subsets are of the typical size of the image patches used as moving window for aerosol determination, at typical diameters of 500-1000m.

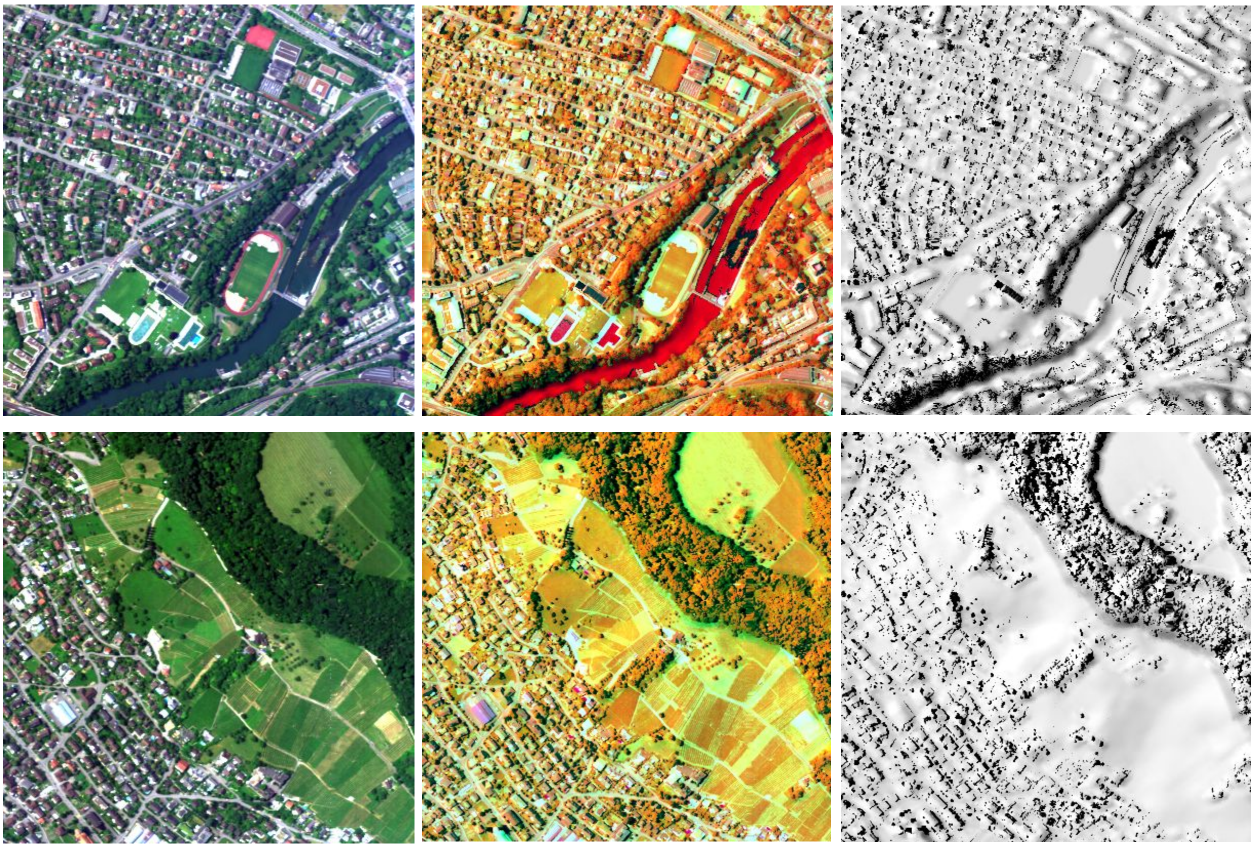

Figure 1: Cast shadow detection routine for APEX imagery; left: RGB image, middle: index combination, right: cast shadow map after thresholding.

An example result for one of the images is shown in Figure 2. ATCOR atmospheric correction has been done under consideration of topographic effects and using empirical incidence BRDF correction. Using the aerosol distribution as derived using the DDV methods leads to undercorrections in the forested areas. Using the SHAOT results for atmospheric compensation leads to a significant improvement. The derived aerosol distribution maps show reasonable AOT values and the correction or aerosol effects is considerably improved.

The AERONET station was situated in the middle of the image and measured an aerosol optical thickness value of 0.51 at 500 nm. The image derived AOT value at 550nm was about 0.56 for the location of the Aeronet station. For the second data set (June 26th), the Aeronet station reported an optical depth of 0.21 whereas the image derived value was at 0.34. These differences may be attributed to the differing measurement geometries of the ground based Aeronet stations in comparison to the airborne situation and the difference in measurement methodology.

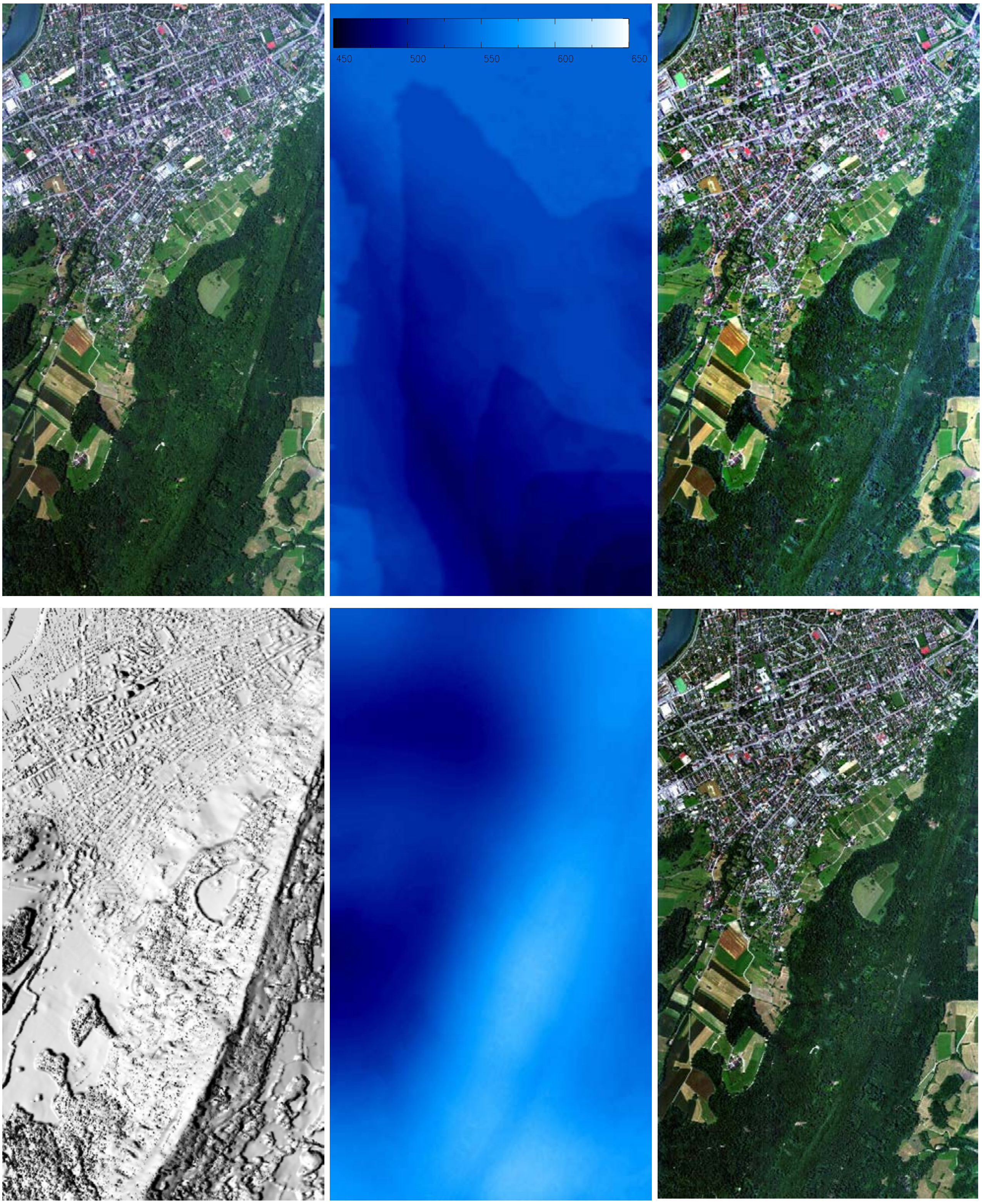

Figure 2: Example of aerosol retrieval and atmospheric compensation for APEX Laegern site: Top row: original image, DDV based aerosol retrieval and atmospheric compensation result. Bottom row: cast shadow map, SHAOT based aerosol retrieval and atmospheric compensation result.

If sample spectra are compared as shown in Figure 3, the difference between the standard aerosol retrieval and the SHAOT result is clearly visible. In the blue spectral range, the higher aerosol amounts found from shadow analysis lead to lower reflectance values for dark vegetation which is a more realistic spectrum for such objects. For a bright asphalt object, no such difference is visible in the blue as aerosol scattering and absorption cancel each other at high reflectance levels. However, a clear difference is visible in the near infrared, where the adjacency effects from the dominant vegetation areas are insufficiently corrected with the lower aerosol amounts, whereas the correction level is correct for the SHAOT amount. It has to be noted, that the spectra have not been smoothed or polished in these results, which results in visible spectral spikes in the data.

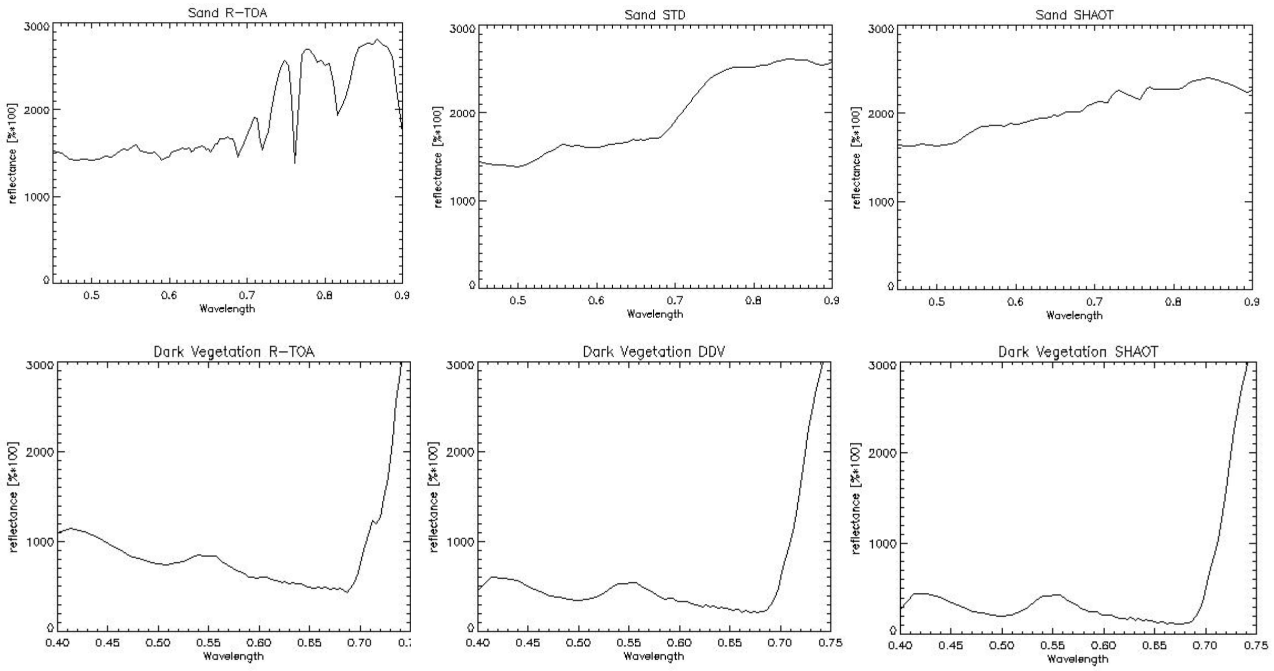

Figure 3: Spectral impact of aerosol content estimation on atmospheric compensation results. Left: at-sensor reflectance spectra, middle: atmospheric compensation with standard aerosol contents, right: atmospheric compensation with SHAOT based aerosol contents.

CONCLUSIONS

A new aerosol optical thickness inversion technique has been developed. It uses an inversion of the ATCOR atmospheric compensation routine to find the aerosol contents over shaded areas. The method is well applicable for high resolution imagery at resolutions below 5-10m, as long as enough pixels in cast shadows are available. As the method is using a moving window technique, the statistics in the moving window over hundreds of pixels are used for the inversion – single pixel inversion is not feasible as the local irradiance regime cannot (yet) be modeled to this level of accuracy.

The method is limited by the availability of spatially distributed cast shadow areas and therefore only works successfully on high resolution images. A further limitation are the instrument dynamics as the dark cast shadows should still be registered with enough fidelity to distinguish surface characteristics. Furthermore, results will be hard to retrieve for high ground altitude data and very clear atmospheres as the diffuse irradiance will be very low for such situations.

The method will be further developed toward full operationality for both high resolution satellite and airborne imagery. Furthermore, it bears the potential to derive the AOT values throughout the visible part of the spectrum by inverting the aerosol amount at various wavelengths. Based on a such extended retrieval, the method could theoretically be used to characterize the spectral aerosol single scattering albedo and aerosol size distribution from imagery.

Another potential application of this method is the pixel-wise cast shadow correction. So far, only average correction factors can be found from the method which leads to strong variation of correction results and related image artifacts within corrected cast shadow areas. Ways and methods have to be found to include more information about the irradiance from adjacent objects to a pixel and to include statistical neighborhood analysis in order to achieve seamless cast shadow corrections in the future.

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REFERENCES

1 Y. J. Kaufman and C. Sendra, “Algorithm for automatic atmospheric corrections to visible and near-IR satellite imagery,” *International Journal of Remote Sensing*, 9:8, 1357-1381, DOI: 10.1080/01431168808954942, 1988.

2 P. S. Chavez Jr., “An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data,” *Remote Sens. Environ.*, vol. 24, no. 3, pp. 459–479, Apr. 1988.

3 A. Makarau, R. Richter, D. Schläpfer, and P. Reinartz, “Combined Haze and Cirrus Removal for Multispectral Imagery,” *IEEE Geoscience and Remote Sensing Letters*, vol. 13, no. 3, 2016.

4 D. Schläpfer, R. Richter, and A. Damm, “Correction Of Shadowing In Imaging Spectroscopy Data By Quantification Of The Proportion Of Diffuse Illumination,” presented at the 8th SIG-IS EARSeL Imaging Spectroscopy Workshop, Nantes, 2013, pp. 1–10.

5 R. Richter and D. Schläpfer, “Atmospheric / Topographic Correction for Satellite Imagery, ATCOR-4 User Guide, Version 7.1” DLR/ReSe, Wessling, DLR-IB 565-01/17, January 2017.

6 A. Berk et al.: “MODTRAN5: a reformulated atmospheric band model with auxiliary species and practical multiple scattering options,” Proc. SPIE, vol. 5655, no. 1, pp. 88–95, 2005.

7 B. Holben, T. Eck, I. Slutsker, D. Tanre, J. Buis, A. Setzer, E. Vermote, J. Reagan, Y. Kaufman, and T. Nakajima, “AERONET--A Federated Instrument Network and Data Archive for Aerosol Characterization,” *Remote Sens. Environ.*, vol. 66, no. 1, pp. 1–16, 1998.