EVALUATION OF BREFCOR BRDF EFFECTS CORRECTION FOR HYSPEX, CASI, AND APEX IMAGING SPECTROSCOPY DATA

Daniel Schläpfer

ReSe Applications
Langeggweg 3, 9500 Wil, Switzerland
daniel@rese.ch

Rudolf Richter

German Aerospace Center (DLR)
DE-82234 Wessling, Germany
rudolf.richter@dlr.de

ABSTRACT

The correction of BRDF effects for airborne wide FOV imaging spectroscopy data is of interest for a consistent data processing and products generation. Recently, a new BRDF effects correction method (BREFCOR) has been implemented as additional processing step after the well-known atmospheric compensation workflow. This paper shows validation results of the method for sample data sets of HYSPEX, CASI, and APEX data. It can be shown that the method is able to deal with a broad variety of sensors and surface characteristics. The quality of the spectral albedo data products is substantially increased in terms of consistency for all data sets. Future potential improvements and additions for a better operational usability and for the processing of complete spectra are finally summarized.

***Index Terms*—** Atmospheric Correction, ATCOR, BREFCOR, BRDF, Radiometric correction, HYSPEX, CASI, APEX.

1. INTRODUCTION

Airborne optical scanners are able to provide measurements of the at-sensor radiance accurate to a level of 2-3% in absolute radiance units. These radiance values are converted to bottom of atmosphere reflectance values, mostly by inverting the radiative transfer using an atmospheric compensation package such as ATCOR-4 [1]. In a first order, this output quantity is a not-well defined reflectance quantity as it depends on the angular distribution of the illumination field, the main solar incidence angles and the observation angle. By improved treatment of the solar irradiance field for the diffuse and the direct component and the terrain influences, and by taking into account the relative solar incidence angle on a per pixel basis, the reflectance may be modeled closer to the ideal situation of a true isotropic hemispherical irradiance field [2]. Taking these additions and assumptions into account, we may describe the output of the atmospheric correction as a hemispheric directional reflectance factor (HDRF, [3]). It is to be noted that the term "HDRF" is often used in an ambiguous way as it is also used for a description of the geometric situation regardless of the distribution of the illumination field across the hemisphere; we use the original physical definition where an isotropic irradiance field is a precondition of any HDRF value. The observation direction, i.e., the second direction of the bidirectional reflectance distribution function BRDF [3] is still to be corrected after this processing as the HDRF values may deviate relative to the average spectral albedo by up to 50% [4, 5].

Recently, a novel correction method has been implemented within the framework of the ATCOR-4 atmospheric correction solution. We name it the BREFCOR *'BRDF effects correction'* method. The method uses the Ross-Li sparse reciprocal BRDF model which is tuned based on a continuous surface cover characterization index. This allows to get a surface cover dependent but yet continuous correction of the HDRF to bihemispherical reflectance (BHR), i.e., to the spectral albedo. The method is of generic nature and has been successfully applied to 4-band photogrammetric imagery as well as to multispectral space borne multi-angle imagery. In this paper, we focus on the use of BREFCOR with imaging spectroscopy data. Firstly, we shortly summarize the principles of the method. Secondly, we'll show sample results for three imaging spectroscopy data sets from three different sensors and surface characteristics by analyzing the spectra in overlap regions of adjacent image lines. Validation is done on the level of spectral albedo which is the basis for a broad variety of imaging spectroscopy applications.

2. THE BREFCOR METHOD - OVERVIEW

The BREFCOR method which is used in this paper is part of the ATCOR atmospheric correction process. It is described in detail in [6] and [7]. The BRDF effects correction is applied subsequently to the atmospheric compensation to convert the hemispherical-directional reflectances to observation-angle independent spectral albedo. The idea is to apply a scaling of the volume scattering and the geometric scattering of the surface cover using a well accepted BRDF model. A fuzzy surface characterization index which we call the BRDF cover index (BCI) is used for this purpose. The index covers all surface types from water to asphalt and concrete, soils, sparse vegetation and dense vegetation as a unified continuous index. This parameter is formed by extension of the NDVI to both, non-vegetated and densely vegetated surfaces. The Ross-Li-sparse reciprocal BRDF model is used as the basis for the correction of reflectance anisotropy [8]. The model is calibrated for the various surface types by estimating the best fitting kernel weight values. In summary, the BREFCOR correction procedure consists of the following steps:

- perform atmospheric compensation to bottom of atmosphere HDRF,
- calculate scene-specific kernels reduced to the image's solar zenith and relative azimuth angle range,
- calculate the BCI from image and aggregate in 4 to 7 discrete classes,
- calibrate the BRDF-model for all classes and scenes (i.e., find the kernel weighting factors),
- create a best suited model by combining all image scenes of the processing,
- calculate a spectral anisotropy map using the continuous BCI applied to the calibrated BRDF model and the observation angles for each image pixel,
- applicate the anisotropy to the imagery on a per-pixel basis.

The final product is a spectral albedo image cube corrected for observation BRDF effects. Hereafter, some sample outputs of this process for three kind of imaging spectrometers are shown.

3. EVALUATION ON HYSPEX IMAGERY

The method has been applied to Hyspex imagery [9]. The sample data was acquired over the Kaufbeuren test site in Southern Germany on the 8th of July 2013; the sun was at 41° zenith and 113° azimuth angle. The Hyspex imaging spectroscopy system scans the surface with a total FOV of 34° in 160 contiguous bands for the VNIR spectral range from 410 to 990 nm. The BRDF model is calibrated for each of the 160 spectral bands individually using 5 steps with calibration limits for dense summer vegetation. One of the scenes contained some clouds and had therefore to be excluded from the model calibration step. A result of this correction is shown in Figure 1. BRDF effects are well removed for both the grassland and forested areas.

A collection of spectra which illustrate the effect of the BRDF correction is given in Figure 2. The figures show two spectra averages from a 10x10 pixel window of the same target viewn from two different observation angles in the overlapping area of the mosaicked images (see red dots in Figure 2). The BRDF effects are strongly reduced for the vegetation cover across the full spectral range, reducing the average difference in reflectance from 2.5% to below 1%. The concrete sample is hardly affected by the correction as it it shows only small BRDF anisotropy.

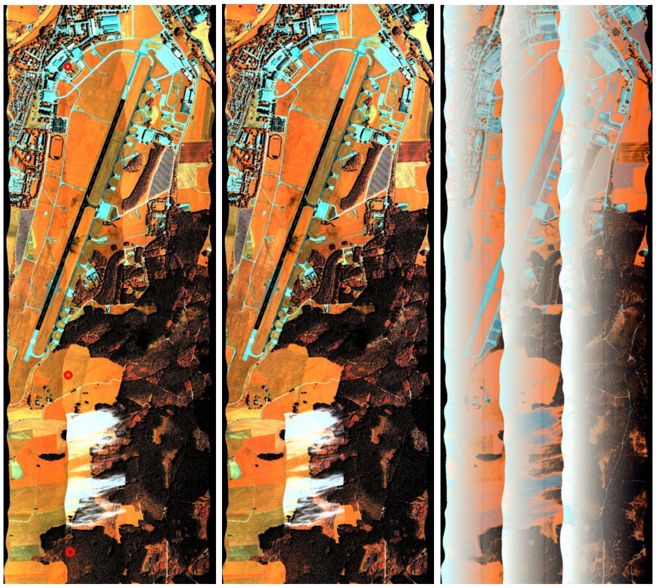

Fig. 1. BRDF correction on Hyspex: left: ATCOR corrected, middle: BREFCOR corrected, right: anisotropy factor. Band combination: R:803nm, G:546nm, and B:426nm.

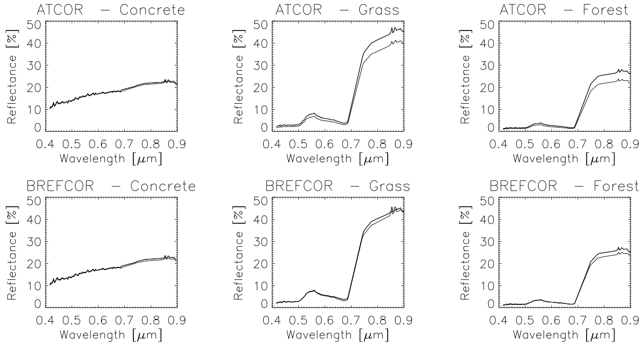

Fig. 2. Spectra of three surface types at edge of image before and after BREFCOR correction.

4. EVALUATION ON CASI IMAGERY

A second evaluation was done on a CASI-1500 VNIR data set acquired on January 17th 2013 in the Copiapo Mining district in Chile [10]. The solar zenith angle was between 13° and 21° whereas the solar azimuth was at 284° to 299° for the five data strips analyzed. The instrument covers a wavelength

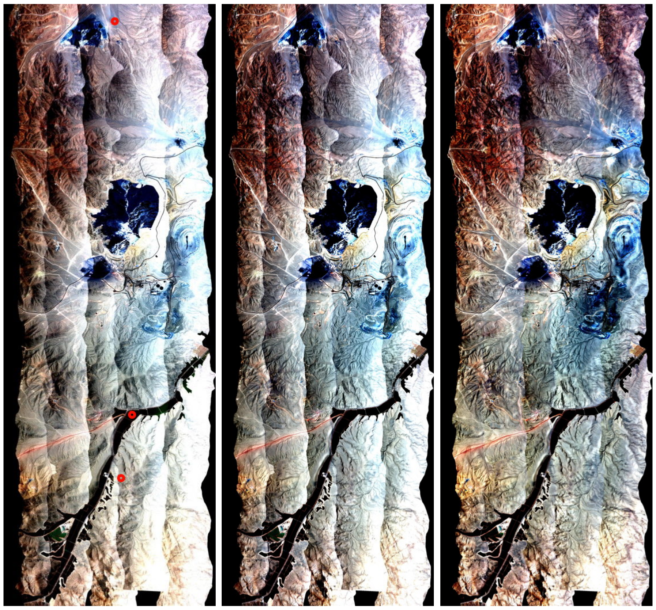

Fig. 3. BRDF correction on a set of 5 adjacent CASI images: left: radiance, middle: ATCOR corrected, right: BREFCOR corrected (image in true color RGB display).

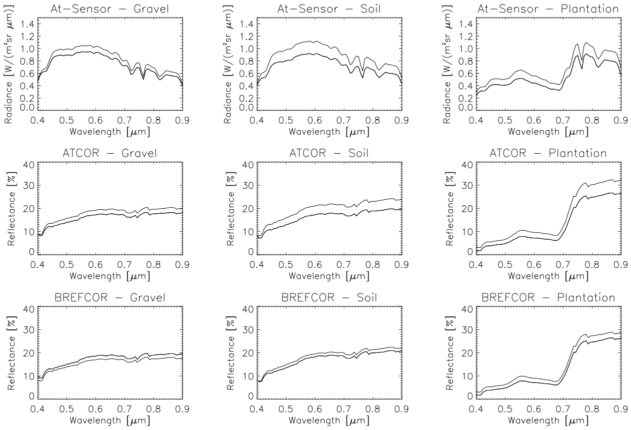

Fig. 4. Spectra of three surface types of CASI from at sensor radiance (top) to BREFCOR correction results (bottom).

range similar to Hyspex, but uses a FOV of 40°. This results in more pronounced BRDF effects as seen in the previous imagery. The underlying digital elevation model stems from ASTER imagery. ATCOR correction was performed with a 60 km visibility. Due to the reduced accuracy of the DEM, the terrain influences could only be roughly corrected, resulting in small scale irradiance variations still being visible in the outputs. An overall BRDF correction function has been found by combined analyses of all strips. The resulting mosaic is shown in Figure 3; the across track variations could be significantly reduced using this model based BRDF correction.

If comparing the spectra from two observation angles in the overlap region (see red dots in Figure 3) , a significant portion of the BRDF effects is corrected with the BREFCOR method (see Figure 4). The correction reduces the BRDF effects from an average of 2-3.9% reflectance difference to 1.3-1.9%. The remaining artifacts can most probably be attributed to the insufficient correction of terrain influences by the coarse DEM involved in this image processing. For vegetation, the correction is less significant as only a small portion of the image could be used for calibrating the BRDF model for vegetation.

5. EVALUATION ON APEX IMAGERY

The third evaluation uses APEX data from Lyss, Switzerland, acquired on May, 14th 2013. The APEX instrument scans the full spectral range between 400 and 2450 nm with a total FOV of 28° [11]. The scene consists of a broad variety of heterogeneous agricultural fields. The solar zenith angle was at 29°. BRDF effects are not as pronounced for these data sets due to the small FOV, but still they account for significant differences of HDRF signature. The data was processed in a setup very similar to the one used in HYSPEX. The terrain had only little influence on the data quality as the area is almost flat.

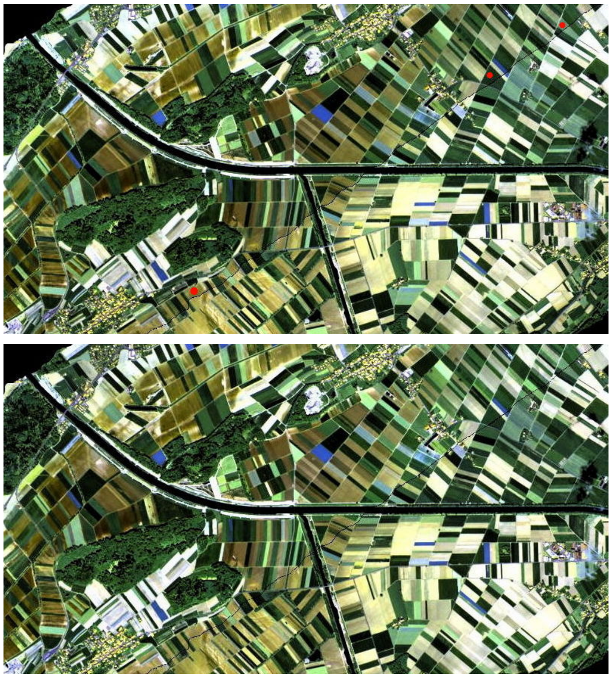

Fig. 5. BREFCOR correction on a set of two APEX images: top: ATCOR corrected, bottom: BREFCOR corrected (image as SWIR-VIS display, wavelengths: 2.20, 1.59, 0.56 μm).

The faintly visible across track variations are apparently well corrected with the BREFCOR method, as shown in Figure 5. Samples of corrected full spectra are displayed in Figure 6 for the positions marked with red dots in Figure 5. Correction is done mostly consistently for soils and sparse vegetation; the average deviation between the two spectra is reduced from 4.2% to 2.1% reflectance. However, if it comes to the spectra of densely vegetated agricultural fields, the spectral variability between various plant types leads to correction artifacts in certain cases. This variation may be explained by the nature of the applied BCI-characterization which was made under the assumption that the vegetation density alone is a good indicator for the BRDF correction type. Also, the (interpolated) atmospheric absorption regions are corrected in a non-appropriate way. Thus, further analysis is required to deal with this situation.

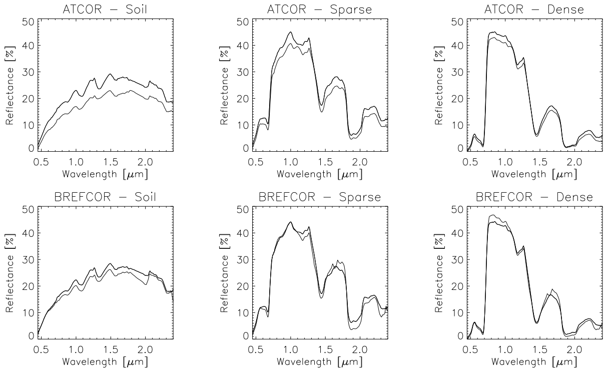

Fig. 6. Spectra of three surface types of APEX with ATCOR (top) and BREFCOR correction (bottom).

6. CONCLUSIONS AND OUTLOOK

The evaluation has shown that the BREFCOR method is applicable for various kinds of imaging spectrometer systems and surface characteristics. It has been shown that the method improves the consistency of surface reflectance products such that the output results are closer to an ideal bihemispherical reflectance than the HDRF results available after atmospheric compensation. The current implementation is operationally implemented and is ready to be used for both, imaging spectroscopy data and multispectral imagery. Future improvements should be focused on the treatment of the full spectrum for highly variable vegetation types (in the same region) and to improve the spectral consistency within strong absorption features of both, the atmosphere and surface spectra.

7. ACKNOWLEDGEMENTS

We acknowledge the German Aerospace Center (DLR) for providing the Hyspex data. Alexander Damm from the Swiss Earth Observatory Network (SEON) at RSL Zurich is thanked for providing the APEX data and ITRES Research Ltd. is acknowledged for the CASI data set.

8. REFERENCES

[1] R. Richter and D. Schläpfer, "Geo-atmospheric processing of airborne imaging spectrometry data. Part 2: Atmospheric/Topographic Correction," *International Journal of Remote Sensing*, vol. 23, no. 13, pp. 2631–2649, 2002.

[2] R. Richter, T. Kellenberger, and H. Kaufmann, "Comparison of Topographic Correction Methods," *Remote Sensing*, vol. 1, no. 3, pp. 184–196, July 2009.

[3] F. E. Nicodemus, J. C. Richmond, J. J. Hsia, I. W. Ginsberg, and T. Limperis, *Geometrical Considerations and Nomenclature for Reflectance*, U.S. Department Of Commerce, National Bureau Of Standards, 1977.

[4] S. R. Sandmeier, "Acquisition of Bidirectional Reflectance Factor Data with Field Goniometers," *Remote Sensing of Environment*, vol. 73, pp. 257–269, 2000.

[5] T. Feingersh, *Aspects Of Reflectance Anisotropy And Its Propagated Influence On Analysis Of Urban Dynamics*, Ph.D. thesis, Tel-Aviv University, Tel Aviv, 2007.

[6] R. Richter and D. Schläpfer, "Atmospheric / Topographic Correction for Airborne Imagery," Tech. Rep. DLR-IB 565-02, DLR, Wessling, Jan. 2014.

[7] D. Schläpfer, T. Feingersh, and R. Richter, "Operational BRDF Effects Correction for Wide Field of View Optical Scanners (BREFCOR)," *submitted to IEEE TGARS*, Jan. 2014.

[8] B. Hu, W. Lucht, X. Li, and A. H Strahler, "Validation of kernel-driven semiempirical models for the surface bidirectional reflectance distribution function of land surfaces," *Remote Sensing of Environment*, vol. 62, no. 3, pp. 201–214, 1997.

[9] V. Lund, "HySpex - High Resolution, High Speed, Hyperspectral Cameras for Laboratory, Industrial and Airborne Applications," http://www.hyspex.no/pdfs/HySpex_general.pdf, Mar. 2013.

[10] ITRES Research Inc., "CASI-1500 Hyperspectral Imager," url - http://www.itres.com/products/imagers/casi1500/.

[11] K.I. Itten et al., "APEX - the Hyperspectral ESA Airborne Prism Experiment," *Sensors*, vol. 8, no. 10, pp. 6235–6259, 2008.