A NEW SMOOTHNESS BASED STRATEGY FOR SEMI-SUPERVISED ATMOSPHERIC CORRECTION: APPLICATION TO THE LÉMAN-BAÏKAL CAMPAIGN

M. Cubero-Castan, D. Constantin, K. Barbieux, V. Nouchi, Y. Akhtman, B. Merminod

École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

ABSTRACT

The estimation of reflectance from hyperspectral data, a process called atmospheric correction, is a critical first step. Most of the methods need measurements of ground reflectances or atmosphere. When no information is available, unsupervised methods as Quick Atmospheric Correction (QUAC) exist assuming a large variability on the scene. But when studies on specific materials are conducted, no such large variability occurs. To solve the atmospheric correction in that case, we propose a new atmospheric correction method, called Smoothing Technique for Empirical Atmospheric Correction (STEAC) using the smooth property of the reflectance. This method is benchmarked against QUAC method on images acquiered during the Léman-Baïkal campaign. Results shows that this new method outstands QUAC method, both in terms of accuracy and stability with respect to the scene heterogeneity.

Index Terms**—** Hyperspectral image, semi-supervised atmospheric correction, reflectance, Léman-Baïkal project

1. INTRODUCTION

Remote sensing technologies are proved to be effective solutions for the exploration and the study of Earth surface [1]. In particular, hyperspectral images acquired from satellite or airborne sensors provide useful information for a wide range of application from security defence to precision agriculture [2, 3].

The key parameter in those applications is linked to the reflectance, i.e. the optical properties of the materials composing an observed scene. Unfortunately, hyperspectral sensors measure, most of the time, only radiances that are function of atmospheric terms and ground material reflectances.

To remove the impact of the atmosphere on the radiance in order to retrieve these ground material reflectances, a process called atmospheric correction is applied. Many atmospheric correction methods have been designed over the last three decades but they either assume available reflectance spectra measured in the field [4] or are derived from forward radiative transfer model (RTM) as the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) method [5] or the atmospheric COrrection Code for Hyperspectral Images of remote SEnsing sensors (COCHISE) method [6]. The major drawback of those supervised methods is their need of field measurements or atmospheric profiles.

When such information are not available, the atmospheric correction can be perform using the QUick Atmospheric Correction (QUAC) method [7]. However, this method is based on a physical assumption linked to the variability of the material within the observed scene.

In this paper, we propose to tackle these limitations and present a new method, called Smoothing Technique for Empirical Atmospheric Correction (STEAC), aiming at estimating the reflectance from an hyperspectral data without any prior information of the observed scene.

The paper is structured as follows. Section 2 introduces the physical problem formulation and our new algorithm. Section 3 presents the hyperspectral data, taking during the Léman-Baïkal project, on which our atmospheric correction is tested. Eventually, results are discussed in Section 4.

2. PROBLEM FORMULATION

The standard equation of the radiance at sensor level in the Visible and Near Infrared (VNIR) domain is function of the ground material reflectance and several atmospheric terms [5]. It is written as:

$$R_\lambda^{sens} = \frac{A_\lambda \cdot \rho_\lambda}{1 - S_\lambda \cdot \rho_\lambda^{mean}} + \frac{B_\lambda \cdot \rho_\lambda^{mean}}{1 - S_\lambda \cdot \rho_\lambda^{mean}} + R_\lambda^{\uparrow} \tag{1}$$

where $R_\lambda^{sens}(i)$ is the at sensor radiance at the pixel i, $\rho_\lambda(i)$ the reflectance of the material composing the pixel i and ρ_λ^{mean} the spatially average reflectance. The terms A_λ, B_λ, S_λ and $R_\lambda^{\uparrow}$ corresponds to the atmospheric terms weighting the observed radiance. A_λ stands for the solar irradiance weighted by the sun-surface-sensor transmittance, B_λ for the solar irradiance weighted by the diffuse transmittance, S_λ

Both financial and logistic support of this study by the Foundation pour l'Etude des Eaux du Léman (FEEL), Ferring Pharmaceuticals, the Consulat Honoraire de la Féderation de Russie in Lausanne, as well as the Dr. Paulsen Foundation and the Lake Baikal Protection Fund are gratefully acknowledged. The authors are grateful for the help provided by D. Tuia of University of Zurich and D. Ziegler of EPFL, as well as A. Ayurzhanaev, E. Garmaev and A. Tulokhonov of BINM. Special thanks are due to the team of French and Russian ULM pilots F. Bernard, J. Couttet, A. Barisevsky, V. Vikharev and N. Belyaev, who made this research possible.

the scattering effect of the atmosphere and $R_{\lambda}^{\uparrow}$ the upwelling radiance corresponding to the solar irradiance that has only be scattered by the atmosphere.

With low flight altitude, the scattering effect is small [7] and the standard equation can be written as :

$$R_{\lambda}^{sens} = \alpha_{\lambda} \cdot \rho_{\lambda} + \beta_{\lambda} \tag{2}$$

where α_{λ} and β_{λ} is two terms combining all the atmospheric terms linked to the solar irradiance and the atmospheric scattering.

2.1. QUAC method

The QUAC method [7] is divided in three steps:

- The selection of endmembers, i.e. pure materials composing the scene,
- The estimation of the baseline, β_{λ} in equation (2), and the standard deviation, $\sigma(R_{\lambda}^{sens})$, of the radiances coming from the selected endmembers,
- The estimation of the reflectance ρ_{λ}.

The main idea of the QUAC method is to estimate the refectance using the standard deviation $\sigma(R_{\lambda}^{sens})$. Considering that the atmosphere parameters is constant within the image, α_{λ} and β_{λ} are constant. The standard deviation $\sigma(R_{\lambda}^{sens})$ is then:

$$\sigma(R_{\lambda}^{sens}) = \alpha_{\lambda} \cdot \sigma(\rho_{\lambda}) \tag{3}$$

where $\sigma(\rho_{\lambda})$ is the standard deviation of the endmembers reflectance. With good condition weather, the standard deviation is constant and can be retrieved using the 1500 - 2500 nm atmospheric windows where $\alpha_{\lambda} = 1$. Knowing $\sigma(\rho_{\lambda})$, the atmospheric terms α_{λ} is then estimated on the other wavelengths.

Eventually, the baseline is retrieved considering the dark pixel, i.e. the pixels having a low value of reflectance, like deep water. The reflectance ρ_{λ} is then retrieved using the equation (2).

Unfortunately, this process needs to have a variety of different endmembers. With a scene composed by few different materials (typically water and vegetation), $\sigma(\rho_{\lambda})$ is no longer constant and another approach is needed.

2.2. STEAC method

The proposed approach is similar to the QUAC method. Its main idea is to remove the atmospheric terms by using the average reflectance in order to be robust with the scene heterogeneity.

First, the baseline β_{λ} is retrieved as the QUAC method and removed from the radiances. The average radiance $\overline{R}_{\lambda}$ is then written as:

$$\overline{R}_{\lambda} = \alpha_{\lambda} \cdot \overline{\rho}_{\lambda} \tag{4}$$

where $\overline{\rho}_{\lambda}$ is the average reflectance of the materials composing the scene.

The main idea of this method is that nearly all the atmospheric trends are with high spectrally frequency. The only low frequency effect is the Sun Black Body radiation, which can be easily retrieved when the sensor is radiometrically calibrated.

After removing the Sun Black Body radiation from the average radiance, a max-smooth function $f(x)$ is then applied: it smooths the signal and keeps only the maximum value of the smooths estimation and the signal. The function is written as:

$$f(x) = max(smooth(x), x) \tag{5}$$

This function is then applied on average radiance where the Black Body Radiance of the sun has been removed, in order to retrieved the average reflectance $\overline{\rho}_{\lambda}$.

Then, the α_{λ} is retrieved from equation () and the reflectance of all pixels can be estimated using equation (**??**). Eventually, a smooth function is applied on the estimated reflectance to remove the remaining noise.

3. THE LÉMAN-BAÏKAL CAMPAIGN

The Léman-Baïkal project [8] was originally designed to conduct a comparative study of the functioning of Geneva lake in Switzerland, also called Léman lake, and Baïkal lake, in Russian Federation. This study includes analysis of hydrological processes, lake energy balance and the study of processes pertaining to the land-water and air-water interfaces in lakes.

To perform all these studies, acquisition of hyperspectral data in the Visible and the Near InfraRed (VNIR) domain are needed to have access to the ground material reflectances. Therefore, atmospheric correction is a crucial step.

The atmospheric correction is applied on hyperspectral data presented in section 3.1 and assessed using ground truth described in section 3.2.

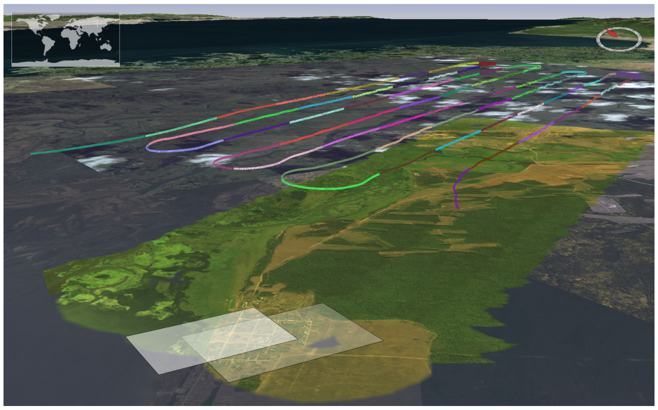
3.1. Airborne acquisition

The hyperspectral sensor used in this project is the Headwall Photonics Micro Hyperspec VNIR sensor. Because of the degrading Signal-to-Noise Ratio (SNR) in the higher bands, only the 250 first bands were used, ranging the data between 400 - 850 nm. The remote sensing platform was carried on an Ultralight aircraft flying at 1500 m above ground.

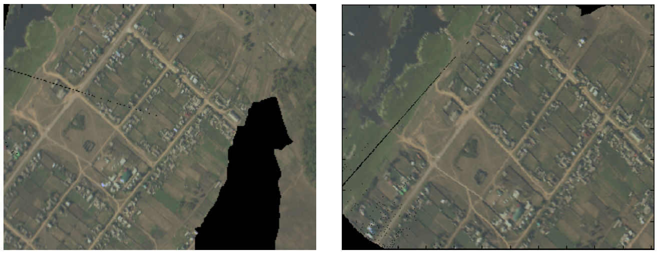
The hyperspectral data have been acquired at the Baïkal lake the 18th of August 2014 around 5PM (local time). The weather condition was good with no cloud implying no strong atmospheric effect on the at-sensor radiances.

Two images of a ground scene with known materials are studied in this paper. The ground scene is composed by manmade material, soils, vegetation and water. Both images were acquired during the same flight (less than 5 minutes between both acquisitions) but with different flight lines. The flight can be seen in figure 1-a).

All the pre-processing of these images including the radiometric correction, the Digital Elevation Model based orthorectification and georeferencing, have been applied on the hyperspectral data [8]. The estimated reflectance image after STEAC is represented in RGB in figure 1-b) and -c).



(a) Illustration of the flight lines



(b) Reflectance for image 1 (c) Reflectance for image 2

Fig. 1. Spatial representation of the flight lines in (a). Both areas of interest is represented in (a) with shadowed panel. The RGB images of the reflectance estimated by STEAC are represented in (b) and (c).

3.2. Ground truth acquisition

During this project, the reflectance of the materials composing two large area have been measured at ground level : road and sand.

The instrument used to estimate the reflectances is the radiometer OceanOptics USB 2000+. It measures the solar irradiance, the atmospheric scattering radiance and the solar radiance reflected by the material. This measurements lead to an estimation of the ground reflectance.

These estimations have been compared with 83 reflectances of the ASTER spectral library [9] measured between 400 - 850 nm, mainly composed of man-made and soil materials. It has been found a good matching between both ground measures and standard reflectance: a spectral angle of $1.2°$ between road and construction concrete and $2.3°$ between sand and sandy loam.

4. RESULTS AND DISCUSSION

This section aims to assess STEAC method and compared the estimated reflectance with QUAC method [7], which implementation is provided in ENVI software.

Two properties of the estimated reflectances have to be assessed:

- Reproductibility: the estimated reflectance of one material observed in two data with different scene spectral variability has to be similar.
- Accuracy: the estimated reflectances has to be similar to the ground level.

To assess both properties, the Root Mean Square Error (RMSE) and the Spectral Angle Mapper (SAM) are computed:

$$RMSE(X,Y) = \sqrt{\frac{1}{N}\sum_{\lambda=1}^{N}(X_\lambda - Y_\lambda)^2} \tag{6}$$

$$SAM(X,Y) = cos^{-1}\left(\frac{\sum_{\lambda=1}^{N} X_\lambda \cdot Y_\lambda}{\sqrt{\sum_{\lambda=1}^{N}(X_\lambda)^2} \cdot \sqrt{\sum_{\lambda=1}^{N}(Y_\lambda)^2}}\right) \tag{7}$$

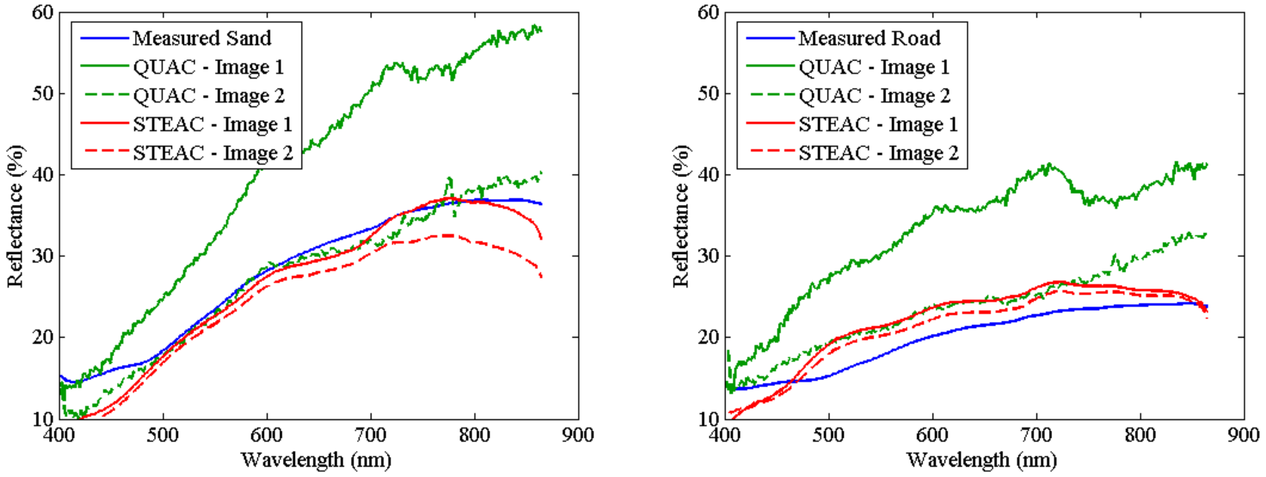
where for reproductibility test, X_λ and Y_λ stand for the reflectance estimated by atmospheric correction on both HS data respectively, and for the accuracy test, X_λ and Y_λ stand for the reflectance estimated by atmospheric correction and the ground truth reflectance respectively.

The estimated reflectance is represented in figure 2-a) and -b) for the sand and the road, respectively. The table 1 groups all the SAM and the RMSE computed values.

		SAM		RMSE	
		QUAC	STEAC	QUAC	STEAC
Accuracy	Sand	3.8°	3.9°	7.7%	3.1%
	Road	4.0°	4.3°	8.9%	2.4%
Reprod.	Sand	2.7°	2.5°	13.7%	2.8%
	Road	5.3°	1.4°	9.8%	1.1%

Table 1. Comparison between QUAC and STEAC estimation for sand and road material. The accuracy reproductibility propertiesare assessed with SAM and RMSE.

Accuracy: One of the major drawbacks of both atmospheric methods is their bad results on the border of the spectral range (400 - 450 nm and 750 - 850 nm). Here, the atmosphere, coupling to degrading SNR of the sensor, induces



(a) Sand reflectance

(b) Road reflectance

Fig. 2. Reflectance measured at ground level are represented in blue, estimated by QUAC in green and by the new method in red. The estimation using the first and the second image are represented in solid and in dashed line, respectively.

smoothing effect and disturb the estimation. Therefore, the SAM is high for both methods. Because of the few variability in the observed scene (large proportion of soils, water and vegetation), STEAC outstands QUAC in terms of RMSE with a decrease from 8.3% to 2.8%.

Reproductibility: The measure of RMSE and SAM clearly show that STEAC better estimates the same reflectance whatever the heterogeneity of the scene is. On the image 1, there is much more vegetation that on the scene 2, where water is much more present. These differences impact the estimation of both sand and road reflectances with QUAC method: an atmospheric impact is seen between 700-750 nm. On the other hand, STEAC method is designed to be stable with the heterogeneity and provides nearly the same reflectance for both images (RMSE below 3%).

5. CONCLUSION AND PERSPECTIVES

This paper presents a new atmospheric correction method that use the smooth property of the reflectance to estimate them on the scene. This method has been tested over hyperspectral images acquired during the Léman-Baïkal campaign. It has been shown that this new method is accurate and stable with respect to the heterogeneity of the scene.

Further work is focussed on the improvement of STEAC in the sensor range limits, where both QUAC and STEAC badly estimate the reflectance. This method needs also to be assessed on other images with different atmospheric condition. The robustness of the method with respect to radiometric correction need also to be investigated.

6. REFERENCES

[1] J. B. Campbell, *Introduction to remote sensing*, CRC Press, 2002.

[2] I. Renhorn, et al., "Detection in urban scenario using combined airborne imaging sensors," 2012, vol. 8353, pp. 83530I–83530I–9.

[3] M. E. Schaepman, et al., "Earth system science related imaging spectroscopy: An assessment," *Remote Sensing of Environment*, vol. 113, Supplement 1, no. 0, pp. S123 – S137, 2009, Imaging Spectroscopy Special Issue.

[4] J. E. Conel, et al., "AIS-2 radiometry and a comparison of methods for the recovery of ground reflectance," *The 3rd Airborne Imaging Spectrometer Data Analysis Workshop, JPL Publication*, vol. 87-30, 1987.

[5] S. M. Adler-Golden, et al., "Atmospheric correction for shortwave spectral imagery based on modtran4," 1999.

[6] C. Miesch, et al., "Direct and inverse radiative transfer solutions for visible and near-infrared hyperspectral imagery," *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 43, no. 7, pp. 1552–1562, July 2005.

[7] L. S. Bernstein, et al., "Validation of the QUick atmospheric correction (QUAC) algorithm for VNIR-SWIR multi- and hyperspectral imagery," 2005.

[8] Y. Akhtman, et al., "Leman-Baikal: Remote sensing of lakes using an ultralight plane," in *6th Workshop on Hyperspectral Image and Signal Processing*, 2014.

[9] A. M. Baldridge, et al., "The ASTER Spectral Library Version 2.0.," *Remote Sensing of Environment*, vol. 113, 2009.