REMOTE SENSING OF AEROSOLS IN URBAN AREAS: SUN/SHADOW RETRIEVAL PROCEDURE FROM AIRBORNE VERY HIGH SPATIAL RESOLUTION IMAGES: FIRST RESULTS

C. Thomas [a, b, *], S. Doz [a, b], X. Briottet [a], R. Santer [c], D. Boldo [d], S. Mathieu [e]

[a] Département Optique Théorique et Appliquée, Onera, Toulouse, France - colin.thomas@onera.fr
[b] Université de Toulouse, ISAE, Toulouse, France
[c] Université du Littoral Côte d'Opale, Wimereux, France
[d] IGN, Saint Mandé, France
[e] Thales Alenia Space, Cannes, France

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ABSTRACT:

Remote sensing of urban areas is currently in significant development thanks to the achievement of instruments allowing the observation of cities at very high spatial resolution (~1m). With those new resolutions, appropriate techniques must be developed. The characterization of urban aerosols to perform atmospheric corrections of remote sensing images is an issue that can take advantage of those new possibilities. A new characterization method of the aerosols optical thicknesses, based on the observation of sun/shadow transitions, is presented in this paper. The first results obtained with this method from synthetic images are presented.

1. INTRODUCTION

The study of urban areas is becoming a high challenge with the advent of a new generation of very high spatial resolution (VHSR) sensors which allows a better characterization of such medium. For instance, airborne sensors like PELICAN (Déliot et al., 2006, Fig. 1) developed at Onera allow the observation of cities with a spatial resolution of about 20cm.

Figure 1. Colour composition of a PELICAN image of Toulon, France (20cm resolution).

The characterization of urban atmospheres and especially of the aerosols is a major issue. In fact, the atmospheric correction of remote sensing data (Lachérade et al., 2008) requires the knowledge of their abundance and of their optical properties. To this end, well-known retrieval methods are used for several years from low spatial resolution (~100m to ~1km) optical sensors such as the "Dense Dark Vegetation" method (Kaufman et al., 1997), the use of multi-angular viewing (Martonchik et al., 1998) or the use of multi-temporal data (Holben at al., 1998a). But those methods are not adapted to our constraints as they require homogeneous surfaces with low reflectance or the use of several images of the same target. At high or very high spatial resolution, very few studies have been conducted. The use of the "contrast reduction" method has been tested on high spatial resolution images (Sifakis et al., 1992; Sifakis et al., 1998) but this procedure requires multi-temporal data.

Another procedure based on the observation of sun/shadow transitions on Quickbird images has been settled (Vincent et al., 2005). But this method requires an estimate of the surface reflectance without a priori knowledge.

The settlement of a new aerosol characterization procedure is necessary. In this paper, a new method is presented allowing the characterization of their abundance directly from one multispectral image. To this end, the vector elevation model (VEM) of the scene is required.

2. AEROSOLS CHARACTERIZATION PROCEDURE

2.1 Definition of radiative and geometric parameters

First, it is necessary to introduce the radiative terms that will be used. The different components of the signal at ground and at sensor levels in urban areas are defined on Fig. 2.

The irradiance at ground level on a surface P (I^P_{tot}) is the sum of four components: the direct irradiance (I^P_{dir}), the diffuse irradiance (I^P_{diff}), the earth-atmosphere coupling irradiance (I^P_{coup}) and the reflected irradiance (I^P_{refl}). The direct irradiance corresponds to the photons coming directly from the sun, the diffuse irradiance to the photons scattered by the atmosphere, the earth-atmosphere coupling irradiance to the photons resulting from multiple surface reflections and atmospheric scatterings, and the reflected irradiance to the photons that are directly transmitted to the ground after reflections on the neighbourhood.

The radiance at sensor level measured by the pixel corresponding to the direction of the surface P (R^P_{meas}) is the sum of three components: the direct radiance (R^P_{dir}), the environment radiance (R^P_{env}) and the atmospheric radiance (R^P_{atm}). The direct radiance corresponds to the photons directly coming from the surface P, the environment radiance to the photons coming from the ground after scattering by the atmosphere and the atmospheric radiance to the photons scattered by the atmosphere without reaching the surface.

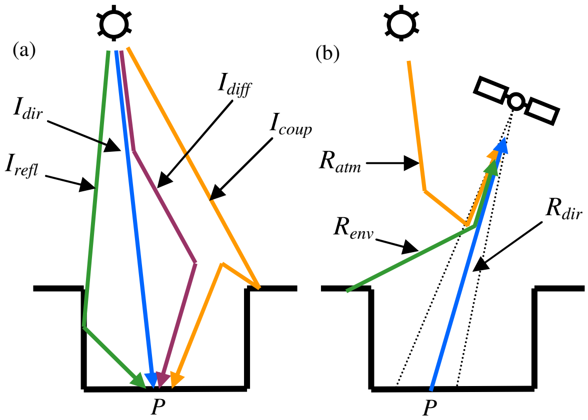

Figure 2. Components of the signal, at ground level (a) and at sensor level (b).

2.2 "Shadow/sun" retrieval procedure

The signal incident to the sensor R^P_{meas} measured by the pixel corresponding to the direction of the surface P is (1).

$$R^P_{meas} = \frac{\rho^P}{\pi}.I^P_{tot}.T^P_{dir} + R^P_{atm} + R^P_{env} \qquad (1)$$

where T^P_{dir} is the direct transmission from P to the sensor

ρ^P is the reflectance of the surface P

The direct estimate of the aerosols optical thickness from a multispectral image from (1) is not possible without an accurate estimate or a measure of the surface reflectance ρ^P. To overcome this problem, the "shadow/sun" method is proposed.

By observing two close points S and O corresponding to the same material at each side of a transition between a sunny (S) and a shadowed (O) area (Fig. 3), we can write(2).

$$\rho^S . T_{dir}^S = \rho^O . T_{dir}^O \quad (2)$$

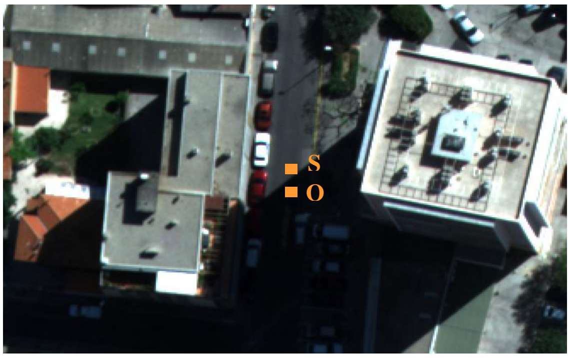

Figure 3. Example of sunny (S) and shadowed (O) pixels that can be used in the retrieval procedure.

Assuming also the atmospheric radiances are identical in S and O and so for the environment radiances, we obtain the retrieval equation (3).

$$\frac{R_{meas}^O - R_{atm} - R_{env}}{R_{meas}^S - R_{atm} - R_{env}} = \frac{I_{tot}^O}{I_{tot}^S} \quad (3)$$

Thus to solve this equation, the irradiating conditions (zenith and azimuth angles of the sun) and the viewing conditions (altitude and zenith and azimuth angles of the sensor) must be known. Furthermore, to achieve a good estimate of the radiative term, the scene geometry must also be known by the way of its VEM.

The inputs of the retrieval procedure are the multispectral image acquired by the sensor and expressed in radiance, the VEM of the scene, and aerosol properties: several aerosol optical thicknesses τ_{LUT} (AOT), and an aerosol model m.

The aerosols characterization consists in determining a spectral AOT $\tau(\lambda)$ corresponding to the abundance of the aerosol model m in the atmosphere of the observed city. To do so, R_{atm}, R_{env} and the irradiances incident to the two observed points are computed for each τ_{LUT} and for each wavelength λ centred on the sensor's band, assuming the aerosol distribution corresponds to the model m.

Those radiative terms are calculated thanks to the 2D radiative transfer code 6S (Vermote et al., 1997) and the VEM. For each AOT, I_{dir} and R_{atm} are directly calculated by 6S. R_{env} is also calculated by 6S using a mean reflectance value of the ground estimated from the radiance image of the scene. I_{diff} and I_{coup} are calculated by 6S at the canopy level and estimated at the ground level taking into account the geometry of the scene thanks to the VEM. Finally, I_{refl} is estimated from the VEM, and an a priori estimate of the wall reflectances.

To obtain the spectral AOT of the model m, we keep, for each wavelength λ, the AOT that minimizes (4).

$$abs\left(1 - \frac{R_{meas}^O - R_{atm} - R_{env}}{R_{meas}^S - R_{atm} - R_{env}} . \frac{I_{tot}^S}{I_{tot}^O}\right) \quad (4)$$

3. SIMULATION OF VERY HIGH SPATIAL RESOLUTION IMAGES

To test this characterization procedure, synthetic images are computed from the radiative transfer code Amartis v2.

3.1 Amartis v2

Amartis v2 (Doz et al., 2008), is a 3D direct radiative transfer code. It allows the simulation of the observation of 3D heterogeneous scenes with an airborne or satellite monochromatic sensor. Allowing simulations of VHSR observations, this code is dedicated to urban areas.

This code simulates all the radiative components contributing to the signal at ground and sensor levels. It requires the following input parameters: the geometrical and radiative description of the scene, the sun and viewing conditions, and a description of the atmosphere. The atmosphere is modelled thanks to the radiative transfer code 6S in a plan parallel atmosphere composed of homogenous layers. The aerosols can be described by standard models or by more sophisticated distributions (Junge distributions, bimodal distributions, etc.).

3.2 Synthetic images

The observation of a crossroad is simulated with Amartis v2 at 490, 550, 660 and 840nm.

The geometry of the scene is described in Fig. 4. This crossroad is modelled by tiles for the roofs, bricks for the walls and two kinds of tar for the roads and the sidewalks. Those materials have a lambertian behaviour. Their reflectances, measured during the CAPITOUL campaign (Masson et al., 2008), are given in Fig. 5.

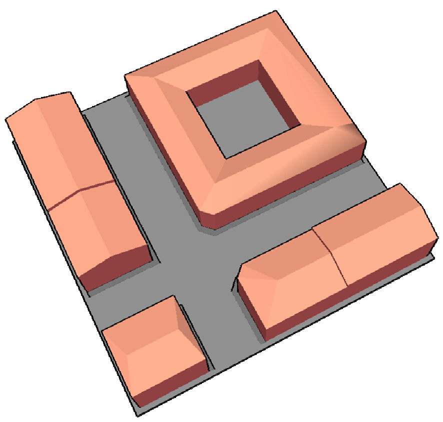

Figure 4. Geometry of the scene.

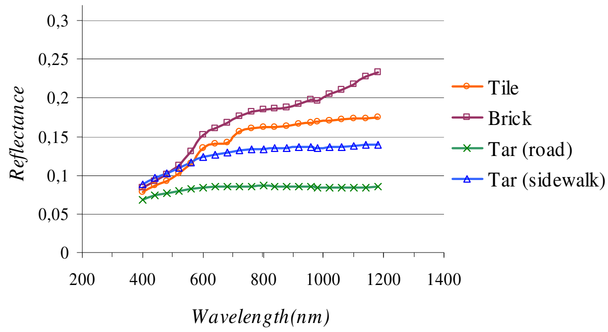

Figure 5. Spectral lambertian reflectances of the urban materials used in the Amartis v2 simulations.

The sun has a zenith angle of 40° and the sensor, onboard an aircraft flying at 3km high, is performing a nadir viewing.

The atmosphere is described by the standard “midlattitude summer” model of 6S for molecules and with the “urban aerosol” model of 6S for aerosols. The aerosol abundances correspond to 20km and 10km of visibility (V) which corresponds to respectively quite clear and loaded atmospheres.

One of the resulting synthetic images is presented in Fig. 6.

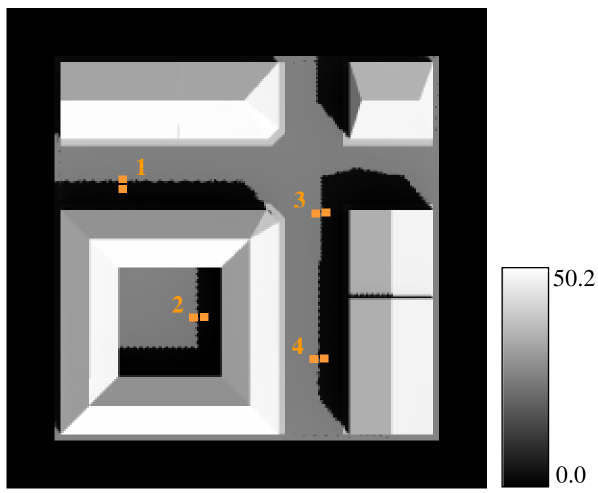

Figure 6. Simulated at sensor radiance image (in $W.m^{-2}.sr^{-1}.\mu m^{-1}$) at 660nm for a 20km visibility and the 4 “shadow/sun” pixels couples selected for the aerosols characterization.

4. AEROSOLS CHARACTERIZATION

4.1 Inputs

Four “shadow/sun” pixels couples are selected for the aerosols characterization (Fig. 6). To perform the retrieval, we suppose the VEM and the wall reflectance are known.

The aerosol model used to perform the retrieval is the urban standard model of 6S that has been used to compute the Amartis v2 simulations. The AOT used for the retrieval are chosen from 0.00 to 0.60 with a step of 0.02.

4.2 Results

The mean results obtained for the four “shadow/sun” pixels couples are presented in Fig.7.

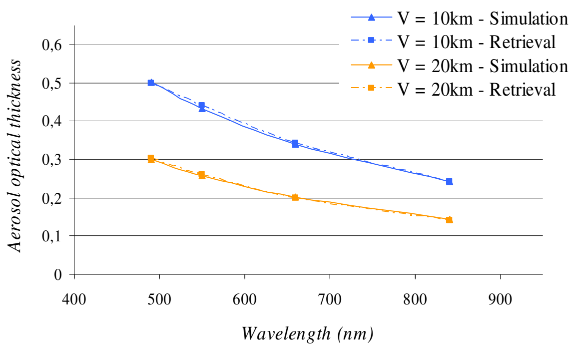

Figure 7. Comparison of the AOT used to perform the Amartis v2 simulations and of the mean results of the retrievals, for the two visibilities.

We note very good results in the retrieval of the AOT for the two visibilities. Indeed, we obtain after performing an average on the four sun/shadow pixels couples, retrieved AOT with less than 3% of error.

Those results are very encouraging. They show great possibilities of this retrieval procedure. Of course, those first results are obtained in a simple case, with an a priori knowledge of the optical properties of the atmospheric aerosols. This method must now be improved to retrieve also an aerosol optical model.

5. CONCLUSION

This paper presents a new aerosol retrieval procedure dedicated to the remote sensing of urban areas with multispectral high spatial resolution sensors. This method, based on the observation of shadow/sun transitions allows the retrieval of the aerosols spectral optical thicknesses.

The first results are obtained from synthetic images and are very encouraging. Indeed, this procedure retrieves precisely the optical thicknesses of the atmospheric aerosols (less than 3% of error).

But this method must now be used to retrieve also a model of urban aerosols. Indeed, We can’t use a priori knowledge about their optical properties. To do so, urban aerosol models will be developed. A preliminary statistical study of the optical properties of urban aerosols has been done (Thomas et al., 2008) thanks to AERONET data (Holben et al., 1998b). This work will be continued to develop a relevant climatology of urban aerosols.

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