ATMOSPHERIC CORRECTIONS OF AVIRIS IMAGES WITH A PROCEDURE BASED ON THE INVERSION OF 5S MODEL

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Abstract: An atmospheric correction methodology was developed for correcting AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) images that were acquired during the 1991 NASA/JPL campaign over "The Landes" (S.W. France). It is based on the inversion of the 5S atmospheric model, through an iterative approach that uses the Gauss Seidel principle. Adjacency effects are fully taken into account with the use of circular neighbourhoods, for each pixel, the radii of which vary with wavelength. Atmospheric optical parameters were estimated with in-situ atmospheric profile and visibility measurement combined with the 5S model. Due to the poor accuracy of the visibility parameter a procedure was developed for retrieving the aerosol optical depth directly from the remotely acquired image alone. At different wavelengths, the aerosol optical depth must be such that the reflectance of dark objects, which is supposed to lie in an a-priori defined interval, lead to the right apparent reflectances. For each pixel, the target reflectance is computed as the most probable. This approach led to the determination of an aerosol optical depth map, after some spatial interpolation. This map is used as an input parameter in the atmospheric correction algorithm. For all AVIRIS bands, convergence was attained after less than 5 iterations. Accuracy better that 0.5% was obtained with radii of neighbourhoods at least equal to 30 pixels in the visible region and 5 pixels in the near-infrared region. The use of these radii values resulted in reflectance variations as large as 60%, 40%, and 6% in the VIS, PIR and MIR

multiple scattering from the surroundings of each individual target (Tanré *et al.*, 1987). This serious drawback is partly eliminated by the correction procedure that is introduced in this paper.

The atmospheric correction procedure that was developed, relies on radiative transfer computation and fully takes into account the available information about the spatial variability of local reflectances; *i.e.* the apparent reflectances. It is an iterative method that makes an inversion of the 5S radiative transfer model (Tanré *et al.*, 1990). The apparent reflectances converge to theoretical target reflectances that can fully explain the apparent reflectances obtained by using the 5S model. It is assumed that these theoretical target reflectances are equal to the real target reflectances. This correction procedure requires the introduction of atmospheric characteristics as input parameters. These can be retrieved directly with the 5S model, provided in-situ atmospheric measurements were completed when the image was acquired. Because such measurements, especially the aerosol optical depth, are not always available, and when they are they may not be accurate (*e.g.* the visibility parameter with the 5S model), it was developed a method that allows us to compute the aerosol optical depth on a pixel per pixel basis, directly from the image that must be corrected. The aerosol optical depth retrieval is based on the use of spectral information acquired in the red and the blue regions. It is particularly interesting when the aerosol optical depth is not a constant throughout the image; the atmospheric correction procedure takes into account such a spatial variability.

III. Correction algorithm

The atmospheric correction algorithm is displayed on figure 1. Because of spectral dependence of atmospheric effects, this procedure is applied separately for each sensor's spectral band.

This algorithm relies on inputs from the atmospheric model 5S (Tanré *et al.*, 1990). Radiances are first converted to apparent reflectances ρ^*

$$\rho^*(\theta_s,\theta_v,\phi_{sv})=\rho_a^*+\rho_c^*+\rho_e^*=[\rho_a(\theta_s,\theta_v,\phi_{sv})+\rho_c\cdot\frac{T(\theta_s)}{1-\bar{\rho}_e\cdot S}\cdot e^{-\tau/\mu_v}+\bar{\rho}_e\cdot\frac{T(\theta_s)}{1-\bar{\rho}_e\cdot S}\cdot t_d(\theta_v)]\cdot T_{gas}$$

with ρ_a: intrinsic atmospheric reflectance,
$\rho_c,\bar{\rho}_e$: target and its average environment reflectance,
T_{gas}: total gaseous transmittivity,
$T(\theta_s),t_d(\theta_v)$: total/diffuse atmospheric transmittance,
τ: vertical atmospheric optical thickness, without gas absorption,
S: spherical albedo of the atmosphere,
θ_s,θ_v: zenithal solar/viewing angle, $\mu_v=\cos(\theta_v)$,
ϕ_{sv}: relative azimuth angle between solar/viewing direction.

The environment reflectance $\bar{\rho}_e$ depends on neighbouring reflectances that are modulated by an environmental function. This

[redacted]

IV. Aerosol optical depth retrieval method

The approach is depicted on figure 2. The algorithm relies on at least 2 spectral measurements in the blue and the red portions of the spectrum. It is an extension of the method of Kaufman and Sendra (1988). It uses the following hypothesis:

> "presence of dense dark vegetation (*i.e.* forested area), the spectral reflectance ($\rho_{C\lambda}$) of which can slightly vary throughout the image within the interval $[\rho'_{C\lambda}-\Delta\rho_C,\rho'_{C\lambda}+\Delta\rho_C]$. This reflectance value ($\rho_{C\lambda}$) is supposed to be low and to lie in an interval ($\mathcal{R}_\lambda$) that is selected at the start of the procedure; $\Delta\rho_C$ is also selected at that stage."

The exact value of $\rho'_{C\lambda}$ is unknown. It is determined through an iterative procedure that converges towards the reflectance ($\bar{\rho}'_{C\lambda}$) when some probability criteria for obtaining realistic Angström coefficients (α) are verified. Finally, the knowledge of the most probable reflectances ($\rho_{C\lambda}$) of dense dark vegetation leads to the aerosol optical depth ($\tau_\lambda^{aer}(i,j)$) at each pixel (i,j), for each spectral band considered. The mean Angström coefficient α is computed as the average of all Angström coefficients $\alpha(i,j)$ associated to each pixel. Spatial interpolation of the $\tau_\lambda^{aer}(i,j)$ values leads to spatial maps of the

More than 1% pixels scattered throughout the AVIRIS scene were identified to dense dark vegetation. The "aerosol optical depth retrieval" procedure was applied to these pixels, for all possible channels combinations with one channel in the red region and two in the blue region. It was chosen the possible domain (ℓ_λ=[0-5%]) and variability ($\Delta\rho_c=\pm0.5\%$) of the reflectance ($\rho_{c\lambda}$) of dense dark vegetation, for all spectral bands. The best set of channels that led to the maximal number (N) of satisfactory pixels, was 7 [455.1nm-464.5nm], 10 [484.7nm-494.1nm] and 22 [603.2nm-612.6nm].

The most probable values of reflectances ($\rho_{c\lambda}$) were found to be equal to 0.022, 0.022 and 0.025 for channels 7, 10 and 22, respectively. The average values of the aerosol optical depth in the channels 7, 10 and 22 were equal to 0.21±0.05, 0.19±0.04 and 0.14± 0.03, respectively, with a 1.4 mean value of the Angström coefficient.

Figure 3 displays a map of the aerosol optical depth for the AVIRIS channel 7 that was obtained after some spatial interpolation. It shows a strong increase of the aerosol optical depth from the left to the right side of the image; *i.e.* $\Delta\tau^{aer}\simeq0.07$ in band 7. This result was partially validated with a simple analyse of AVIRIS channel 7: a 1.5% variation of the mean reflectance value, in absolute value, was found between the left and right sides of the image. This could be explained by the presence of an important aerosol source in the neighbourhood of our area study, *i.e.* the city of Bordeaux.

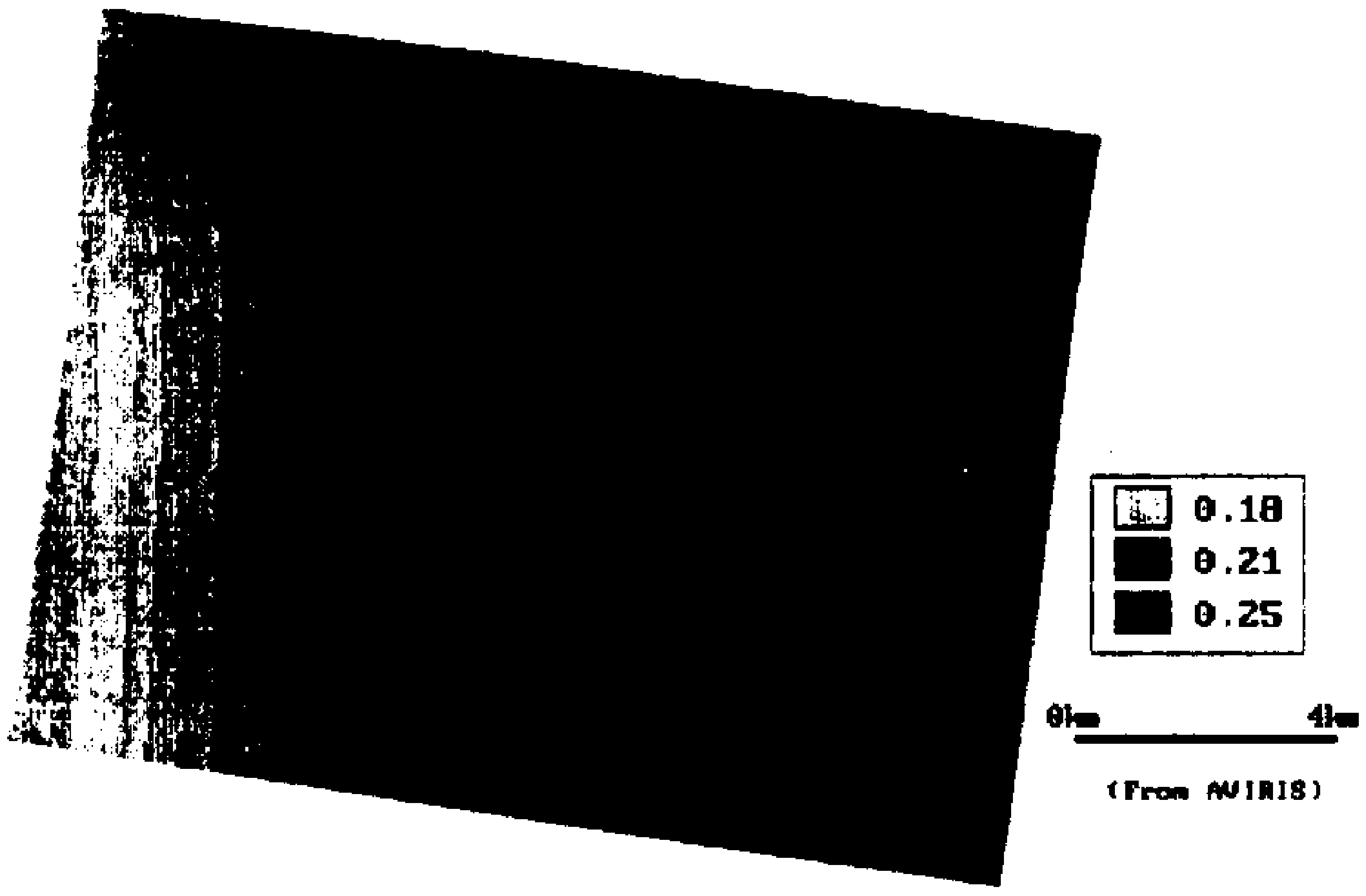

Figure 3: Spatial map of the aerosol optical depth within the AVIRIS channel 7 [455.1nm-464.5nm] image.

This aerosol optical depth map and the mean value of the Angström coefficient were used as input parameters to the atmospheric correction algorithm. For all spectral bands, convergence from apparent reflectances towards target reflectances was attained after less than 5 iterations. Aerosol effects were strongly minimized: the 1.5% reflectance difference, originally observed in the raw channel 7 image was reduced to less than 0.3%.

Tests were conducted for assessing the stability of the correction procedure. Increasing from 0 to 100 pixels the radius of the neighbourhood, that is used for computing the adjacency effect, leads to a convergence. In fact, depending on the required accuracy level, on the target and its surrounding, and on the channel, smaller or larger neighbourhoods should be considered; here, in order to retain an accuracy $\Delta\rho=0.5\%$, we found that the optimal value of the radii should be at least 600m in the blue region, 400m in the red region and 100m in the near-infrared region (Zagolski *et al.*, 1994).

Figure 4b shows atmospherically corrected reflectance spectra of several land surfaces (bare soil, pine trees, deciduous,...). They were obtained with a theoretical accuracy of $\Delta\rho=0.5\%$. The comparison with the raw reflectance spectra of these surfaces (Fig.4a) indicates that mean absolute reflectance differences are 60%, 30%, 5% et 10% in the [0.4μm-0.7μm], [0.8μm-1.1μm], [1.5μm-1.7μm] and [2.1μm-2.3μm] spectral regions.

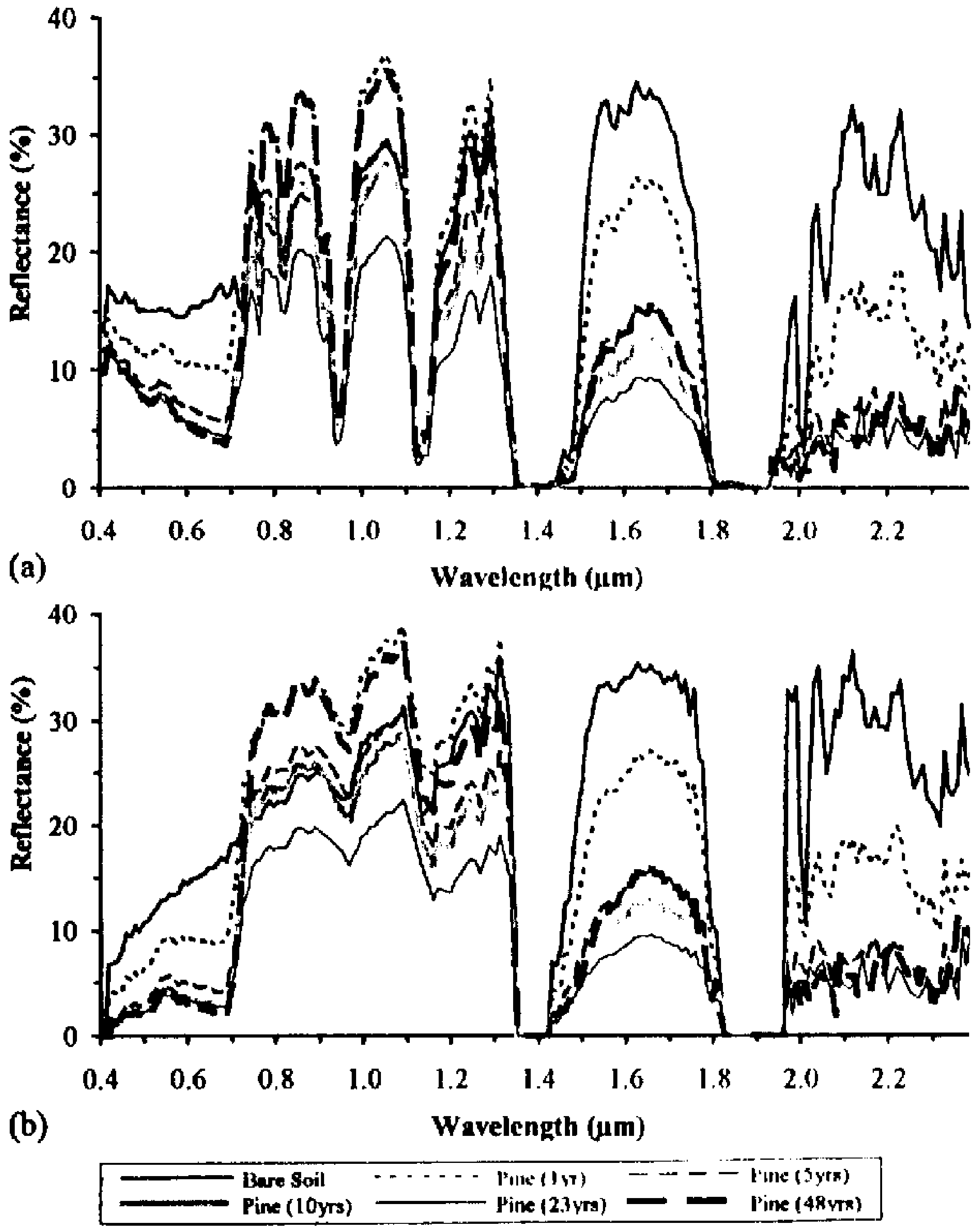

Figure 4: AVIRIS reflectance spectra: (a) without atmospheric corrections, (b) with atmospheric corrections.

VI. Concluding remarks

This paper presents a methodology for removing atmospheric effects from remotely acquired images. It consists of the inversion of the 5S model with an iterative approach, taking into account the environment of each pixel. It relies on input parameters that represent local optical characteristics of the atmosphere.

In order to assess the spatial influence of the aerosol, an approach was developed for retrieving directly the aerosol optical depth for each sensor's band and each pixel, from the original image. This allowed us to quantify an important spatial variability of the aerosol optical depth within the AVIRIS images at hand; *i.e.* $\Delta\tau^{aer}\simeq0.07$ over 10km, in channel 7 (blue region).

A study of the stability of our methodology emphasized the importance to take into account adjacency effects especially in the visible and near-infrared regions.

References:

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