INVESTIGATIONS ON THE 1.7 μm RESIDUAL ABSORPTION FEATURE IN THE VEGETATION REFLECTION SPECTRUM.

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1. INTRODUCTION

The detection and interpretation of the weak absorption features associated with the biochemical components of vegetation is of great potential interest to a variety of applications ranging from classification to global change studies. This recent subject is also challenging because the spectral signature of the biochemicals is only detectable as a small distortion of the infrared spectrum which is mainly governed by water. Furthermore, the interpretation is complicated by the complexity of the molecules (lignin, cellulose, starch, proteins) which contain a large number of different and common chemical bonds.

In this paper, we present investigations on the absorption feature centred at 1.7 μm; these were conducted both on AVIRIS data and laboratory reflectance spectra of leaves.

2. ANALYSIS ON AVIRIS DATA

The ground reflectance has been first obtained by using the "Atmosphere Removal program" developed at the CSES/CIRES - University of Colorado . The pixel reflectance ($R_p(\lambda)$) is then unfolded as a linear mixture of a soil and a vegetation spectrum ($R_s(\lambda)$and $R_v(\lambda)$):

$$R_p(\lambda) = a_s . R_s(\lambda) + a_v . R_v(\lambda) \qquad (1)$$

The soil spectrum is taken from the scene as the mean spectrum of a small area known to be bare soil. The vegetation spectrum is modelled with a Kubelka-Munk formula for an optically thick homogeneous medium:

$$R_v(\lambda) = \frac{2 - \omega_0(\lambda) - 2.\sqrt{1-\omega_0(\lambda)}}{\omega_0(\lambda)} \quad (2) \quad \text{with} \quad \omega_0(\lambda) = \frac{s}{s + k(\lambda)} = \frac{1}{1 + \frac{k(\lambda)}{s}} \qquad (3)$$

where $\omega_0(\lambda)$ is the single scattering albedo , s is the scattering coefficient (as the scattering in leaf tissue is mainly due to multiple reflection and refractions, it can reasonably be assumed to be wavelength independent) and $k(\lambda)$ is the absorption coefficient of the medium

We further assume that the absorption in vegetation is due to chlorophyll and water and write:

$$\frac{k(\lambda)}{s} = \frac{1}{s}.(c_{chl}.k_{chl}(\lambda) + c_w.k_w(\lambda)) = a_{chl}.k_{chl}(\lambda) + a_w.k_w(\lambda) \quad (4)$$

where $k_{chl}(\lambda)$ is the specific absorption coefficient of chlorophyll; the in vivo absorption coefficient (expressed in $cm^2.\mu g^{-1}$) of the PROSPECT model was used; $k_w(\lambda)$ is the specific absorption coefficient of water (expressed in cm^{-1}) (the measurement of Curcio and Petty was used ; c_{chl} and c_w are the chlorophyll and water concentration; a_{chl} and a_w are the above concentrations divided by the scattering coefficient and are the independent parameters of the vegetation spectrum model

By combining formula (1), (2) ,(3) and (4), one obtains a model of the pixel reflectance as a non linear function of four parameters: a_s , a_v, a_{chl} and a_w, which are determined by least mean square fitting on the AVIRIS pixel reflectance by using a Marquardt algorithm. Two spectral windows were used in the fitting: 0.5 to 0.73 μm where the chlorophyll absorption is dominant and 1.5 to 1.65 μm which is governed by water while excluding the 1.7 μm absorption feature.

Once the inversion is performed, a measured spectrum of the vegetation fraction ($R_{vm}(\lambda)$ is extracted as:

$$R_{vm}(\lambda) = \frac{R_p(\lambda) - a_s.R_s(\lambda)}{a_v} \quad (6)$$

If we assume that the 1.7 μm feature is an absorption due to a component of vegetation, we logically evaluate its magnitude from the absorptance corresponding to the measured and fitted vegetation spectra (A_{vm} and A_v). The absorptance is defined here as k/s, and obtained from the reflectance by inverting equations (2) and (3) :

$$A(\lambda) = \frac{(R(\lambda)+1)^2}{4.R(\lambda)} - 1 \quad (7)$$

The residual has then been evaluated in the 1.65 to 1.76 μm spectral interval as :

$$res = \frac{1}{N} \bullet \sum (A_{vm} - A_v) \quad (8)$$

where the average is taken on the N AVIRIS channels in the spectral window.

Figure 1 shows a result obtained with the above procedure applied to a fraction of the Freiburg test site which contains both forested and agricultural areas. The following comments can be made:
- the residual amplitude is markedly higher on the forest than on the agricultural fields
- well defined structures are seen inside the forest both in the residual amplitude and in the water parameter (a_w), these may reflect the mixed species composition (conifers/deciduous); a recently obtained composition map will allow to verify this hypothesis

- over the forest, the residual amplitude is positively correlated with the water parameter while this correlation breaks on the agricultural zones

Figure 2 shows the residual amplitude over a small fraction of the Black Forest which is completely composed of conifers, Norway spruce being the dominant species. When compared with an age class map, a positive correlation of the residual amplitude with the forest age can be distinguished.

Figure 1. The water parameter (left) and the residual amplitude (right) over the Freiburg test site ; the brighter areas in the residual image are the forested zones.

Figure 2. The residual image of a fraction of the Black Forest test site (left) and the age class map (right) of the same area (lighter grey corresponds to older forest).

3. LABORATORY STUDIES

To support the interpretation of the airborne sensor data, we have undertaken to build a data set associating VIS-IR spectra of vegetation elements (leaves, stems, bark) with physical measurements and chemical analyses.

In order to have a wide range of variation of the leaf internal structure, pigmentation, water content and biochemical components, plant species with different types of leaves have been collected outdoor. About 30 species of woody and herbaceous plants were obtained from trees grown within the JRC and from crops. For each sample, 5 representative leaves were selected: we immediately measured the blade thickness and the fresh weight of 4.10 cm^2 discs which were placed in a drying oven in order to determine the water content, the equivalent water thickness, and the specific leaf area. Samples of leaf material have been also kept to perform later some measurements of photosynthetic pigments, lignin, cellulose, starch and nitrogen concentration. A Perkin Elmer Lambda 19 spectrophotometer equipped with an

integrating sphere was used for the measurements of the directional-hemispherical reflectance and transmittance of the upper faces of the 5 leaves. Moreover, the reflectance of an optically thick sample was obtained by stacking leaves in order to magnify the radiometric signal and minimise the leaf to leaf variability. Spectra were scanned over the 400-2500 nm wavelength interval with 1 nm step and special attention has been paid to the calibrations problems. Finally, we dried some leaves of each species and repeated the above procedure. Conifer needles, bark , stems and substances such as powdered starch or proteins have also been included in the data set.

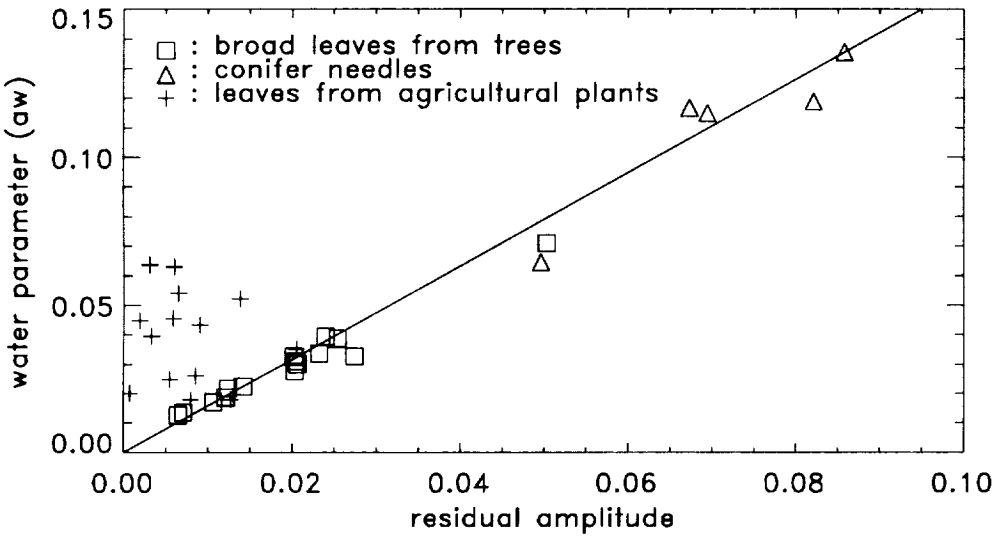

Figure 3. Water parameter and residual obtained from laboratory spectra of optically thick stacks of leaves and needles of various types of vegetation.

The analysis performed on the vegetation fraction spectra of AVIRIS was conducted on the reflectance of optically thick stacks of leaves and needles with the idea that the Kubelka-Munk formula might also be applicable in this case . Figure 3 shows the results obtained for the water parameter and the residual amplitude. Interestingly, these results are coherent with those obtained on the AVIRIS data:
- for tree leaves and conifer needles, a remarkable linear correlation is found between the residual amplitude and the water parameter
- this correlation does not exist for leaves from agricultural plants
- the residual amplitude is lower for leaves from agricultural plants

4. CONCLUSION

This study has established that the 1.7 μm absorption residual shows systematic behaviours with respect to the vegetation type. These behaviours have been independently found from the analysis of AVIRIS spectra and laboratory reflectance spectra of optically thick stacks of leaves and needles. The underlying explanation is not clear at present but, once complemented by chemical analyses, the laboratory data set will allow deeper investigations.