Investigations on the Biochemical Components NIR Absorption Features in AVIRIS and Laboratory Reflectance Spectra of Vegetation.

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Abstract

The reflectance spectrum of green vegetation is mainly determined by the leaf content in chlorophyll and water, the respective spectral signatures being modulated by the structural characteristics of the leaf and the canopy . However, in the near infrared, additional absorption features are present which are attributed to other components such as lignin, cellulose, proteins, etc. . Of particular interest is an absorption centred around 1.7μm; it is indeed placed in an atmospheric window and therefore accessible to remote sensing, in particular to imaging spectrometry.

This paper presents a procedure, based on a very simple radiative transfer model , which evaluates the amplitude of this residual absorption. The technique has been applied to several AVIRIS scenes acquired during the MAC-Europe campaign to produce "residual absorption amplitude maps". Comparing with maps of chlorophyll indices (i.e. NDVI, GEMI, SAVI,..) and water indices (MSI, equivalent water thickness,...), it is clear that the residual absorption contains different information which is probably related to the biochemical content. Several investigations are now pursued to document the link between this new parameter and the plant/canopy characteristics.

The work on the Mac-Europe scenes has shown that the residual exhibits systematic behaviours with respect to the plant species: it is markedly higher on forests than on agricultural fields and, inside the forest, higher for the conifers than for the deciduous trees. These variations have also been found from laboratory spectra of leaves and needles. On the Black Forest, which is an almost homogeneous spruce forest, the residual shows some correlation with the forest age. The procedure has now also been applied on the 1992 AVIRIS scene over Blackhawk Island and the residual image shows similarities with the published lignin map, obtained by regression analysis.

INTRODUCTION

The analysis of the leaf and canopy reflectance spectra attempted in this work is based on a number of simple ideas:

i. The reflectance of a dense canopy can be approximated by the reflectance of an optically thick stack of leaves; the reflectance of this stack can, in its turn, be approximated by the reflectance of a thick homogeneous medium (doing this, we neglect the specular reflectance at the leaf surface and the complex leaf internal structure) The reflectance will then be given by the Kubelka-Munk formula for a semi infinite medium:

$$R_\infty(\lambda) = \frac{2 - \omega_0(\lambda) - 2.\sqrt{1-\omega_0(\lambda)}}{\omega_0(\lambda)} \quad (1)$$

$$\omega_0(\lambda) = \frac{s}{s + k(\lambda)} = \frac{1}{1 + \frac{k(\lambda)}{s}} \quad (2)$$

where $\omega_0(\lambda)$ is the single scattering albedo of the medium
s is the scattering coefficient of the medium
$k(\lambda)$ is the absorption coefficient of the medium

The assumption has been made here that the scattering coefficient is wavelength independent. This is partly justified, considering that the scattering inside the leaf tissue is mainly due to multiple reflections and refractions and that the index of refraction weakly depends on the wavelength. These assumptions are necessary to develop algorithms sufficiently simple to be applied to entire AVIRIS images.

ii. The leaf tissue is considered as a homogeneous mixture of chlorophyll, water and biochemical components (lignin, cellulose, proteins, starch, etc.) and its absorption coefficient can be described as a linear combination of the constituents absorption coefficients :

$$k(\lambda) = c_{ch}.k_{ch}(\lambda) + c_w.k_w(\lambda) + k_b(\lambda) \quad (3)$$

where $k(\lambda)$ is the absorption coefficient of the leaf tissue
$k_{ch}(\lambda)$ and $k_w(\lambda)$ are the specific absorption coefficients of chlorophyll and water
c_{ch} and c_w are the mixing coefficients for chlorophyll and water
$k_b(\lambda)$ is the absorption coefficient corresponding to the biochemical content

In this formula, chlorophyll and water have been separated because their absorption coefficients are well known while the determination of the biochemical components absorption coefficients is part of the problem. It should be noticed that the chlorophyll absorption is largely decoupled from the other as it affects the visible part of the spectrum while the other components determine the infrared reflectance.

The measurement of Curcio and Petty (Curcio and Petty,1991) is used for water, the in vivo absorption coefficient of the PROSPECT model has been chosen for chlorophyll.

iii. The absorption due to the biochemical content can itself be described as a linear combination of specific absorption coefficients of biochemical components :

$$k_b(\lambda) = \sum_i c_i.k_i(\lambda) \quad (4)$$

Through this decomposition one can hope to retrieve information on the concentrations of the various compounds.

ANALYSIS OF AVIRIS DATA OF THE MAC-EUROPE 91 CAMPAIGN

The analysis procedure has been described in more detail elsewhere (Verdebout et. al.,1993; Schmuck et. al., 1993).

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Concerning the biochemical content, it only uses the spectral range from 1.5 to 1.8 μm because the D spectrometer was not functional during the MAC-Europe campaign. In this window, the analysis was designed to evaluate the amplitude of an absorption feature, centred at 1.7 μm and observed in the spectrum of lignin (Wessman, 1990).

The first step is to obtain the ground reflectance. This has been performed using the "Atmosphere Removal program" developed at the CSES/CIRES - University of Colorado (Gao and Goetz, 1990). The reflectance is then modelled as a linear combination of a soil and a vegetation spectrum. This last component is itself modelled according to equations (1) , (2) and (3) where the biochemical component is first neglected. The parameters of the model are simultaneously determined using a non-linear least mean squares fitting procedure. Finally, the amplitude of the residual absorption around 1.7 μm is evaluated from the difference between the fitted and measured spectra. Among others, this procedure also yields values for a water parameter which, according to the equations is the water mixing coefficient by the scattering coefficient.

Figure 1 shows a result obtained on a fraction of the Freiburg test site which contains both forested and agricultural areas. The following observations 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 , these reflect the mixed species composition (conifers/deciduous)
- over the forest, the residual amplitude is positively correlated with the water parameter while this correlation breaks on the agricultural zones (see Figure 2)

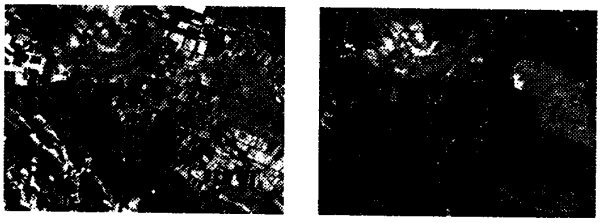

Figure 1.
The water parameter (left) and the residual amplitude (right) over the Freiburg test site; the brighter areas in the residual image are the forested zones.

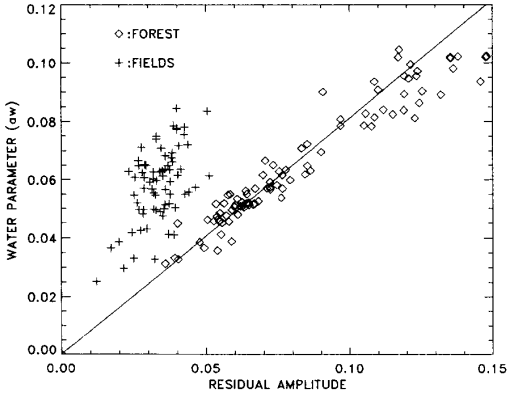

Figure 2.
Residual amplitude plotted versus the water parameter for a number of pixels from the Freiburg scene.

Figure 3 shows the residual amplitude over a small fraction of the Black Forest which is completely composed of conifers, Norway spruce being the dominant specie. When compared with an age class map, a positive correlation of the residual amplitude with the forest age can be distinguished.

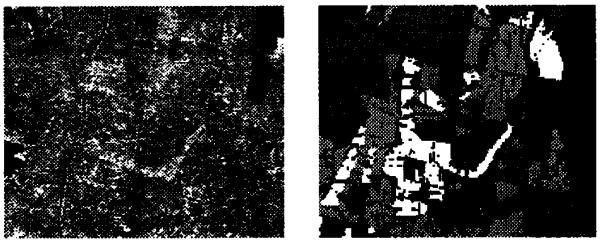

Figure 3.
The residual amplitude image of a fraction of the Black Forest test site (left) and the age class map (right) of the same area (lighter grey indicates older forest).

LABORATORY DATA SET

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 outdoors. About 30 species of woody and herbaceous plants were obtained from trees and crops in the area of the JRC. 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 calibration 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.

The analysis performed on the vegetation fraction spectra of AVIRIS was conducted on the reflectance of optically thick stacks of leaves and needles and Figure 4 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

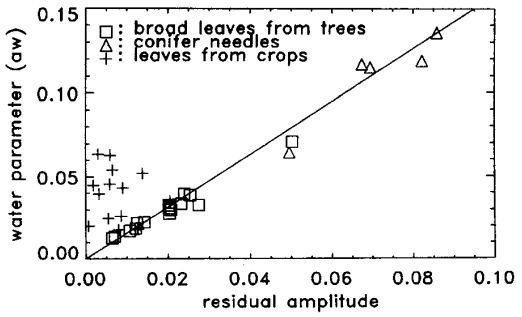

Figure 4.
Water parameter and residual amplitude obtained from laboratory spectra of optically thick stacks of leaves and needles.

1992 AVIRIS DATA

Figure 5 represents the residual image obtained for the 1992 AVIRIS scene over Blackhawk Island. The scene was calibrated in reflectance by Roger Clark and Gregg Swayse at the USGS. The gradient from left to right in the residual amplitude shows similarities with the published result obtained, by regression analysis, for the lignin concentration (Martin and Aber, 1993).

However, the 1992 AVIRIS scenes (containing valid data in the 2.0 to 2.5 μm spectral window) should allow a more detailed and straightforward analysis. This would consist in transforming the reflectance spectrum in an absorptance spectrum using equations (1) and (2) and then unmix this absorptance according to equations (3) and (4). However, one necessary condition is to have good specific absorption coefficients for the biochemical components. We have tried this approach, using specific absorption coefficients:

- deduced from published reflectance spectra (Wessman, 1990)
- deduced from our own reflectance measurements on "pure" substances (starch, cotton, wood, etc.)
- deduced from our measurements on stacks of fresh or dried leaves, accompanied by the corresponding biochemical analysis.

At the time of writing this paper, none of these absorption coefficients sets has yielded satisfactory results.

Figure 5.
Residual amplitude image of Blackhawk Island, obtained from the 1992 AVIRIS scene.

CONCLUSION

The amplitude of the residual absorption at 1.7 μm shows systematic behaviours with respect to the vegetation type. These are found independently both in AVIRIS spectra of canopies and laboratory reflectance measurements on leaves and needles. The residual amplitude map obtained on Blackhawk Island suggests that this feature is indeed related to the lignin concentration.

The extension of the technique to other biochemical signatures still needs additional work on the determination of the specific absorption coefficients and/or on refining the reflectance model.

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