

USING HYPERSPECTRAL REMOTE SENSING DATA FOR RETRIEVING CANOPY WATER CONTENT

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ABSTRACT

Canopy water content (CWC) is important for understanding functioning of terrestrial ecosystems. Spectral derivatives at the slopes of the 970 nm and 1200 nm water absorption features offer good potential as estimators for CWC. An extensively grazed fen meadow is used as test site in this study. Results are compared with simulations with the PROSAIL radiative transfer model. The first derivative at the left slope of the feature at 970 nm is found to be highly correlated with CWC and the relationship corresponds to the one found with PROSAIL simulations. Use of the derivative over the 940 – 950 nm interval is suggested. In order to avoid interference with absorption by atmospheric water vapour, the potential of estimating CWC using the first derivative at the right slope of the 970 nm absorption feature is recommended. Correlations are a bit lower than those at the left slope, but better than those obtained with water band indices, as shown in previous studies. FieldSpec measurements show that one may use derivatives around the middle of the right slope within the interval between 1015 nm and 1050 nm.

Index Terms— Remote sensing, hyperspectral, canopy water content, water absorption features, spectral derivatives

1. INTRODUCTION

Currently one of the main scientific issues is to understand and quantify the impact of global climate change on the Earth system. One of the challenges is the understanding of the role of terrestrial ecosystems in the carbon cycle and the changes they may undergo. The water cycle is one of their most important characteristics. In this respect, the canopy water content is of interest in many applications. In this paper, we focus on retrieving canopy water content from optical remote sensing data, in particular hyperspectral data. Remote sensing techniques provide an integrated signal over the spatial resolution element of the detector. As a result, the canopy water content, being the amount of water per unit ground area, is a variable of interest. However, in radiative transfer (RT) models often the amount of water per unit leaf area, the so-called equivalent water thickness (EWT), is

used [1, 2]. By multiplying the EWT with the leaf area per unit ground area (called the leaf area index, LAI) we get the canopy water content (CWC):

$$CWC = LAI \times EWT \quad (1)$$

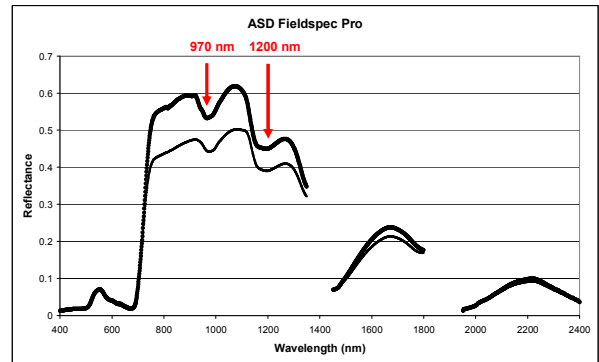


Fig. 1. Example of two spectral signatures of grassland plots measured with the ASD FieldSpec Pro. The position of the water absorption features at 970 nm and 1200 nm are indicated.

Fig. 1 shows some spectral measurements on grassland plots performed with an ASD FieldSpec [3]. It shows two water absorption features at approximately 970 nm and 1200 nm that are caused by the absorption by O–H bonds in liquid canopy water [4]. Accurate measurements at these absorption features in the NIR are feasible with the increasing availability of hyperspectral images. One of the first vegetation indices based on these absorption features was the water band index (WI), defined as the ratio between the reflectance at 900 nm and the one at 970 nm [5]:

$$WI = \frac{R_{900}}{R_{970}}, \quad (2)$$

where R_{900} and R_{970} are the spectral reflectances at 900 nm and 970 nm, respectively.

Analogously to the normalised difference vegetation index (NDVI), which uses the absorption feature in the red, Gao [6] defined the normalised difference water index (NDWI), which uses the 1200 nm absorption feature. It is defined as:

$$NDWI = \frac{R_{860} - R_{1240}}{R_{860} + R_{1240}}, \quad (3)$$

where R_{860} and R_{1240} are the spectral reflectances at 860 nm and 1240 nm, respectively.

Danson *et al.* [7] showed that the first derivative of the reflectance spectrum corresponding to the slopes of the absorption features provides better correlations with leaf water content than those obtained from the direct correlation with reflectance. Rollin & Milton [8] found moderate correlations between the first derivative at the left slope of both absorption features and CWC for a grassland site in the UK. Clevers *et al.* [9] applied derivatives in a preliminary study at the field and airborne level. These studies showed that spectral derivatives at the slopes of the 970 nm and (to a lesser extent) 1200 nm absorption feature have good potential as predictors of CWC.

Recently, Clevers *et al.* [3] showed that the first derivative of the reflectance spectrum at wavelengths corresponding to the left slope of the minor water absorption band at 970 nm was highly correlated with CWC and PROSAIL model simulations showed that it was insensitive to differences in leaf and canopy structure, soil background and illumination and observation geometry. However, these wavelengths are located close to a water vapour absorption band at about 940 nm [10]. In order to avoid interference with absorption by atmospheric water vapour, the potential of estimating CWC using the first derivative at the right slope of the 970 nm absorption feature in addition to the one at the left slope is studied in this paper for a dataset acquired in 2008. Results are compared with PROSAIL simulations, using a new version of the PROSPECT model [11].

2. MATERIAL AND METHODS

2.1. Study site

The study site is an extensively grazed fen meadow acting as a buffer zone around a protected bog ecosystem, located in the Achterhoek area in the Netherlands and forming part of Europe's Natura-2000 ecological network. Ground sampling took place from June 9th – 11th, 2008. 40 Plots of 3 by 3 m were randomly distributed over the site. In three corners of each plot subplots of 0.5 x 0.5 m were harvested by cutting all above-ground vegetation. Vegetation fresh weight for every subplot was determined after harvesting. After drying for 24 hours at 70°C, vegetation dry weight and CWC were determined. Subsequently, the average CWC per plot was calculated.

2.2. Field Spectroradiometry

The study site was measured with an ASD FieldSpec on June 9th and 10th, 2008. All subplots of all 40 plots were

measured before harvesting the biomass. Measurement height above the plot was about 1.5 m and the instrument field of view was 25°. As a result, at the plot level a circular area of about 0.35 m² was measured. Calibration was done by using a Spectralon white reference panel.

2.3. PROSAIL radiative transfer model

PROSAIL is a combination of the PROSPECT leaf RT model [2] and the SAIL canopy RT model [12], which has been used extensively over the past few years for a variety of applications [13]. At the leaf level, PROSAIL is using leaf chlorophyll content (C_{ab}), equivalent leaf water thickness (EWT), leaf structure parameter (N) and leaf dry matter (C_m) as inputs. At the canopy level, input parameters are LAI, leaf inclination angle distribution, soil brightness (assuming a constant spectral reflectance for various brightness values), ratio diffuse/direct irradiation, solar zenith angle, view zenith angle and sun-view azimuth angle. It also includes a parameter describing the hot-spot effect [14]. In a previous study, we used an older version of PROSPECT (version 3) simulating leaf reflectance and transmittance at a 5 nm spectral sampling interval. Recently, version 5 of PROSPECT has been released, performing simulations at a 1 nm spectral sampling interval and using updated values for the specific absorption coefficients of leaf constituents [11]. Since previous PROSAIL simulations already showed that spectral derivatives at the left and right slope of the 970 nm absorption feature are strongly correlated with CWC (meaning EWT and LAI) and little influenced by other PROSAIL model input parameters, in this study only EWT and LAI were varied and all other PROSAIL parameters were assumed constant (and representative for the measured grassland site).

3. RESULTS AND DISCUSSION

A linear regression of the various spectral derivatives and indices with CWC was performed. Fig. 2 shows the coefficient of determination (R^2) between CWC and the spectral derivatives in the 900 – 1400 nm spectral range. Results for this test site confirm previous findings [9]. Best results are obtained for the left slope of the 970 nm absorption feature (region A). Fig. 3 illustrates the result for the relationship of the derivative over the 940 – 950 nm spectral interval with CWC. An R^2 of 0.81 is obtained. When using the leave-one-out technique the root mean square error of prediction (RMSEP) is 1.82 ton/ha. However, when using observations from an airborne or spaceborne platform, the atmospheric water vapour absorption band at about 940 nm might cause problems at this left slope. Moreover, at the left slope the position of the derivative is quite critical. Therefore, we will also look at the right slope. Fig. 2 shows a lower R^2 at the right slope (region B). However, the figure is less spiky than at the left

slope. The right slope of the 970 nm feature also extends over a larger region. Therefore, the wavelength position is less critical at the right slope and a larger interval can be used. Fig. 2 shows that the interval 1015 – 1050 nm might be used. The resulting R^2 value between derivative and

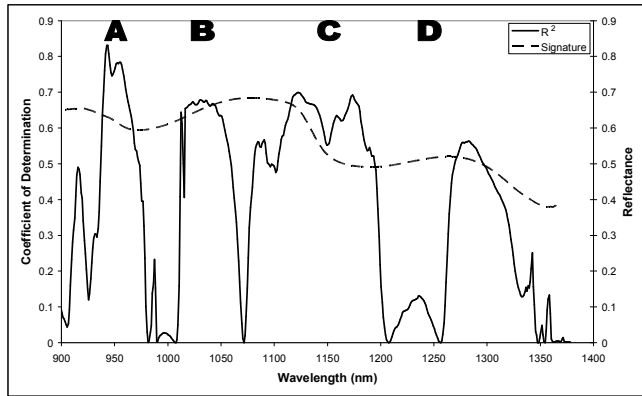


Fig. 2. Coefficients of determination between CWC and first derivative of canopy reflectance measured with the FieldSpec. The dotted line provides an example of a canopy reflectance signature.

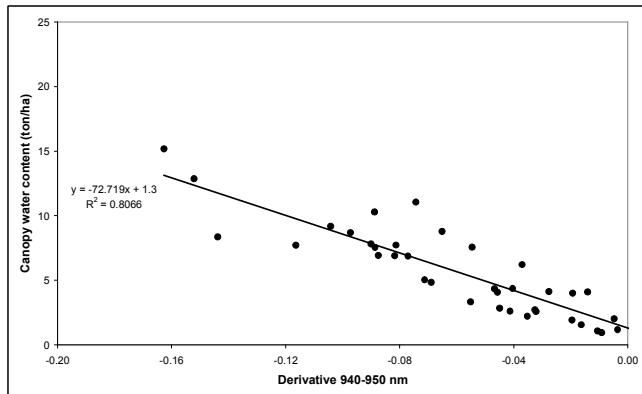


Fig. 3. Relationship between first derivative of FieldSpec canopy reflectance over the interval 940 – 950 nm and CWC at the Achterhoek test site in 2008.

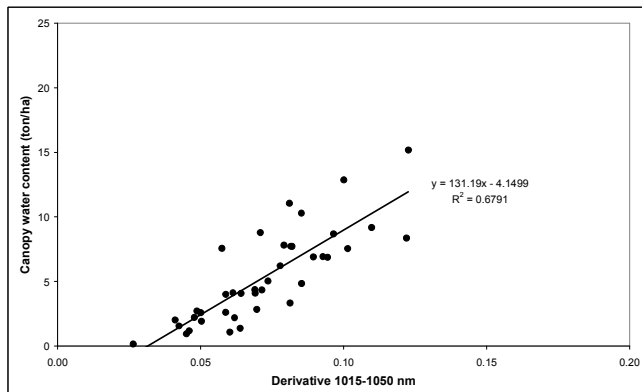


Fig. 4. Relationship between first derivative of FieldSpec canopy reflectance over the interval 1015 – 1050 nm and CWC at the Achterhoek test site in 2008.

CWC appears to be 0.68 (Fig. 4), which is clearly less than the best one found at the left slope. The calculated RMSEP is 2.35 ton/ha using the leave-one-out method.

The experimental results are compared with PROSAIL simulations. For the 940 – 950 nm interval the experimental results (Fig. 3) correspond very well with the PROSAIL simulations (Fig. 5). There seems to be a small offset in the experimental data (slope is nearly identical), which can be caused by the assumption of a spectrally constant soil brightness, which is not occurring in reality. For the 1015 – 1050 nm interval the difference between the experimental data and the model simulations is larger (cf. Fig. 4 with Fig. 6). Looking at the signatures with lower coverage, the slope at this interval appears to be significant. This is shown in Fig. 4 by the large offset of the regression line. In addition, the slopes in Figs. 4 and 6 clearly are different.

Results for the water band indices appeared to be somewhat worse when using the PROSAIL simulations. The R^2 value for the WI is 0.93 and for the NDWI it is 0.92. For the Achterhoek data set the R^2 values are similar to the best one at the left slope and better than the one at the right slope of the 970 nm absorption feature (R^2 for WI is 0.85 and for

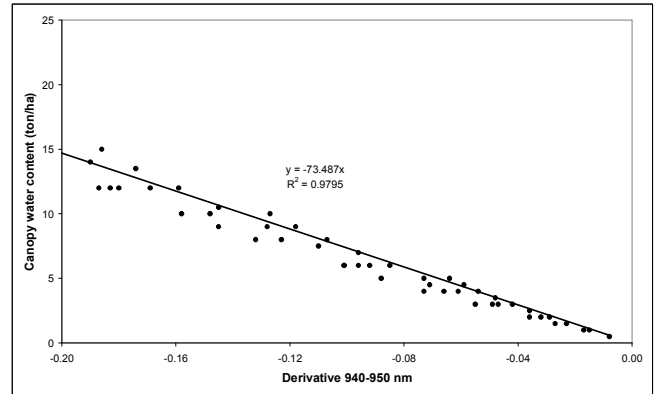


Fig. 5. Relationship between the derivative over the interval 940 – 950 nm and CWC as simulated by PROSAIL.

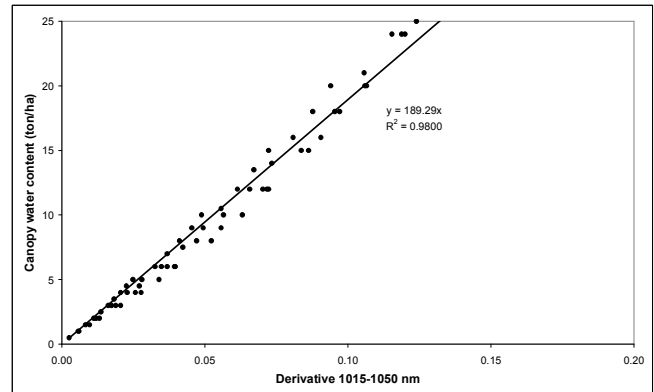


Fig. 6. Relationship between the derivative over the interval 1015 – 1050 nm and CWC as simulated by PROSAIL.

NDWI 0.82). For other data sets the water band indices mostly appeared to perform worse than the derivatives [9].

4. CONCLUSIONS

Results from this study show that the first derivatives of the reflectance spectrum at the left and the right slope of the 970 nm absorption feature are linearly correlated with CWC. Correlations are a bit higher at the left slope than at the right slope, but the spectral position of the calculated derivative is much less critical at the right slope. In this study we suggest to use the average derivative over the 1015 – 1050 nm interval. Due to the broader interval, this derivative is more robust than the ones used at the left slope.

The experimental regression line between the derivative at the left slope of the 970 nm absorption feature and CWC is quite similar to the one simulated with the PROSAIL radiative transfer model. Results for the right slope of the 970 nm feature are deviating from modelling results, but it is noted that most of these differences can be explained by not taking the actual background reflectance into account in the PROSAIL model. Further research is still required.

For drought detection in vegetation or for mapping fire susceptibility the water concentration (or EWT) is more important than the total content. This quantity can be estimated by dividing the water content by the LAI. So, an independent estimate of LAI is needed, which, e.g., can be obtained by using the weighted difference vegetation index WDVI [15].

5. ACKNOWLEDGEMENT

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