# USING THE RIGHT SLOPE OF THE 970 NM ABSORPTION FEATURE FOR ESTIMATING CANOPY WATER CONTENT

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## ABSTRACT

Canopy water content (CWC) is important for understanding the functioning of terrestrial ecosystems. Biogeochemical processes like photosynthesis, transpiration and net primary production are related to foliar water. The first derivative of the reflectance spectrum at wavelengths corresponding to the left slope of the minor water absorption band at 970 nm was found to be 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 also located close to the water vapour absorption band at about 940 nm.

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 was studied. Measurements obtained with an ASD FieldSpec spectrometer for three test sites were related to CWC (calculated as the difference between fresh and dry weight). The first site was a homogeneous grassland parcel with a grass/clover mixture. The second site was a heterogeneous floodplain with natural vegetation like grasses and various shrubs. The third site was an extensively grazed fen meadow.

Results for all three test sites showed that the first derivative of the reflectance spectrum at the right slope of the 970 nm absorption feature was linearly correlated with CWC. Correlations were a bit lower than those at the left slope (at 942.5 nm) as shown in previous studies, but better than those obtained with water band indices. FieldSpec measurements showed that one may use any derivative around the middle of the right slope within the interval between 1015 nm and 1050 nm. We calculated the average derivative at this interval. The first site with grassland yielded an $R^2$ of 0.39 for the derivative at the previously mentioned interval with CWC (based on 20 samples). The second site at the heterogeneous floodplain yielded an $R^2$ of 0.45 for this derivative with CWC (based on 14 samples). Finally, the third site with the fen meadow yielded an $R^2$ of 0.68 for this derivative with CWC (based on 40 samples). Regression lines between the derivative at the right slope of the 970 nm absorption feature and CWC for all three test sites were similar although vegetation types were quite different. This indicates that results may be transferable to other vegetation types and other sites.

## 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 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

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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 (Hunt Jr. and Rock, 1989; Jacquemoud and Baret, 1990). 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):

$$CWC = LAI \times EWT \tag{1}$$

Figure 1 shows some spectral measurements on grassland plots performed with an ASD FieldSpec (Clevers *et al.*, 2007b). It shows two water absorption features at approximately 970 nm and 1200 nm that are caused by absorption by O–H bonds in liquid canopy water (Curran, 1989). 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 at 970 nm (Peñuelas et al., 1997):

$$WI = \frac{R_{900}}{R_{970}}, \tag{2}$$

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 (1996) defined the normalised difference water index (NDWI), which uses the 1200 nm absorption feature. It is defined as:

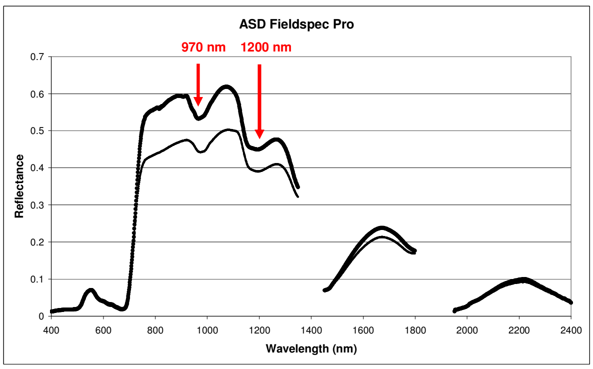

Figure 1. Example of two spectral signatures of grassland plots measured with the ASD FieldSpec Pro. The position of the water absorption features at 970 nm and 1200 nm are indicated.

$$NDWI = \frac{R_{860} - R_{1240}}{R_{860} + R_{1240}}, \tag{3}$$

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

Danson et al. (1992) showed that the first derivative of the reflectance spectrum corresponding to the slopes of the absorption feature provides better correlations with leaf water content than those obtained from the direct correlation with reflectance. Rollin & Milton (1998) 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. (2008) 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 1200 nm absorption feature have good potential as predictors of CWC. Recently, Clevers et al. (2007b) 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 the water vapour absorption band at about 940 nm. 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 was studied in this paper.

## 2. MATERIAL AND METHODS

### 2.1 Study site 1

Study site 1 is a grassland field with a mixture of grass and white clover at the 'Droevendaal' experimental farm in Wageningen, the Netherlands (Clevers *et al.*, 2007a; Clevers *et al.*, 2008). After having performed field spectroradiometric measurements, a total of 20 plots (each 15 m long and 3 m wide) were harvested using a plot-harvester on July 30$^{th}$, 2004. Above-ground fresh weight was determined with a built-in weighing unit on the harvester. Samples of the harvested material were oven dried for 24 hours at 70°C and dry weight was determined. Subsequently, CWC was calculated.

## 2.2 Study site 2

The second site is located in the floodplain Millingerwaard along the river Waal in the Netherlands (Kooistra et al., 2008; Schaepman et al., 2007). The site is a nature rehabilitation area allowed to undergo natural succession, which has resulted in a heterogeneous landscape with a mosaic pattern of different succession stages (pioneer vegetation, grassland, shrubs). Nature management within the floodplain is aiming at improvement of biodiversity. Based on the available vegetation map of the area, 12 locations with specific vegetation structure types were selected. For each location a plot of 20 x 20 m was selected with a relatively homogeneous vegetation cover. End of June 2005 vegetation was sampled in three subplots per plot measuring 0.5 x 0.5 m, by cutting all above-ground vegetation just above the surface. Vegetation fresh weight for every subplot was determined immediately 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.

## 2.3 Study site 3

Finally, site 3 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 9$^{th}$ – 11$^{th}$, 2008. 40 Plots of 3 by 3 m were randomly distributed over the site, taking into account that each plot and its surroundings should be homogeneous based on information on soil and vegetation diversity given by available maps. 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.

## 2.4 Field spectroradiometry

We measured all plots of the homogeneous grassland field (site 1) with an ASD FieldSpec Pro FR spectroradiometer on July 29$^{th}$, 2004. 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 m$^2$ was measured. We performed 10 measurements per plot, whereby each measurement represents the average of 50 readings at the same spot. The sampling interval was 1 nm. Calibration was done by using a Spectralon white reference panel.

On June 19$^{th}$, 2005, all plots of the heterogeneous floodplain (site 2) were measured with an ASD FieldSpec Pro FR spectroradiometer. At every plot 12 measurements were performed according to the VALERI (VAlidation of Land European Remote sensing Instruments) sampling scheme (Morisette et al., 2006), whereby each measurement was the average of 50 readings at the same spot. Measurement height was about 1 m above the vegetation, resulting in a measurement area of about 0.15 m$^2$. A Spectralon white reference panel again was used for calibration.

Site 3 was measured with an ASD FieldSpec on June 9$^{th}$ and 10$^{th}$, 2008. Each subplot of all 40 plots was 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 m$^2$ was measured. Calibration again was done by using a Spectralon white reference panel.

After calculating average spectra per plot, we smoothed the resulting spectra using a 15 nm wide moving Savitsky-Golay filter, applying a second order polynomial fit within the window, to reduce noise.

# 3. RESULTS AND DISCUSSION

## 3.1 Test site 1: Wageningen

Clevers et al. (2008) already showed that the variability within the grassland plots of site 1 was limited. No treatment differences have been applied at this site. Figure 2 shows the coefficient of variation ($R^2$) between CWC and the spectral derivatives in the 900 – 1400 nm spectral range based on a linear regression analysis. Clevers et al. (2008) found best results for the left slope of the 970 nm absorption feature (region A). However, they also indicated that, 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. Therefore, they recommend looking also at the right slope. Figure 2 shows a lower $R^2$ at the right slope. However,

the figure is less spiky than at the left slope. The right slope of the 970 nm feature also is less steep and extends over a larger region. Therefore, the wavelength position is less critical at the right slope and a larger interval can be used. Figure 2 shows that the interval 1015 – 1050 nm might be used. The resulting $R^2$ value between derivative and CWC appears to be 0.39 (Figure 3), which is clearly less than the best one found at the left slope ($R^2$ = 0.71 @ 942.5 nm).
The predictive power of the derivatives as indices for estimating CWC was assessed by estimating the root mean square error of prediction (RMSEP) using the leave-one-out method. For the Wageningen site this results in a RMSEP of 2.43 ton/ha.
The results for the NDWI are in-between these for the left and right slope ($R^2$ = 0.56), whereas those for the WI are worse ($R^2$ = 0.26). Results are summarised in Table 1. Problem of this test site is the small variability of the samples.

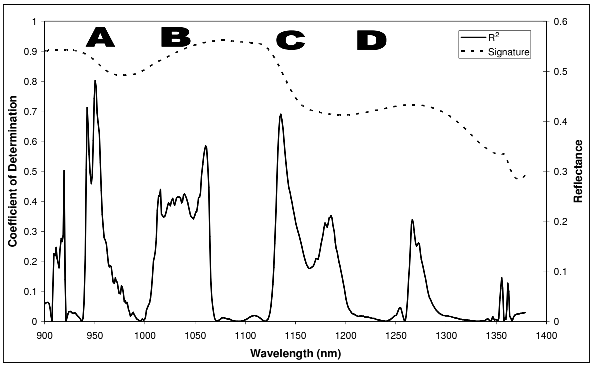


Figure 2. Coefficients of determination between CWC and first derivative of canopy reflectance measured with the FieldSpec at the Wageningen test site. The dotted line provides an example of a measured canopy reflectance signature.

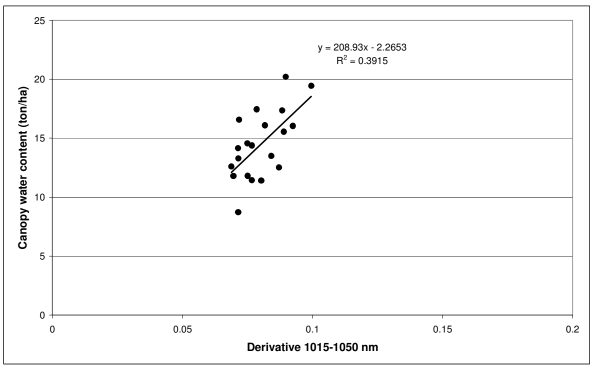


Figure 3. Relationship between first derivative of FieldSpec canopy reflectance over the interval 1015 – 1050 nm and CWC at the Wageningen test site in 2004.

Table 1. Results for the indices tested in estimating CWC as shown by the coefficient of determination ($R^2$).
WI = Water Index; NDWI = Normalised Difference Water Index.

| | Site 1 2004 | Site 2 2005 | Site 3 2008 |
|---|---|---|---|
| Derivative 1015-1050 nm | 0.39 | 0.45 | 0.68 |
| Derivative @ 942.5 nm | 0.71 | 0.43 | 0.83 |
| WI | 0.26 | 0.40 | 0.85 |
| NDWI | 0.56 | 0.36 | 0.82 |

### 3.2 Test site 2: Millingerwaard

Figure 4 depicts the results in terms of the $R^2$ between spectral derivatives and CWC for the test site 2 with very heterogeneous natural vegetation. For this site we again observe quite a constant $R^2$ for the interval 1015 – 1050 nm at the right slope of the 970 nm feature. Values are not much different from those at the left slope (Table 1). The $R^2$ at the right slope is 0.45 (Figure 5). The calculated RMSEP is 7.32 ton/ha using the leave-one-out method. Detailed analysis of the data shows that the higher CWC values above 18 ton/ha (4 plots) correspond to plots containing tall shrubs, which were very difficult to measure with the FieldSpec. Leaving out these 4 plots results in a RMSEP of 2.41 ton/ha, but the number of remaining plots then is limited.

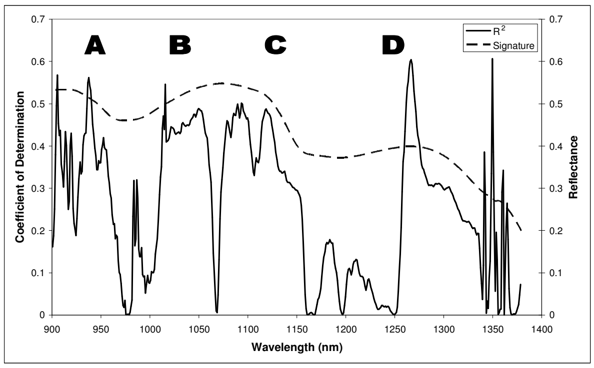


Figure 4. Coefficients of determination between CWC and first derivative of canopy reflectance measured with the FieldSpec at the Millingerwaard test site. The dotted line provides an example of a measured canopy reflectance signature.

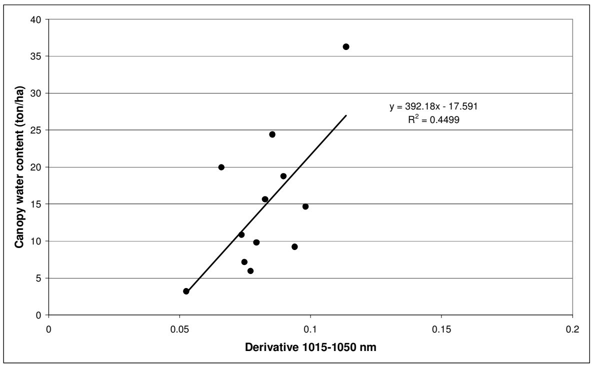


Figure 5. Relationship between first derivative of FieldSpec canopy reflectance over the interval 1015 – 1050 nm and CWC at the Millingerwaard test site in 2005.

Results for the water band indices are slightly worse than those for the derivatives (Table 1).

## 3.3 Test site 3: Achterhoek

Test site 3 shows a varying species composition, but the vertical distribution of the canopy is not as big as for test site 2. Figure 6 shows the $R^2$ values for the relationship between spectral derivatives and CWC. The $R^2$ for the 1015 – 1050 nm interval also is constant for this test site. Again it is lower than the best value at the left slope (Table 1). However, at the left slope the position of the derivative is quite critical. The $R^2$ at the right slope is 0.68 (Figure 7). The calculated RMSEP is 2.35 ton/ha using the leave-one-out method.

Results for the water band indices are also very good (Table 1). $R^2$ 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. In general, this site yields the best results, which can

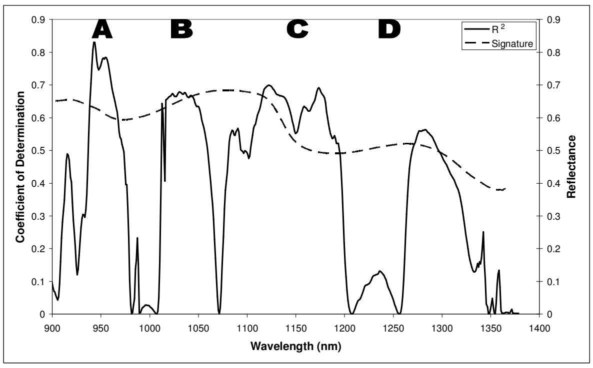


Figure 6. Coefficients of determination between CWC and first derivative of canopy reflectance measured with the FieldSpec at the Achterhoek test site. The dotted line provides an example of a measured canopy reflectance signature.

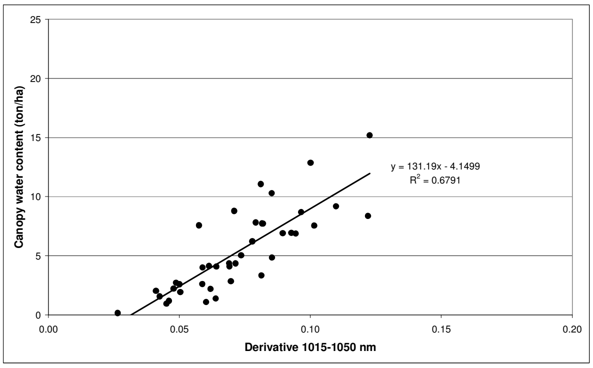


Figure 7. Relationship between first derivative of FieldSpec canopy reflectance over the interval 1015 – 1050 nm and CWC at the Achterhoek test site in 2008.

be explained by the larger number of samples available for this site.

## 4. CONCLUSIONS

Results from this study show for all three test sites that the first derivative of the reflectance spectrum at the right slope of the 970 nm absorption feature is linearly correlated with CWC. Correlations were a bit lower than those at the left slope (at 942.5 nm) as shown in previous studies, but the spectral position of the calculated derivative is much less critical. 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 before at the left slope. As a result, the value of this derivative is much less influenced by measurement noise, thus making a mathematical smoothing of the measurements superfluous.

Regression lines between the derivative at the right slope of the 970 nm absorption feature and CWC for all three test sites were quite similar although vegetation types were very different. This indicates that results may be transferable to other vegetation types and other sites. However, results are not yet such that this now has been proven. 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 (Clevers, 1989).

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