REMOTE SENSING OF CANOPY WATER CONTENT DURING SMEX'04 AND SMEX'05 USING SHORTWAVE-INFRARED REFLECTANCES

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ABSTRACT

The Soil Moisture Experiments in 2004 and 2005 were conducted to validate algorithms for soil moisture retrievals. One of the key parameters for determination of soil moisture from microwave sensors is the vegetation water content of canopy and stems. We tested if canopy water content could be determined from reflectances in the shortwave-infrared and if the amount of canopy water content was related to the total vegetation water content by allometric equations. The normalized difference infrared index (NDII) was linearly related to canopy water content for all plants up to an equivalent water thickness of 1.0 mm. The biggest factor affecting the estimation of canopy water content was the soil background reflectance. For corn and soybean canopy equivalent water thickness were linearly related to total vegetation water content. However, there may be a separate allometric equation required for each vegetation type.

Index Terms— Soil Moisture Experiment, Normalized Difference Infrared Index, Vegetation Water Content

1. INTRODUCTION

The Soil Moisture Experiments in 2004 (SMEX'04) and 2005 (SMEX'05) were conducted to validate algorithms on the retrieval of soil moisture content using microwave remote sensing [1,2,3,4]. One of the biggest sources of error for estimation of soil moisture content is the amount of water in the vegetation [1,2]. Typically, passive microwave radiometers can not detect changes in soil moisture when the vegetation water content is greater than 5 kg m^{-2}. Canopy water content is the total foliage water mass per ground area and is only a fraction of the total vegetation water content. The objectives of this study are to first determine if there is an overall relationship between canopy water content and indices using the shortwave infrared reflectances (1650 nm wavelength), and second to determine if total vegetation water content could be estimated from canopy water content.

2. BACKGROUND

Changes in canopy water can be detected using reflected shortwave-infrared radiation from about 950 nm to 2500 nm wavelength. Several indices have been proposed, such as the normalized difference water index (NDWI) which uses the reflectance at 1240 nm, which is equivalent to MODIS band 5 [5].

Reflectances at 1650 nm wavelength have been used to detect changes of leaf and canopy water content [6, 7]. Leaf and canopy water contents are frequently expressed in terms of water volume per leaf area and ground area, respectively, which is termed the equivalent water thickness (EWT). A canopy water content of 1 kg m^{-2} equals a canopy EWT of 1 mm. Canopy EWT is calculated from the product of leaf EWT and leaf area index (LAI).

Hardisky et al. [8] proposed the Normalized Difference Infrared Index (NDII):

$$\text{NDII} = (R_{850} - R_{1650}) / (R_{850} + R_{1650}) \qquad (1)$$

where R_{850} is the land-surface reflectance of the near-infrared channel (TM band 4, ASTER band 3N, MODIS band 2, and AWiFS band 3) and R_{1650} is the land-surface reflectance at 1650 nm (e.g. TM band 5, ASTER band 5, MODIS band 6, and AWiFS band 4). Two studies have shown linear relationships between NDII and EWT [9, 10], and NDII avoids some problems encountered using a ratio [6, 7].

Total vegetation water content (VWC) is the sum of canopy and stem water content [4]. Because the leaves of plants have to be supported by the stems, usually there is a relationship between the amount of leaves and the size of stems, termed an allometric relationship [11]. Allometric equations can be determined statistically, allowing VWC to be estimated from canopy EWT.

3. METHODS

SMEX'04 was conducted in Arizona, USA and Sonora, Mexico (Fig. 1). To obtain a large range of CWC, different plant communities were sampled from desert shrubs to irrigated agriculture [3]. The SMEX'05 was conducted in Iowa, USA (Fig. 1), which was also the site for the Soil Moisture Experiment 2002 [2]. Soybean and corn fields were measured over time to obtain a large range of CWC [4]. VWC was estimated during SMEX'05 by sampling the water content of one plant per plot, and multiplied by the plot density [4]. Furthermore, at SMEX'05, a series of woodland sites were selected for determination of CWC and VWC [4].

Leaf area index (LAI) was determined using canopy hemispherical photographs for all sites in SMEX'04 [3] and for the woodland sites in SMEX'05 [4]. Photographs were analyzed by the HemiView Canopy Analysis Software version 2.1 (Delta-T Devices, Cambridge, United Kingdom). LAI was determined for corn and soybean plots [4] using a LAI-2000 Plant Canopy Analyzer (LI-COR, Lincoln, Nebraska, USA).

During both experiments, Landsat 5 Thematic Mapper (TM) data were acquired, geographically registered, and atmospherically corrected to land-surface reflectances [3,4]. For SMEX'05, India's ResourceSat Advanced Wide Field Sensor (AWiFS) and NASA Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) were also acquired, registered, and atmospherically corrected [4].

The regression between NDII and canopy EWT was compared to SAIL model simulations [12] using measured spectral reflectance and transmittance of corn leaves and spectral reflectance of various backgrounds from Daughtry et al. [13].

4. RESULTS AND DISCUSSION

During both SMEX'04 and SMEX'05, there were linear relationships between NDII and canopy water content (Fig. 2). There was no significant difference between the two regression equations even though there were large changes in soil background reflectance and major differences in vegetation type. Furthermore, data from Hunt [7], Davidson et al. [9], and Ceccato et al., [10] were included in the analysis, and there were no significant statistical differences among the different datasets in the regression between NDII and canopy EWT (Fig. 2). The data indicate that NDII is saturated by canopy EWT at about an NDII of 0.5 and or a canopy EWT of 1.0 mm. Excluding the data of Hunt [7], a single regression equation (canopy EWT = 0.224 + 1.095 NDII, R^2 of 0.81) summarized the data well (Fig. 2). The standard error of the y estimate from the regression is about ± 0.094 mm, which is about one half of leaf EWT (Fig. 2). Because the range of leaf EWT between completely hydrated water-stressed leaves is less than 0.05 mm, it is unlikely that the overall regression would be useful for detecting the onset of drought stress [6]. Since canopy EWT equals the product of leaf EWT and LAI by definition, the standard error of the y estimate of 0.094 mm is also equivalent to ± 0.47 m^2 m^{-2} LAI.

The SAIL model simulations show the overall regression equation averages out the differences caused by different soil backgrounds (Fig. 3). Moist soil and residue backgrounds tended to increase NDII for a given canopy EWT (Fig. 3). Remote sensing using microwave sensors and multispectral sensors can provide better estimates of canopy EWT and soil moisture content in an iterative manner.

The relationship between canopy water content and total vegetation water content varies with vegetation type, corn has much more VWC for a given canopy EWT. Corn and soybean both had linear relationships between VWC and NDII; however, the regression slope was much higher for corn (Fig. 4). We compared the NDII-WVC relationship for SMEX'02 [2] with the data from SMEX'05 (Fig. 4). The regressions for corn were not significantly different between years whereas the regressions for soybean were significantly different at $P > 0.95$. Therefore, it is likely that canopy water content can be used to predict vegetation water content for some land-cover types where a good allometric relationship exists between leaves and stems.

5. REFERENCES

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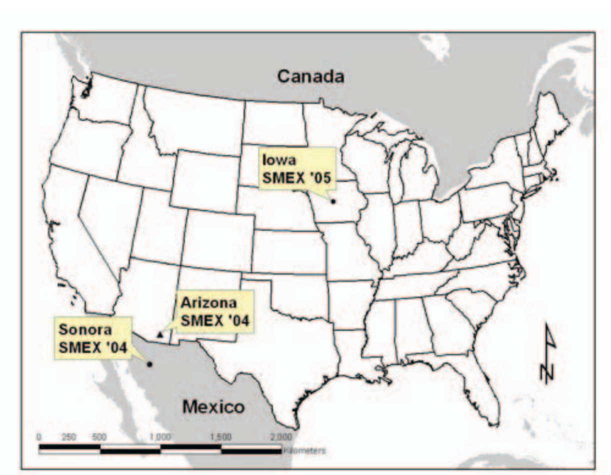

Figure 1. Map of North America showing the locations of the Soil Moisture Experiments 2004 (SMEX’04) and 2005 (SMEX’05).

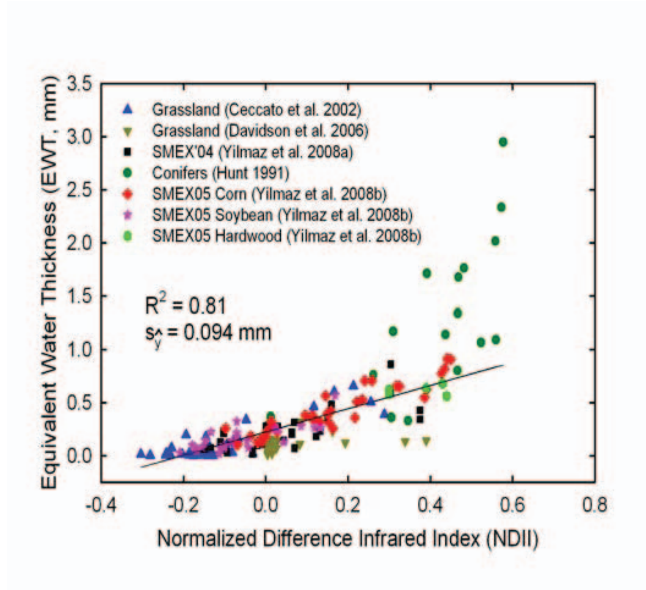

Figure 2. Canopy Equivalent Water Thickness estimated from the Normalized Difference Infrared Index from SMEX’04, SMEX’05 and other studies [7, 8, 9]. NDII was calculated from Landsat 5 TM, ASTER or AWiFS imagery.

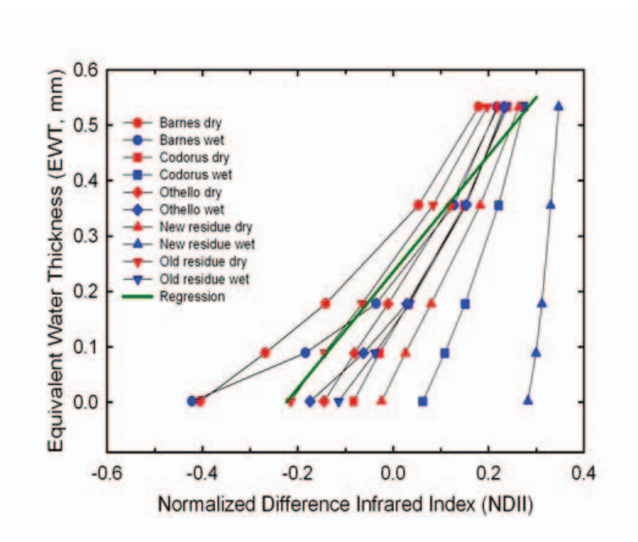

Figure 3. SAIL model simulations using different wet and dry backgrounds. The leaf spectral reflectances and transmittances for input into the SAIL model were measured using corn leaves. The green line is the regression equation from Fig. 2.

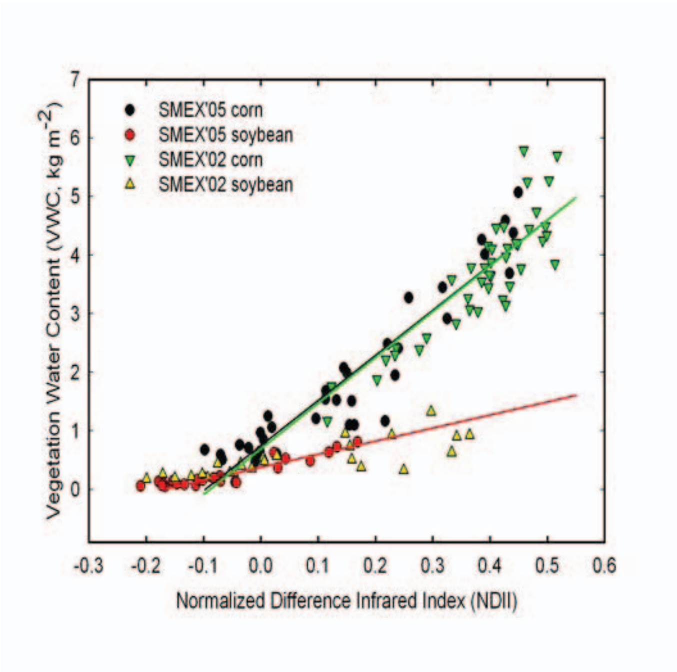

Figure. 4. Vegetation Water Content of corn and soybean from SMEX'02 and SMEX'05. The SMEX'02 data are from Jackson et al. [2]. Vegetation water content is the sum of stem water content and canopy equivalent water thickness. NDII is used to determine the canopy equivalent water thickness, which is related to stem water content by different allometric equations.