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THE IMPORTANCE OF OVERPASS TIME IN AGRICULTURAL APPLICATIONS OF RADAR

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ABSTRACT

The objective of this study was to investigate the effect of diurnal variation in internal and surface canopy water on L-band backscatter in the context of the influence of overpass time on agricultural applications. A unique and intensive dataset was collected during a full growing season of corn in Florida, USA in 2018. L- band data was collected by using a fully polarized scatterometer mounted on a crane. In order to measure internal vegetation water distribution and dry biomass, pre-dawn destructive sampling was conducted three times a week for a full growing season. In addition, soil moisture, meteorological, dew, and interception data were measured every 15 minutes for the entire growing season. Results demonstrate that the presence of surface canopy water and diurnal internal water dynamics can each affect the radar backscatter up to 3-4 dB. The surface canopy water also affects the relationship between radar and crop biophysical variables. In corn, the spearman rank correlation between backscatter and biophysical variables is, on average, about 0.2 higher for dry vegetation compared to wet vegetation. The results highlight the possible influence of overpass time on the interpretation of radar data for vegetation monitoring.

Index Terms— surface canopy water, sub-daily radar, L-band backscatter, crop monitoring, VWC

1. INTRODUCTION

Radar is a valuable tool in agricultural applications including soil moisture retrieval, crop monitoring and classification, and water stress monitoring [1–6]. A major advantage of radar compared with optical data is the ability of radar to acquire data regardless of weather conditions during day and night. Radar data can penetrate through different layers of the vegetation and can be more or less sensitive to vegetation or soil effects depending on frequency and polarization. Moreover, radar backscatter is highly sensitive to dielectric properties of crops, primarily determined by their water content, as well as the moisture of the underlying soil.

The launch of sun-synchronized satellite such as ESA's Sentinel-1 mission in 2014, the Radarsat Constellation Mission (RCM) in 2019, and future missions such as NiSAR [7] and ROSE-L [8] improve the potential of near real-time agricultural monitoring [3, 4, 6]. Furthermore, new SAR systems in Low Earth Orbit (LEO) such as those from Iceye and CapellaSpace could provide new opportunities for sub-daily monitoring of soil and vegetation [2, 9].

Several studies have used sun-synchronized satellite data (ascending and descending observation) to demonstrate the capability of radar data to detect diurnal variation in internal vegetation water content[10, 11]. They reported differences between evening and morning observations that were attributed to a change in internal vegetation water content. In addition, several studies have demonstrated that the presence of surface canopy water increases the radar backscatter[2, 12].

However, the limited radar datasets (using ascending and descending overpass) in previous studies leave open questions in terms of sub-daily pattern in backscatter and the sensitivity of backscatter to both variation in surface and internal water content. Moreover, the limited ground validation datasets on surface canopy water limit quantitative analysis. The main goal of this study is to investigate the possible influence of overpass time on backscatter variations due to surface canopy water, and its effect on the retrieval of biophysical parameters.

2. DATA AND METHODS

2.1. Study area

The study was conducted at UF/IFAS Extension Plant Science Research and Education Unit (PRSEU), Citra, Florida, USA. Sweet corn (Zea mays L. var. rugosa) was planted with an average density of 7.9 plants m^{-2} on 13 April 2018 and harvested on 18 June 2018. The corn field was around 250 m by 150 m and the soil consisted of $> 90\%$ by volume fine sand. The study area has a humid subtropical climate and midnight irrigation was necessary at the beginning of the season to control the soil moisture content.

2.2. Hydrometeorology

Meteorological data were obtained from the Florida Automated Weather Network (FAWN) weather station located 600 m east of the corn field. Rainfall, relative humidity, temperature, solar radiation, and wind speed were obtained every 15 minutes. The presence and duration of surface canopy water (SCW) were monitored using three Phytos31 dielectric leaf wetness sensors. These sensors were installed at different heights in the canopy and the heights of the sensors were adjusted as the corn grew. Surface canopy water was classified as precipitation, irrigation or dew using the precipitation and irrigation data. Soil moisture was observed every 15 minutes at 5, 10, 20, 40, and 80 cm depth in two pits near the radar footprint. A site calibration was applied and the average of two locations is presented here. Vegetation water content (VWC) and dry biomass were measured by predawn destructive vegetation sampling every 2-3 days. More details on hydrometeorology and vegetation sampling during this experiment can be found in Vermunt et al. [2].

2.3. Microwave scattering system

The University of Florida L-band Automated Radar System (UF-LARS) was used to acquire radar backscatter (σ^0). The system operates at a central frequency of 1.25 GHz and has a dual-polarization horn antenna, which allows us to acquire data at four polarization combinations (VV, HH, VH, and HV) simultaneously. The UF-LARS was installed on a Genie platform and scanned the corn field with an antenna height of 14 meters and a fixed elevation angle of 40°. The ground range and azimuth resolution were measured using 3dB antenna beamwidth and are provided in Table 1 and a full description of the system can be found in [13]. The UF-LARS system was programmed automatically to acquired 32 measurements per day during the growing season and the internal calibration was applied during each acquisition [2]. The external calibration was conducted using a trihedral corner reflector several times during the growing season. The Single Target Calibration Technique (STCT) was used to calculate backscatter coefficient σ° from the received signal and the total systematic and random error were estimated as 1.49 and 0.85 dB respectively.

Table 1. UF-LARS specifications

Parameter		UF-LARS
Range resolution (m)	HH / VV / cross-pol	8.5 / 6.2 / 6.2
Azimuth resolution (m)	HH / VV / cross-pol	4.7 / 6.4 / 4.7

3. RESULTS

3.1. Meteorological data

The first three weeks of the season were dry and warm. Therefore midnight irrigation was applied on 8 occasions to control soil moisture content. The resultant rapid increase in 5 and 10 cm soil moisture after irrigation can be seen in Fig. 1. Three heavy rain events on 21, 27 and 30 May led to sharp increases in root zone soil moisture content 6. A dry period with few rain events and high humidity between June 1 and June 10 resulted in a rapid decrease in soil moisture at all depths. The mid-season was frequently rainy with very high humidity, which resulted in the presence of water on the canopy surface for long periods during the day. Fig. 2 illustrates that the SCW (dew/interception) was present on most days from midnight until around 10 am. In terms of overpass times note, for example, that SCW was present on 95% of days at 6 am and just 25% of days at 6 pm.

3.2. Factors influencing L-band backscatter

Fig. 3 (a-c) shows that there are slow changes in radar backscatter due to crop growth, and more rapid changes associated with vegetation water dynamics. The increasing trend in all polarizations is due to crop growth, as this time series is during the leaf development growth stage [2, 14]. The daily cycles superimposed on this upward trend are due to dynamics in surface and internal water content and soil moisture. Fig. 3 (d) shows the soil moisture and surface canopy water variations during this time. Interception of irrigation events at midnight on May 7, 9 and 11 led to rapid increase in surface soil moisture. In addition, dew accumulation leads to an increase in backscatter during the night.

The backscatter data in Fig. 3 have been colored to indicate if the observations were acquired in the presence of dew and/or interception. This illustrates that the sharp increase in interception and

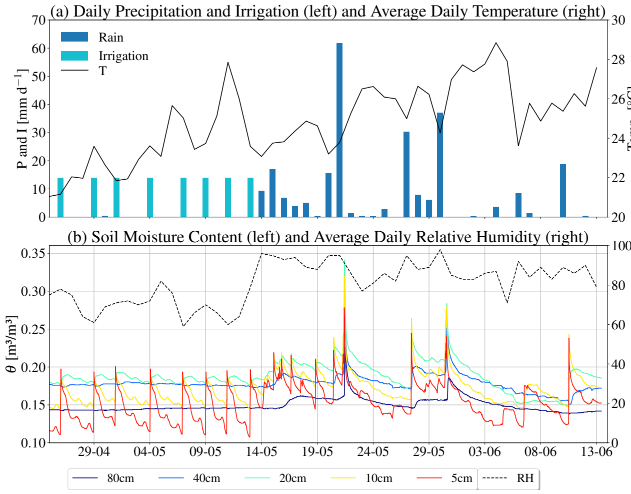

Fig. 1. Time series of meteorological data collected by FAWN and averaged volumetric soil moisture from two pits on different depth

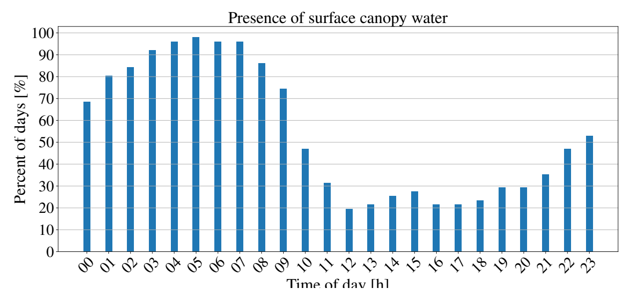

Fig. 2. The percent of days that surface canopy water was presented at each hour of the day

soil moisture following irrigation can result in an increase of more than 5 dB in VV and VH. Results are less convincing in HH due to noise in the observations. During the night, the decrease in backscatter due to soil moisture is inhibited by the presence of interception and the accumulation of dew.

On nights without irrigation, the accumulation of dew from midnight until sunrise led to a gradual increase in backscatter of up to 2-3 dB, even though soil moisture was decreasing. Dew and interception dissipate rapidly after sunrise, so the backscatter variations (highlighted in black) are due to variations in internal water content and surface soil moisture. As the daily radiation cycle drives evapotranspiration, the backscatter in all polarization is found to decrease from 10 am to a minimum in the late afternoon in response to moisture losses.

3.3. Diurnal cycles of water content and backscatter

The clear daily cycle in radar backscatter in response to accumulation and dissipation of dew and variations in internal water content (VWC) can be seen in Fig. 4. These data were collected during the flowering and fruit development stages [14], so the corn has reached maximum biomass and L-band backscatter is dominated by the vegetation contribution [2]. Continuous internal canopy water content were estimated using a water balance approach combining sparse destructive sampling with continuous records of evapotranspiration and sap flow [15]. The diurnal change in VWC is around 0.38 kg

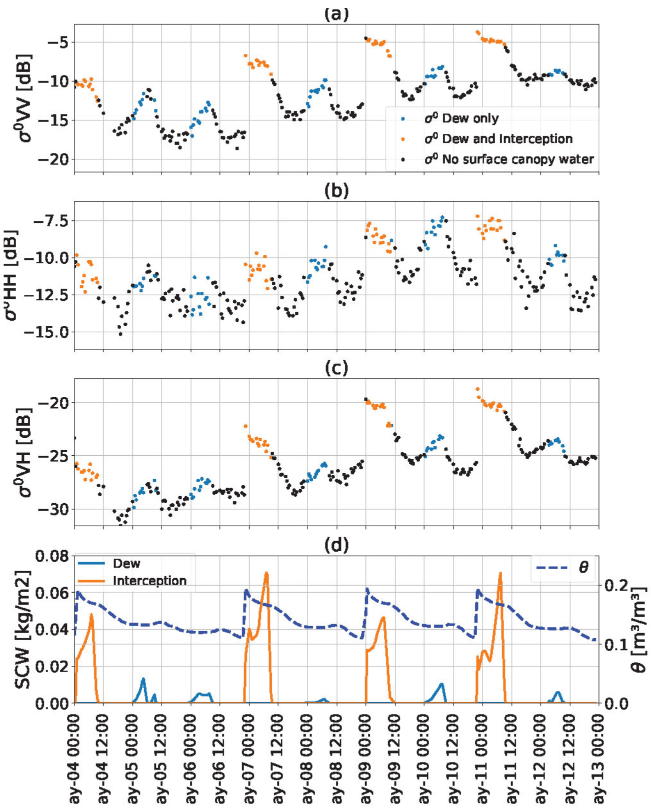

Fig. 3. Time series of co- and cross-polarized backscatter divided to three situations based on presence and absent of SCW (three upper rows), soil moisture profile at 5 cm, and SCW (dew/interception) content (lower row) for 9 days during the early season

m^{-2} which is about 9.1 % of total VWC, and is comparable in magnitude to the variation in SCW. The range of the mean daily cycle in backscatter at this time is 1.64, 2.43, and 1.96 dB in HH, VV and cross-pol respectively. The maximum value is observed at the acquisition of 7:30 am in VV and cross-pol, and the minimum occurs in the late afternoon in all polarizations when the VWC reaches its minimum value.

3.4. Impact of SCW on L-band backscatter

Fig. 5 provides insight into the quantitative change in backscatter due to surface canopy water. The $\Delta\sigma$ indicates the difference in backscatter between 6 am, when the vegetation is covered in dew (red) or dew and interception (yellow) and 9 am when the dew/interception has dissipated. Internal water content is mostly constant during this period as the presence of SCW supresses transpiration, and the difference in soil moisture, $\Delta\theta$, is negligible ($< 0.01 m^3/m^3$). Therefore, any difference in backscatter can be attributed to surface canopy water content. The presence of SCW generally leads to an increase in backscatter, so $\Delta\sigma$ is generally positive. The average value of $\Delta\sigma$ is 1.02 dB for co-pol and 1.27 dB for cross-pol but can reach up to 3-4 dB. This is consistent with values observed in other studies [12].Considerable variability is observed due to variability in SCW, as well as variation in the relative contribution of vegetation to total backscatter during the growing season. The decreasing trend in $\Delta\sigma$ from May 23 to June 1 is due to a decreasing trend in 6 am SCW. The amount of SCW on 23, 26, 28

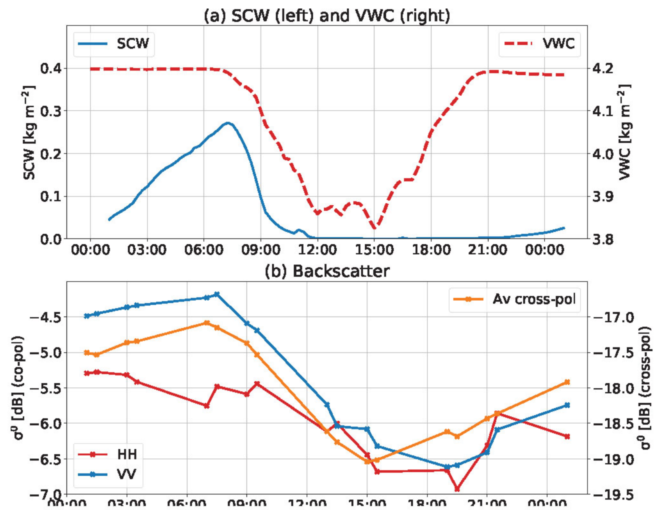

Fig. 4. Mean daily cycle of (a) surface canopy water (dew) and modeled VWC and (b) co- and cross-polarized backscatter for just 3 days without precipitation between June 2 and June 13.

and 31 May was 0.6, 0.31, 0.2, and 0.058 $kg\ m^{-2}$ respectively.

3.5. Effect of Surface canopy water on relationship between backscatter and biophysical variables

Given that the probability of SCW is much higher before dawn than later in the morning (Fig. 2), and that the presence of SCW influences backscatter (Fig. 3), it is hypothesized that acquisition time is an important consideration for the retrieval of biophysical parameters in agricultural monitoring. Fig. 6 shows the relationship between backscatter and three biophysical variables. Blue points correspond to data collected at 6 am, while red points correspond to the first backscatter data collected after dew had dissipated (generally between 10 am and 12 pm). Note that the Spearman correlation coefficient is always higher (up to 0.33) when the radar data are collected in the absense of SCW. The relationship between radar data and the biophysical variable of interest depends on whether or not SCW was present. Among the crop biophysical variables, the impact of SCW is greatest in LAI. Among the polarizations, HH is least influenced by SCW. Therefore, the presence of surface canopy water has a confounding effect on the retrieval of biophysical variables. For the retrieval of VWC, dry biomass and LAI, acquisitions in the late morning are more strongly correlated with the biophysical variables. The difference in variability is likely due to the varying amount of dew and its influence on backscatter.

4. CONCLUSION

Surface canopy water and internal VWC have daily cycles that are driven by local hydrometeorological conditions and root zone soil moisture availability. Backscatter in all polarizations is highly affected by these daily cycles. In the morning, L-band radar backscatter observations in the presence of dew are 2-3 dB higher than those made when the dew has dissipated and the internal water dynamics in fully grown corn can change a radar backscatter around 2 dB. The parameters of the relationship between backscatter and biophysical variables of interest are different for dry and wet vegetation and the correlation coefficient between radar data and plant parameters is

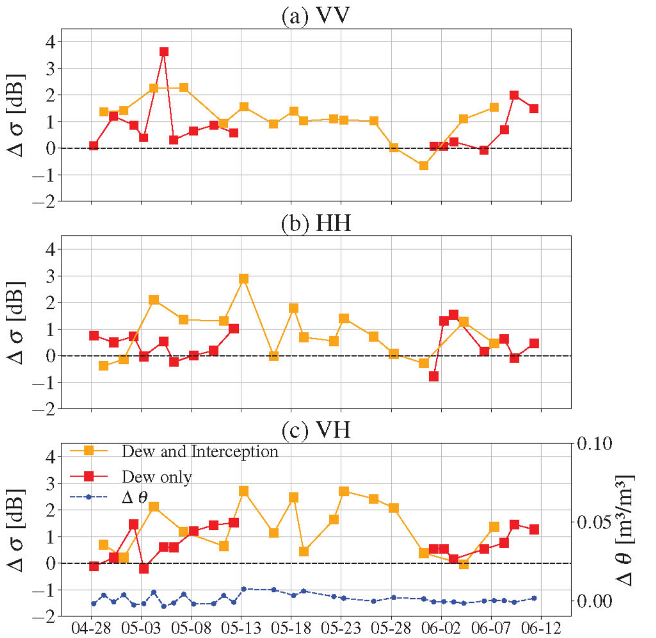

Fig. 5. Time series of difference in radar backscatter between wet and dry vegetation for (a) VV, (b) HH, and (c) VH polarization. Difference was computed by using radar data at 6 am (wet vegetation) and first radar data after 9 am when the surface of canopy was dry (dry vegetation). The blue dashed line shows the difference in surface soil moisture value between wet and dry vegetation.

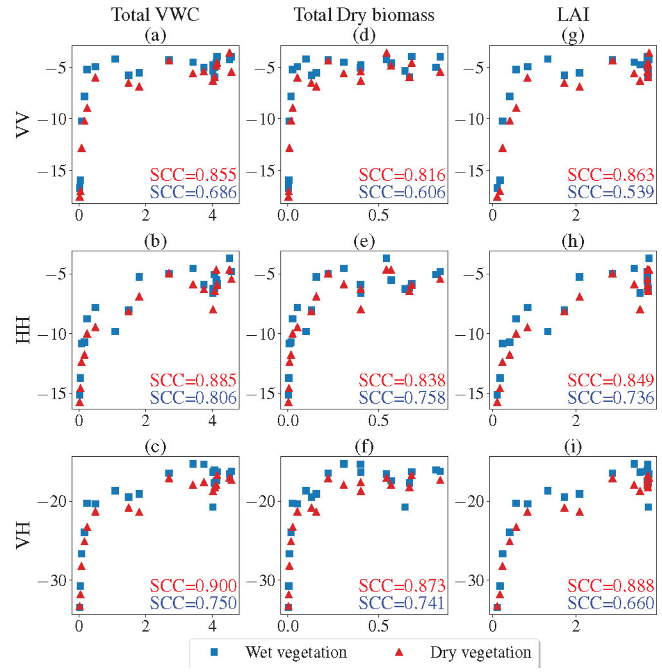

Fig. 6. The relationship between radar backscatter and measured total VWC, total dry biomass and LAI in the presence (red) or absence (blue) of surface canopy water. The corresponding Spearman Correlation Coefficients (SCC) are in the lower right corner.

up to 0.33 higher in the absence of dew. Choice of overpass time affects the probability of dew, and the strength of the relationship between backscatter and biophysical variables in agricultural monitoring. This should be taken into account in any vegetation applications when combining overpass times for a single mission, combining overpasses from multiple missions or selecting an acquisition time for future missions.

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