

Interactive comment on "Reconstructing Continuous Vegetation Water Content To Understand Sub-daily Backscatter Variations" by Paul C. Vermunt et al.

Reviewer comments in black

Reply to comments in blue

This research demonstrates the estimation of continuous vegetation water content (VWC) in corn crops at two research sites by adapting an existing method for measuring internal VWC in trees. Sub-daily VWC was successfully calculated based on the difference between modelled transpiration and sap flow rates at the base of corn stems and constrained and validated with destructive sampling. Second, the research demonstrates the effect of diurnal variations of VWC and dew on radar backscatter. The study is innovative and is a valuable contribution to the field as it provides new methods and insight in current questions in microwave remote sensing, such as the effect of internal VWC and surface canopy water on the radar signal. I highly recommend to publish the paper, but I have some minor comments.

Response: Thanks for the careful consideration of the manuscript and the constructive comments. Below we have addressed the comments in blue. The line numbers in our replies refer to the revised manuscript.

(1) I believe the data and methods can be described a bit better. If I understood correctly, backscatter data is only available for the 2018 campaign in Florida, but sub-daily destructive samples are only available for the 2019 campaign in the Netherlands. So in short, the method to calculate sub-daily VWC is developed and validated on the 2019 data and then applied to the 2018 data to assess the effect of VWC on sub-daily backscatter variations. I think the paper will be easier to follow if this is stated clearly in section 3. I would even suggest to split data and methods in different sections for clarity.

Response: We agree that the use of data from the two campaigns was not described clearly enough early in the paper, and that this could have led to confusion. Therefore, we have now addressed this in the last paragraph of the introduction. The specific sentences in the introduction now read: "An extensive data set from a field campaign in the Netherlands in 2019 was used to evaluate the adapted method against diurnal cycles of VWC obtained by destructive sampling. Finally, the technique was applied to reconstruct sub-daily VWC variability of multiple consecutive days from another field campaign in Florida in 2018. In this campaign, high temporal resolution tower-based polarimetric L-band backscatter was collected. The reconstructed VWC was used, together with simultaneously collected soil moisture, surface canopy water (SCW), to gain better understanding of what controls sub-daily backscatter behaviour.". Moreover, we reorganized the methodology section in such a way that the two objectives of this study and corresponding data sets used are clearly separated now. We repeated which data sets were used to address which objectives in the first sentences of the new Data and Methods section, which now read "Section 3.1 relates to the adjustments and data required to make the sap flow technique (section 2) applicable to corn. Data from a field campaign in The Netherlands in 2019 were used to evaluate the adjusted method. Section 3.2 relates to the methodology and data used from our field campaign in Florida in 2018 for interpreting sub-daily backscatter behaviour."

(2) Figure 2: make the colors more intuitive, either by making the colors an indicator for drought stress (e.g. brown/red), or otherwise a colormap according to date to make it easier to interpret.

Response: Done. We have changed the colors and used a colormap according to date.

(3) Section 3.2.1: It is unclear on which days the destructive samples were taken. It can be seen in fig-

ure 2 (but here there are only 7 days, whereas section 3.2.1 states 14 days?), but I think this information should be mentioned already here. To me it led to some confusion at line 230 in combination with section 3.2.2 where it states that because of power issues when measuring sapflow only three days have all data needed to estimate and validate VWC: July 25, Aug. 23 and 28. A table with an overview of days with destructive samples and sapflow data yes/no would be informative.

Response: We included a Figure in the revised version of the manuscript with an overview of the periods for which sap flow, ETo and sampled VWC are available: Fig. 1.

(4) Line 243: On July 25 all available data for the CDF-matching were used. Why? What is the difference with the other days?

Response: Each panel in Fig. 5 shows the best VWC estimate for the particular day, given the particular rescaling method (linear or CDF-matched). We considered the best VWC estimate the one which has the best fit, i.e. the smallest RMSE between observed and reconstructed VWC. On July 25, the lowest RMSE was found when the CDF-matching was performed with all available 15-minute observations for sap flow and ETo. For August 23 and 28, better fits were found when a smaller subset of data was used for CDF-matching.

(5) Line 277: "A sharp backscatter increase after rainfall was observed in all polarizations". Yes this seem true for those rainfall events where soil moisture is also increasing strongly. The event on June 12th seems different, where CW increases significantly, but soil moisture shows a very small response. Here VV, HH and crosspol backscatter drop strongly, and then go back to the level before the event, or get slightly higher. Can you explain what is happening here?

Response: Please see the zoomed-in situation of June 12 only in Figure 1 below. Actually, we do see that the backscatter increase in all polarizations perfectly corresponds to the increase in rainfall interception (SCW). The backscatter drop between 9:30 and 13:00 can be explained by a drop in VWC, which was clearly visible in all other days but June 12 (see Fig. 9 in the manuscript). It seems that the VWC reconstruction on June 12 was not that good. The fact that the backscatter returned more or less to the level before the event could be due to a combination of slight soil moisture increase, and refilling of the plant's internal water storage (VWC).

(6)Figure 8: maybe only show those days you actually used for the fit?

Response: We think it is valuable to show June 4, 5 and 6 as well in Figure 8 and 9. Despite that VWC reconstruction on June 5 and 6 was considered less reliable, the other data sets (soil moisture and SCW) give us valuable information about backscatter variations on these days. Besides, June 4 contains a dense, reliable data set, including two samples. Moreover, showing June 5 and 6 provides insight in which situations VWC reconstruction does not work well, which could aid improvements in future work.

(7) Figure 9: for the fit you consider the VWC of June 5 and 6 not reliable enough. But for fig 9 a and d are aggregated over 9 days. This means that you did use june 5 and 6 for figure 9, is this correct?

Response: This is correct. The reason why June 5 and 6 are included in Figure 9 is because we explicitly look

at the period midnight to early morning here. In this period, VWC is generally stable. We particularly do not trust the VWC reconstructions in the afternoon-evening on these days, because we see some physically implausible features in the time series there (see lines 315-318). But there is not much reason to doubt the estimated variability of midnight-morning VWC. Excluding June 5 and 6 here because of VWC would also exclude the valuable SCW, backscatter and soil moisture data. That is why we chose to not remove June 5 and 6 from the aggregated data plotted in Fig. 9 (a) and (d). For the regression, we actually needed reliable full days of data. The VWC reconstructions on June 5 and 6 could not meet that condition.

(8) Line 285: delete "the"

Response: Done

(9) Line 286: During the last four aggregated acquisitions... which are these?

Response: The acquisitions at 19:00, 19:30, 21:00 and 21:30. Added ... 'between 19:00 and 21:30' ...

(10) Line 295 and onward: where do the values for changes in soil moisture, VWC and SCW come from for typical dry days? Also the multiple linear regression to assess the effect of moisture stores on backscatter is somewhat unclear. I think it might be more sophisticated to do this calculation with all units in mm? It needs an assumption on soil depth and penetration depth, but it should be possible. If not, I think the statements in line 295 and onward are confusing, since sensitivity and mentioning e.g. "three times more sensitive" is not really the right term here since they units are not the same. Maybe change to something like: Note that the coefficients from soil and vegetation water stores (Table 1) have non-homogeneous physical units. Nonetheless, it shows us that for a typical dry day during the campaign of 2018, e.g. such as June 9th, soil moisture reduced with $0.02 \text{ m}^3\text{m}^{-3}$ and that this translates to a -0.5, -0.8 and -0.8 dB change in VV, HH and cross-polarized backscatter. During the same day VWC changed with 0.5 kg m^{-2} , which would translate to a change of 1.5, 1.1 and 1.2 dB. This shows us that typical diurnal variation in VWC leads to a three times higher change in VV-polarized backscatter than a typical diurnal change in soil moisture.

Response: The suggested text that the reviewer gives entails exactly what we tried to say. Therefore, we adjusted the text in the manuscript in lines 352 - 359, which now read: "Nonetheless, these coefficients indicate that for a typical dry day during the campaign of 2018, e.g. June 9th, the soil moisture reduction of $0.015 \text{ m}^3\text{m}^{-3}$ translates to a -0.4, -0.6 and -0.6 dB change in VV, HH and cross-polarized backscatter, respectively. During the same day, VWC changed with 0.5 kg m^{-2} , which would translate to a change of 1.5 dB (VV), 1.2 dB (HH) and 1.2 dB (cross). This indicates that on this typical dry day, a diurnal variation in VWC leads to an almost four times higher change in VV-polarized backscatter [dB] than a diurnal change in soil moisture does. On the same day, the changes in HH- and cross-polarized backscatter [dB] were two times higher for the diurnal VWC variations than for the soil moisture drydown."

(11) Figure 10 is not discussed much in the text. It shortly states that the effect of SCW on backscatter is underestimated based on Fig. 10, but more explanation here would be good.

Response: Addressed in lines 360 - 366, which now read: "Fig. 12 presents the results of using the regression coefficients (Table 2), and the time series of VWC, SCW and soil moisture, to describe diurnal variations in backscatter. Each day is constrained by the first radar observation of the day, at 01:00. Note from the R^2 values in Table A4 that 68-71% of the variance in backscatter is explained by the three pre-

dictors. The P-values for SCW are always higher than those for VWC and soil moisture. Nonetheless, with the exception of the SCW coefficient in the case of HH-backscatter ($P > |t| = 0.286$), all P values are < 0.05 , indicating statistical significance. However, note from Fig. 12(a) and (c) that the observed nocturnal backscatter increase as a result of dew is barely visible in the calculated backscatter. This suggests that the regression underestimates the effect of dew on backscatter.”

(12) I suggest to split section 5.1 in two at line 330. One deals with the development and validation of the method with in situ data. The second part is applying the method to a longer period and a different region.

To make a distinction between the two parts, we added a blank line. Besides, we changed the first sentences of each parts, which now read: ”We tested the potential of a non-destructive sap flow approach to estimate sub-daily VWC variations in corn with data from our 2019-campaign....” (line 372-373) and ” When the methodology with CDF-matching was applied to the 10-day period from our 2018 campaign, ... ” (line 399).

(13) Line 310: what about August 23rd?

Response: See the evaluation of August 23rd in lines 385-387 and 390-396 of the revised manuscript.

(14) Line 352: Also here, i think using ”1.5 to 3 times more sensitive” is not the right wording.

Response: Addressed this in lines 419 - 421, which now read ”Our regression analysis suggested that, on a typical dry day, the diurnal cycle of VWC led to a two (HH- and cross-pol) to almost four (VV-pol) times higher change in backscatter than the soil moisture drydown did.”

(15) Line 366 and onward: make more clear in the text what the results are from your study. Now it is hard to discern if these results are from another study or yours.

Response: Added references to Table 2 and Figures 9, 10 and 11 to make this clearer.

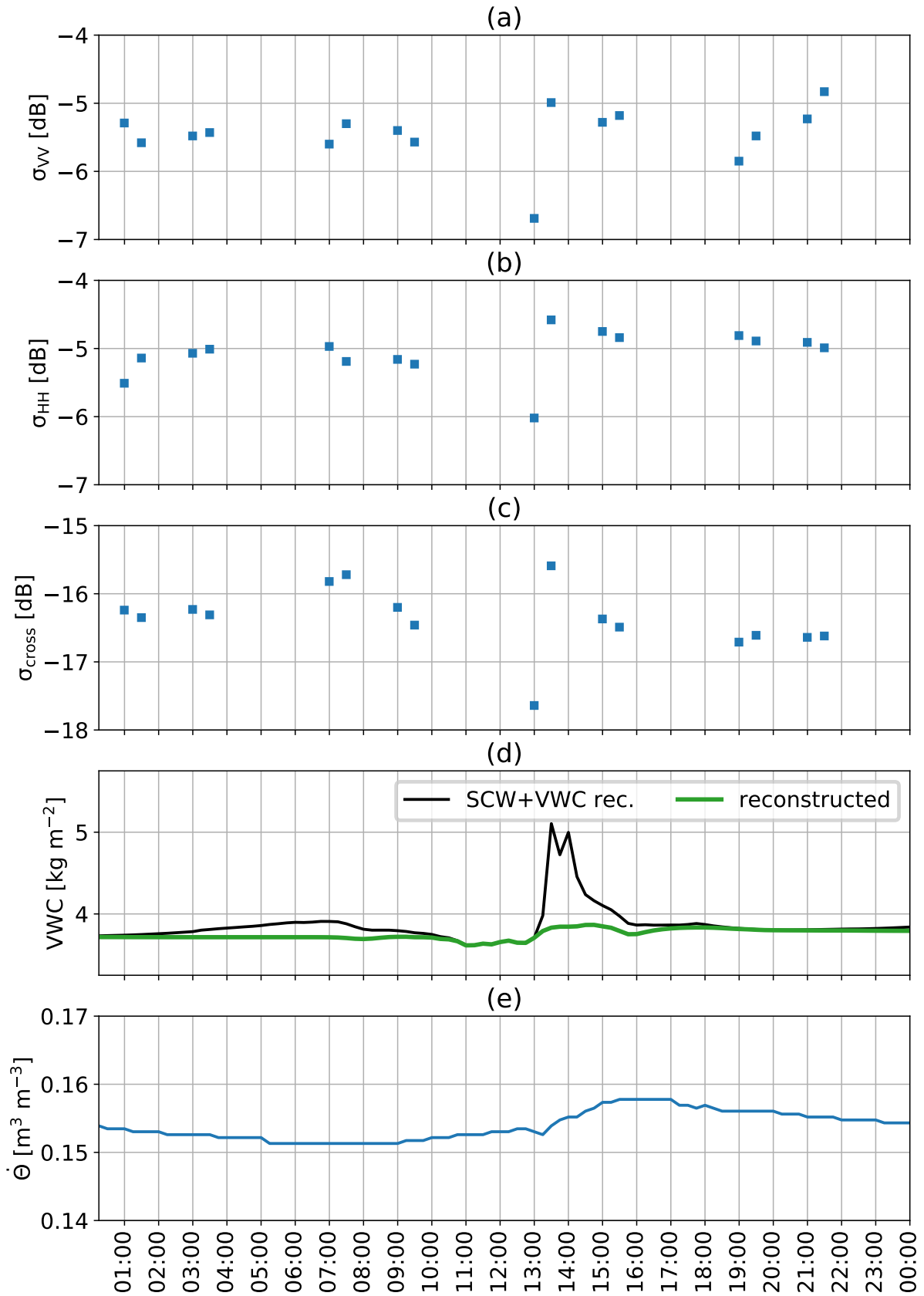


Figure 1: Full polarimetric L-band backscatter and separated effects for a June 12 (2018), with (a) VV-polarized scattering coefficient, (b) HH-polarized scattering coefficient, and (c) averaged VH and HV-polarized scattering coefficients, (d) reconstructed VWC and total canopy water, which is the sum of reconstructed VWC and SCW, and (e) soil moisture at 5 cm depth.