Author's response to Reviewer #2

Thank you very much for the constructive review of our manuscript, as well as for recognizing this work and helping us improve it through valuable comments and suggestions throughout the manuscript. We carefully considered all the comments and proposed revisions for the manuscript accordingly. We address the reviewer's general, specific, and technical comments below. The reviewer's comments are given in italics, our responses in blue.

The paper does exactly what the title suggests, i.e. evaluates GNSS-T VOD sensitivity to plant water dynamics, rainfall interception and dew in a coniferous forest. The authors conclude that, at this site, GNSS-T VOD can be related to interception amounts, that nightly dew amounts estimated from GNSS-T VOD were plausible but that diurnal plant water storage variations at Tharandt were too close to the estimated noise floor to be detectable. GNSS-T VOD is an increasingly popular tool in biogeosciences, and the network of installations is growing. The analysis is limited to a single stand in Tharandt. However, it would be very challenging to conduct and report such a detailed analysis at many sites in a single manuscript. Furthermore, the methodology itself is a key contribution. This kind of analysis and methodological development is essential to ensure that GNSS-T VOD observations are understood before they are used in applications, so the outcomes of the study should be of interest to the readership of BG. The manuscript is generally well structured. The abstract provides a concise and clear summary. The language is fluent and precise, though it could be clearer in places. A strength of the manuscript is the thoughtful and creative approach to quantifying the water storage terms.

General comments

RC#2.G1 *A limitation of the manuscript is the degree to which the results depend on the validity of the model for storage change, or relative storage index. In addition to the potential scale mismatch between the sap flow measurements of uptake and the transpiration estimate from the CanWat model, there is the uncertainty in T itself. The manuscript would be strengthened by a validation of the method outlined in 2.6.1 to account for its influence on uncertainty in the storage terms (Si, Sd, Sp).*

Please see our responses to RC#2.S4 and RC#1.G2. The uncertainty in T can propagate to Sp and to our conclusion on the sensitivity of VOD to plant water content. Given the wide validation of the CanWat model in the literature and the error propagation for Si we added in response to RC#1.G2, we are confident that any remaining error will not change the conclusions.

RC#2.G2 *In addition, the description of the Sp quantity is quite confusing and difficult to follow. The conclusions in terms of interception and dew are quite clear but an improved description of the Sp-related terms would make this aspect easier to follow and accept. Finally, the authors should discuss the uncertainty and limitations of the models and assumptions described in Section 2 on the results and conclusions.*

Please see our response to RC#2.S6 where we address this question in more detail. We agree that Sp is hard to read and will add a clearer interpretation in the revised manuscript. We will also discuss the uncertainty and limitations of the Section 2 models and assumptions in the results and conclusions.

Specific comments

RC#2.S1 *A clearer description of some critical details of the data processing need to be included. They are directly relevant to the assumptions made, the interpretation of the results and the conclusions drawn. In particular, the calculation of the baseline per satellite and sky sector (line 172).*

We aimed to include all relevant processing details and are glad to add any specific point the reviewer finds missing. Regarding the GNSS-T VOD normalization, we agree with the reviewer that the calculation of per-satellite baselines as a novel approach is not formally described but would be helpful for the best possible understanding of the method. Therefore, we will add the details of the baseline calculation per satellite and sky sectors in the appendix, following Humphrey and Frankenberg (2023) with our per-satellite modification:

Humphrey and Frankenberg (2024) form:

$$VOD^{\text{normalized}}_{\varphi_i,\theta_i,t_i} = VOD_{\varphi_i,\theta_i,t_i} - VOD^{\text{mean}}_{\varphi_i,\theta_i} + VOD^{\text{mean}}_{\text{global}}$$

This manuscript:

$$VOD^{\text{normalized}}_{\mathbf{SV},\varphi_i,\theta_i,t_i} = VOD_{\mathbf{SV},\varphi_i,\theta_i,t_i} - VOD^{\text{mean}}_{\mathbf{SV},\varphi_i,\theta_i} + VOD^{\text{mean}}_{\text{global}}$$

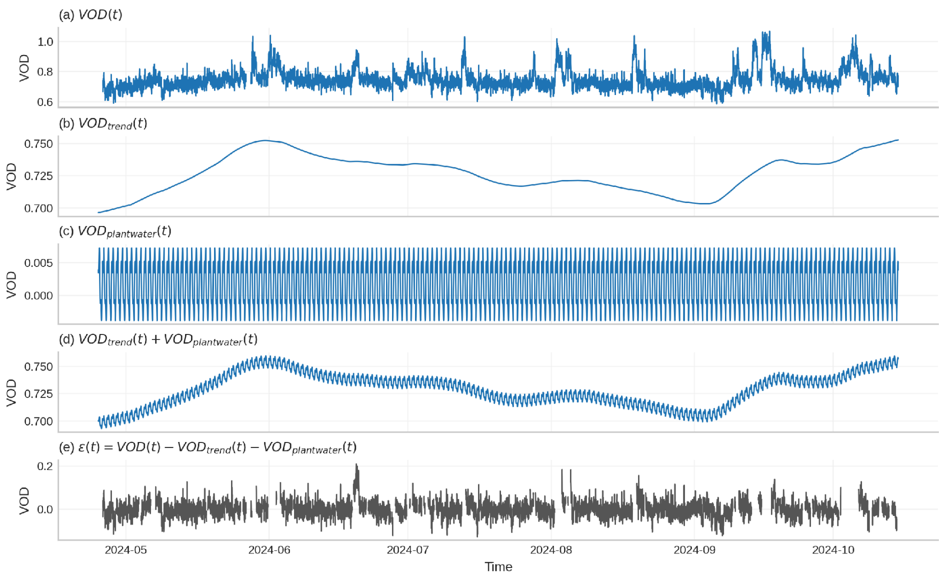
where VOD(φ,θ,t) is the raw VOD time series per azimuth (φ) and incidence angle (θ), VODmean(φ,θ) is the sky-sector mean VOD (biomass offset), VODmean(global) is a single scalar value of the mean hemispheric VOD. Finally, VODnormalized(φ,θ,t) is the biomass-corrected VOD time series (Humphrey and Frankenberg, 2024), first equation. We established the novel approach to perform those corrections per satellite vehicle (SV), second equation.

RC#2.S2 *A key assumption in this study is that noise related to the receiver and wave transmission is purely random, and that all deterministic noise is due to satellite tracks and canopy distribution. The authors should demonstrate that this is the case for their receiver and installation.*

While we aimed to describe satellite tracks and canopy distribution as deterministic components of VOD noise, we did not exclude that there might be more deterministic noise in the remaining noise. However, the distinction between deterministic and random is still helpful to separate the error sources. We correct for one deterministic term, orbit-induced noise, as a part that can (approximately) be explained. The remainder noise is collapsed into δ, which contains the random noise from hardware and wave propagation and may still include residual deterministic noise. δ is therefore a measure of effective noise that includes parts of both terms. We hope we can clarify this point. To ensure that this aspect is better addressed in the manuscript, we will add a sentence to section 2.3. If there are more questions or comments on this topic, we are very happy to discuss.

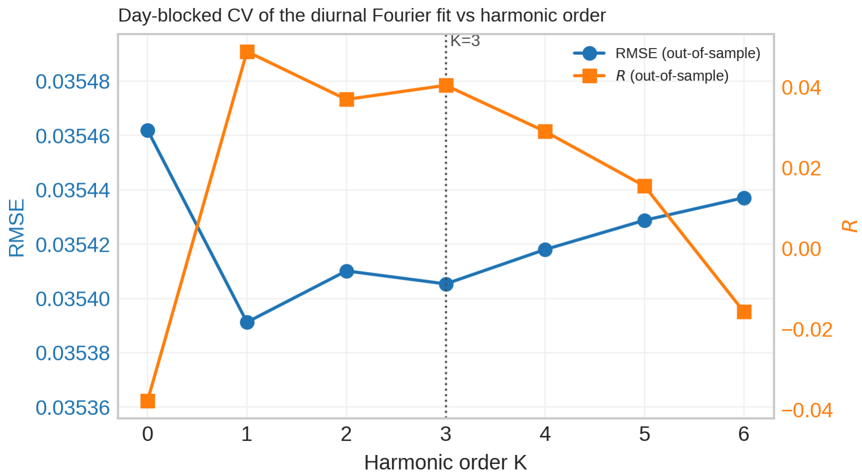
RC#2.S3 *A stationary diurnal Fourier series is fit on dry periods as a rough proxy for plant-water dynamics. The details of this fit and its validity are very relevant for Equation 5, and the calculation of the noise threshold. Please provide the details of this fit in the Appendix. The validity of the fit should be demonstrated, and its impact on the noise threshold should be discussed, as well as the implications on the conclusions regarding detectability. In particular, it is unclear if this term has been removed from the VOD(t)* series used to assess the detectability of Sp.*

The reviewer is right that the diurnal component of VOD is highly relevant for the validity of the noise threshold. We fit a Fourier series on VOD(t) over all daily subsets to estimate the mean diurnal cycle, which we call VODplantwater(t), using order k = 3, no. of sine waves, to keep the model simple. Figure RC#2.Fig1 shows the current signal decomposition, with VODplantwater(t) as the repeating mean diurnal series in panel c.



RC#2.Fig1. *GNSS-T VOD signal decomposition to estimate the residual noise ε(t). The trend is calculated from a 14-day running median after masking out dew and interception periods. The plant-water series is the result of a diurnal Fourier fit at 3rd order (3 additive sine waves).*

Validity of the fit. In response to the reviewer, we cross-validated the fit with a blocked k-fold validation across k = 0 to 6. The diurnal component explains only a negligible fraction of the dry-period residual variance out of sample ($R^2 \leq 0.24$ %, RC#2.Fig2), with no meaningful improvement beyond k = 3. This agrees with our finding that VOD is not sensitive to diurnal changes in plant water at this site (Fig. 8).



RC#2.Fig2. *Day-blocked cross-validation of the diurnal Fourier fit of VOD against harmonic order k. RMSE and Pearson R are out-of-sample scores. Method: We split the dry-period days into five random folds, fit on 4/5 and predict the held-out ⅕ and calculated RMSE and R, average across folds, and repeat for k = 0 to 6 to check whether more harmonics improve prediction.*

Impact on the noise threshold. Because the diurnal component is very small, including VODplantwater(t) in Eq. 5 is practically negligible and its error propagation into ε(t) is very weak. We nevertheless kept the term to retain physical interpretability of longer-term trends (phenology, dry-downs) and diurnal hydraulic variability, in line with Schellenberg et al. (2024). We are equally happy to remove it to reduce complexity, whichever the reviewer prefers. If kept, we will state that it was negligible here but retained for interpretability, and place RC#2.Fig1 and RC#2.Fig2 in the supplement.

Removal from VOD(t)*. We did not use the noise-corrected VOD(t) in the rest of the paper, including the comparison with Sp (Fig. 8). We used the main VOD(t) series instead, in this way no diurnal component is imposed. We will state this more clearly in Sect. 2.7.

RC#2.S4 *A substantial part of the analysis relies on estimates of canopy water storage Si, and transpiration T from the CanWat model. It is stated in line 216 that this model has been applied at Tharandt and provide a reference, but the authors should include relevant details of the model validation. In particular, the uncertainty in the Si and T estimates should be included in Section 2, and taken into consideration in Sections 3 and 4.*

The reviewer is right that the uncertainties from CanWat have not been well described and propagated as uncertainties of the VOD-Sp relationship in the manuscript. Since reviewer #1 has a similar comment, we discuss the uncertainties in Si are discussed in our response to RC#1.G2, which we will implement as uncertainty in the parameter b. Regarding transpiration: In CanWat, transpiration is modelled in a Penman-Monteith framework with a resistance calculation based on Jarvis et al. (1976) and Stewart (1988). These relationships were parameterised with eddy-covariance data from Tharandt and evaluated in several studies, mostly grey literature (Peters et al., 2003; Queck, 2004; Pruskowsky et al., 2005; Kunath, 2015; Fischer et al., 2023). CanWat was developed over an extended period of interception and evaporation measurements (see RC#1.G2), presented at the DACH conference (Queck, 2025), and in Fischer et al. (2025). In Fischer et al. (2025) it was used as a one-layer model (Appendix A, "Model of total evaporation"), where their Fig. 2 shows an evaluation against water-balance measurements from in-canopy rainwater collectors (interception chutes) which yielded R^2 of > 0.85. From the latter study, we used the parameters including leaf width, stomatal conductance, and maximum interception storage capacity for the Penman-Monteith framework. Therefore the confidence in the validity of T is high. Still T is associated with an error that we cannot easily quantify since our model was not simultaneously validated against EC measurements. Instead, we provide indirect evidence by showing that the plant flux is associated with soil moisture variability and dry-downs (Fig 3). To make this evidence more accessible to the reader, we will add one sentence in L330 to make the connection with ΔSp and Fig 3.

RC#2.S5 *Lines 243-245 are unclear. First it is stated that b is an effective parameter integrating over the distribution of GNSS-T incidence angles. Then it is stated that the incidence angle is constant. Please clarify, connecting these statements to how VOD at any timestep is obtained by aggregating data in space (including across incidence angles) and time.*

The paragraph is indeed inconsistent about incidence angles. We meant that elevation angles are static per satellite but effectively change as the satellites move. We will change the paragraph from *"This depends on canopy structure, wavelength, and incidence angle; the latter two are constant in GNSS-T. In our case, the fitted slope is the effective bulk b-parameter that integrates over the distribution of GNSS-T incidence angles (Van de Griend and Wigneron, 2004)"* to *"This depends on canopy structure, incidence angle, and wavelength (Van de Griend and Wigneron, 2004); the latter is constant across bands GNSS-T. The fitted slope is the effective bulk b-parameter that integrates over the incidence angles observed per satellite in time."*

RC#2.S6 *Figure 8 and related discussion: How should Sp,noc values be interpreted? "Sp is a dimensionless quantity, resulting from the integration of percentages of fluxes". "Sp is normalized against the pre-event baseline value". It is difficult to follow from Section 2 what this quantity represents or how it has this range of values.*

We agree that ΔSp,noc is not an easy variable to interpret. It is calculated from the flux ΔSp, where ΔSp = 100 % means the plant water flux is entirely dominated by uptake and ΔSp = −100 % entirely by transpiration, based on transpiration and sapflow data. This is a ratio of fluxes. We integrate it (Eq. 12) into a relative storage index for total changes in plant storage, which is unbounded and can take values in (-Inf, Inf). Because Sp results from several transformation steps, the value itself cannot be interpreted quantitatively easily. We therefore encourage the reader to read it qualitatively, since no physical meaning follows from a single value of Sp,noc. To capture the changes over the day, we normalise it against a pre-dawn mean (Eq. 17), so each day starts at zero and on average decreases until 14:00 (Fig. 7). We take the reviewer's point and will clarify the caption of Fig. 8 and add a shortened version of this explanation at Sect. 2.6.1, L325:

“Sp is a dimensionless, relative storage index. Because it is the running integral of a flux ratio (ΔSp, bounded at ±100 %) rather than of a physical flux, it is itself unbounded ($Sp \in (-\infty,\infty)$) and accumulates through several transformation steps. A single value of Sp therefore carries no direct physical meaning and should be interpreted qualitatively, through its temporal dynamics, rather than quantitatively.”

RC#2.S7 *Lines 400-410: How is this connected to the use of the stationary diurnal Fourier series discussed in line 194? Am I correct to assume that this Fourier series is used purely to estimate the noise? How does it compare to the VOD*(t) in equation 16?*

Yes. The diurnal Fourier series is only used to define $\varepsilon(t)$ and is not used further, where VOD is shown as a function of the water components (see RC#2.S3). VOD*(t) is instead calculated from VOD (Eq. 3, geometric correction with the extended Humphrey and Frankenberg algorithm) and normalised against the pre-event value (rain-onset or transpiration-onset).

Technical corrections

We thank the reviewer for the careful technical reading and address all points below.

RC#2.T1 *Lines 69-76: It would be appropriate to acknowledge efforts prior to the publication of Humphrey and Frankenberg (2023) in which several groups in the USA and Europe provided proof of concept that GNSS transmissivity could be used to monitor attenuation due to vegetation using stationary and mobile sensors.*

Indeed, we will acknowledge the proof-of-concept work that preceded Humphrey and Frankenberg (2023). Rodriguez-Alvarez et al. (2012) estimated vegetation water content from GNSS signal attenuation, Liu et al. (2017) predicted boreal forest attributes from GNSS signals at low cost, and Camps et al. (2020) estimated L-band VOD from transmitted GNSS signals from a single dual-pol antenna, relating it to NDVI and a tau-omega structural parameter. Zribi et al. (2017) further showed with low-cost GPS receivers that GNSS-VOD tracks daily VWC variations in a sunflower canopy with $R^2 > 0.9$ against destructive samples. We will add these at L69-76.

RC#2.T2 *Line 145: "... and three m coaxial cables" (?). Something is missing in this sentence.*

Corrected. The sentence now reads "… connected with 3 m coaxial cables to the receiver boards".

RC#2.T3 *Figure 1 caption: "... maximum extent ...".*

Corrected. The caption now reads "extent".

RC#2.T4 *Line 206-211: It is unusual to express VWC in mm. Please explain here that this is motivated by the use of VOD for interception, in which VWC refers to mm of interception rather than the more conventional (internal) vegetation water content which is generally expressed in kg m^{-2}.*

VWC is indeed commonly used for internal plant water. This is exactly why we refer to the literature that proposed the linear VOD-VWC relationship through b, and extend it by assuming that surface water on the canopy attenuates the microwave signal in a similar way to internal water. This assumption leads to Eq. 8 (alt) at L242. See also RC#2.T6 for backing for this assumption. kg m2 is equivalent to mm for water, and consistent with meteorological quantities used throughout the manuscript. We, therefore, decided to follow this convention.

RC#2.T5 *Line 204: "To express the threshold metric in mm, so that it might be compared to interception amounts, a linear model is used:".*

We accept the reviewer's suggested rewrite of this sentence, which is easier to read. Thank you.

RC#2.T6 *Line 207: the VOD = b·VWC relationship of Jackson and O'Neill (1990) was obtained for internal vegetation water content of a growing crop, changes in which were primarily due to biomass increase* *associated with growth. There is an implicit assumption in Line 207 that the same relationship applies without reservation to free water on the surface of the canopy. Acknowledge and justify this assumption, even if it is just a necessary, pragmatic one.*

Water in the canopy can be differentiated into bound water, which is chemically held to the organic material, and free water, which is either free within the plant tissue or present as surface water on the leaves. Ulaby and El-Rayes (1987) show that bound and free water differ in their dielectric behaviour, and therefore in their attenuation properties. They also show that the bound-water volume fraction rises steeply at low moisture but levels off and approaches a plateau as the leaves get wetter (Fig. 5). Romanov (2025) shows that the slope of VOD against VWC becomes non-linear when the ratio of bound to free water changes. Assuming the trees at Tharandt did not suffer excessive drought stress, we can therefore assume the bound-water fraction stays stable, so that variability in VOD reflects the absolute water content, whether free or bound, including surface water. This is certainly an important aspect, is very understudied but potentially very important. Thus, motivates further study, especially for GNSS-T VOD. We will add this assumption as well as our justification in line 207.

RC#2.T7 *Line 291: Should this say crown? The later discussion suggests that the VOD is also sensitive to water in the stem. Please clarify/correct.*

The reviewer is right. We mean the total tree water content. There is evidence that GNSS-T VOD varies with the water content of the tree, but validation data at sub-daily scales is currently missing. We will rephrase L291 accordingly.

RC#2.T8 *Section heading 2.6.1: "Dynamic plant water (or storage) proxy"?*

We will rename the Section 2.6.1 heading to "Dynamic plant water proxy".

RC#2.T9 *Line 337: "As an alternative".*

Corrected as suggested.

RC#2.T10 *Line 393: "In a comparison maximum-change framework" (?).*

We removed "In a comparison maximum-change framework", as it is not necessary.

RC#2.T11 *Line 395: ". However, due to …".*

Corrected.

RC#2.T12 *Table 3 caption: "used for estimation of the …".*

Corrected. The caption now reads "used for estimation of the …".

RC#2.T13 *Line 405: What is meant by baseline-normalized here? If you just mean normalized according to equations 16 and 17, it would be better to avoid the term baseline to avoid any confusion between this and the baseline correction mentioned in line 170.*

We agree and will rename “baseline-normalized” to “normalized” to avoid confusion with the baseline correction at L170.

RC#2.T14 *Lines 208-209 [corrected to 408-409, the authors]: Should the b in brackets be L?*

Thanks a lot for finding this important typo. Yes, the baseline length is L, not b.

RC#2.T15 *Line 431: "… influence of the spatial domain is obvious …".*

Corrected as suggested.

RC#2.T16 *Line 528: Re-write sentence.*

We rewrote the sentence for clarity: "Dew (ΔSd) is harder to detect at 30 min resolution, where only 23.3 % of cases exceed δ3dB. Detectability rises to 34.9 % when VOD is averaged to 6 h intervals (Table 6); however, this requires dew to be present through this interval which is an impractical constraint to the method. The largest dew amounts, around 0.8 mm, are readily detectable (Fig. 9). We conclude that, because dew is a small flux, VOD needs further noise reduction, at best without reducing the temporal intervals, to detect most dew occurrences."

RC#2.T17 *Line 531: "This, however, contrasts empirical observations shown before". Correct grammar, but also specify the empirical observations to which you refer.*

We corrected the grammar and now specify the reference. The empirical observations are those in Fig. 8, on the sensitivity of VOD to plant water changes under the transpiration forcing during the day.

RC#2.T18 *Figure 8, caption: Where is the *dry (wet canopy) on this figure?*

The label "*dry (wet canopy: 2 dry hours before onset of rain)" is a leftover from an earlier version of the figure. We will remove it from the caption. Thank you.

RC#2.T19 *Line 548 and line 644: The expected range of b values from the cited papers refers to the relationship between VOD and (internal) VWC. While the values may be similar, there is no reason to assume they are expected.*

It is true that reported values of b refer to the VOD-VWC relationship. Since we assume similar attenuation properties of bound and free water (see RC#2.T6), we expect that the b holds for internal and surface water. We find it, therefore, appropriate to at least compare the magnitude to b with literature values. We will add a notion about the bound-free water ratio assumption in L548 to clarify this point.

RC#2.T20 *Line 551: b is an effective parameter in general.*

Indeed, b is always an effective parameter. We change the sentence accordingly from

“Still, b is an "effective" parameter at GNSS footprint scale, integrating structural properties of the canopy and the biomass changes into a bulk coefficient.”

to

“Still, b integrates structural properties of the canopy into an effective coefficient at GNSS footprint scale.”

RC#2.T21 *Line 638: "bridge the gap".*

Corrected as suggested.

RC#2.T22 *Line 641: What is storage in this sentence? Are internal and surface water storage lumped together and assumed to be equivalent?*

Yes, internal and surface water storage are lumped. We will change "… to translate the VOD noise floor into an equivalent water-storage detectability threshold" to "… into an equivalent water-storage detectability threshold for surface and internal water storage".

References

Camps, A., Alonso-Arroyo, A., Park, H., Onrubia, R., Pascual, D., Querol, J., 2020. L-Band Vegetation Optical Depth Estimation Using Transmitted GNSS Signals: Application to GNSS-Reflectometry and Positioning. Remote Sensing 12(15), 2352. https://doi.org/10.3390/rs12152352

Fischer, S., Moderow, U., Queck, R., Bernhofer, C., 2023. Evaporation of intercepted rainfall – Comparing canopy water budget and energy balance related long term measurements at a Norway spruce site. Agricultural and Forest Meteorology 341, 109637. https://doi.org/10.1016/j.agrformet.2023.109637

Fischer, S., Queck, R., Bernhofer, C., Mauder, M., 2025. Quantifying evaporation of intercepted rainfall: a hybrid correction approach for eddy-covariance measurements. EGUsphere 1–33. https://doi.org/10.5194/egusphere-2025-2118

Guerriero, L., Martín, F., Mollfulleda, A., Paloscia, S., Pierdicca, N., Santi, E., Floury, N., 2020. Ground-Based Remote Sensing of Forests Exploiting GNSS Signals. IEEE Transactions on Geoscience and Remote Sensing 58(10), 6844. https://ieeexplore.ieee.org/document/9044645/

Humphrey, V., Frankenberg, C., 2023. Continuous ground monitoring of vegetation optical depth and water content with GPS signals. Biogeosciences 20, 1789–1811. https://doi.org/10.5194/bg-20-1789-2023

Jarvis, P.G., Monteith, J.L., Weatherley, P.E., 1976. The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Philosophical Transactions of the Royal Society of London. B 273, 593–610. https://doi.org/10.1098/rstb.1976.0035

Kunath, M., 2015. Räumlich hochaufgelöste Untersuchung des Interzeptionsprozesses in einem Fichtenaltbestand (Diploma Thesis). TU Dresden, Dresden.

Liu, J., Hyyppä, J., Yu, X., Jaakkola, A., Kukko, A., Kaartinen, H., Zhu, L., Liang, X., Wang, Y., Hyyppä, H., 2017. A Novel GNSS Technique for Predicting Boreal Forest Attributes at Low Cost. IEEE Transactions on Geoscience and Remote Sensing 55(9), 4855. https://ieeexplore.ieee.org/document/7987712/

Peters, R., Queck, R., Bernhofer, C., 2003. Modellierung der Transpiration auf Basis mikrometeorologischer Verdunstungsmessungen, in: Bernhofer, C. (Ed.), Flussbestimmung an komplexen Standorten, Tharandter Klimaprotokolle. TU Dresden, pp. 79–98.

Pruskowsky, I., Queck, R., Bernhofer, C., 2005. Modelling the deposition of nitric oxides into a spruce stand (Tharandt Forest). Meteorologische Zeitschrift 14, 123–127. https://doi.org/10.1127/0941-2948/2005/0012

Queck, R., 2004. Fraktionierung und zeitliche Differenzierung von Depositionsraten in Waldbeständen, Tharandter Klimaprotokolle. TU Dresden.

Queck, R., 2025. CanWat - A Tool for Investigating Rainfall Interception with high spatial Resolution. Presented at the DACH 2025, Bern. http://dx.doi.org/10.13140/RG.2.2.33956.59529

Rodriguez-Alvarez, N., Bosch-Lluis, X., Camps, A., Ramos-Perez, I., Valencia, E., Park, H., Vall-llossera, M., 2012. Vegetation Water Content Estimation Using GNSS Measurements. IEEE Geoscience and Remote Sensing Letters 9(2), 282. https://ieeexplore.ieee.org/document/6034516/

Romanov, A.N., 2025. Vegetation optical depth taking account of dielectric characteristics of water in living trees. Remote Sensing Letters 16(4), 354–364. https://doi.org/10.1080/2150704X.2025.2463697

Schellenberg, K., Jagdhuber, T., Chaparro, D., Binks, O., Hellwig, F., Dubois, C., Kurum, M., Camps, A., Hartmann, H., Schmullius, C., 2024. Estimating Canopy Interception Water Storage with GNSS-Transmissometry. IGARSS 2024, 4507–4510. https://doi.org/10.1109/IGARSS53475.2024.10641964

Stewart, J.B., 1988. Modelling surface conductance of pine forest. Agricultural and Forest Meteorology 43, 19–35. https://doi.org/10.1016/0168-1923(88)90003-2

Ulaby, F.T., El-Rayes, M.A., 1987. Microwave Dielectric Spectrum of Vegetation - Part II: Dual-Dispersion Model. IEEE Transactions on Geoscience and Remote Sensing GE-25(5), 550–557. https://doi.org/10.1109/TGRS.1987.289833

Van de Griend, A.A., Wigneron, J.-P., 2004. The b-factor as a function of frequency and canopy type at H-polarization. IEEE Transactions on Geoscience and Remote Sensing 42(4), 786–794. https://doi.org/10.1109/TGRS.2003.821889

Zribi, M., et al., 2017. Low-Cost GPS Receivers for the Monitoring of Sunflower Cover Dynamics. Journal of Sensors 2017, 6941739. https://doi.org/10.1155/2017/6941739