

Reply to the comments of referee #1

We thank the reviewer for the thoughtful and constructive comments.

General Comments:

Pan et al. presented in the manuscripts (ms) a field experiment where they analysed the feasibility of multi-offset GPR to monitor the soil water dynamics in a sandy dune environment. The study is based on the idea that multi-offset GPR contains enough information to estimate the reflector depth as well as the water content above the reflector simultaneously.[...]

The written of the manuscript is improved in the revised paper. Thanks for the reviewer's suggestion.

Abstract:

In general, I do miss out some major findings in terms of hard numbers of hypothesis verified. To say that multi-offset GPR is a powerful tool for estimating the boundary layer depths and the water content above this layer is not enough [...]

Generally, we agree with the reviewer that the abstract did not completely include our major findings. The paragraph is rephrased. Indeed this method has been already demonstrated. However, to measure the rather small change of average or total water content within a layer during a short-duration infiltration event, the stability of the measuring procedure should be further explored. Particularly for a 2D heterogeneous soil, the capability of the multi-channel GPR to monitoring the redistribution of soil water content is of important for 3D soil hydrologic modelling.

Introduction:

(1) P8029 L3: please introduce TDR (time domain reflectometry): Additionally, Theta-Probe is only a brand name. [...]

Rephrased as "time domain reflectometry (TDR) and capacitance sensors".

(2) P8029 L11-13: weak sentence

Text is rephrased as "Geophysical methods for mapping the distribution of soil properties and soil water content at field scale are more and more popular".

(3) P8029 L17: should be Huisman et al. (2003a), Lambot et al. (2008), and Slob.....

Done.

(4) P8029 L28: Weak sentence.

Text is rephrased as "Differing from traditional on-ground GPR, off-ground GPR focuses on the surface reflection."

(5) P8030 L1: this is not fully correct. It measures the surface reflection coefficient (or backscattering coefficient) but is can also use the full waveform to draw information [...]

The sentence is deleted in the revised paper.

(6) P8030 L5: I do not believe that the papers listed up showed any soil water content profiles. Please check again.

The improper citation is corrected. But the paper by Minet et al. (2012) does demonstrate the retrieval of shallow vertical soil water content profiles with GPR and inverse modeling at the field scale (e.g. Fig. 7 in the paper).

(7) P8030: L27: it should be: ... would help to understand...

Done.

(8) P8030: L28: it should be: ... on crop growth...

Done.

Site description and measurements

(1) P8031 L7: it should be: ... of land area.

Done.

(2) P8031 L12-17: weak sentence

Text is rephrased as "At the study site, the surface soil texture consists of 82% of sand, 6% of

clay and 12% of silt according to field samplings. The water table (including the capillary fringe, same as following) was at about 1.7 m depth measured from drilling, and the measured water tables in two dug profiles (one is about 20 m away from the western border of the land, and the other one is about 25 m away from the southern border) nearby ponding waters were at around 1.9 m."

(3) P8031 L20: *do you come back to salinity later? If not please delete the information as long as it is not of any importance for the signal retrieved.*

We agree that the salinity information is not necessary. Delete in the revised paper.

(4) P8031 L28: *I would use the term soil layering instead of architecture.*

Done.

(5) P8031 L29: *referring to Fig. 1: maybe clearly indicate which reflection is clearly caused by stratigraphy. This would help the non GPR readers.*

Done.

(6) P8032 L25: *would be better to use drilled instead of conducted.*

Done.

Chapter 3.1:

(1) *This chapter needs some more information, especially for the non GPR specialists. Additionally, even if someone else already introduced the methodology [...]*

Done.

(2) P8033 L10: *please insert unit after depth d. This should be checked for the entire ms.*

Done.

(3) P8033 L11: *please introduce CMP*

Done.

(4) P8033 L14: *please add reference for the CRIM model.*

Done.

(5) P8033 L15: *please provide units for Theta (I know that it will be dimensionless but gravimetric water content will be also without any dimensions. [...])*

Done.

(6) P8034 L5: *please add references*

Done.

Result and Discussion:

(1) P8035 L3: *should be ... borehole sampling information as listed in Table 1 from seven....*

Done.

(2) P8035 L13: *how did you obtain the maps? Did you use ordinary Kriging? Otherwise you should have discrete block data and not a smooth map.*

The maps were produced with the contour function in Matlab, where it uses linear interpolation to smooth the filled color.

(3) P8035 L21: *as introduced by Pan et al. (2012)*

Done.

(4) P8036 L4: *is assessed by the data of the seven boreholes..*

Done.

(5) P8036 L28: *Again I would add the units to indicate that vol. water content is listed*

Done.

(6) P8037 L1: *and L2: same as above*

Done.

(7) P8037 L11-13: *I would not call it truth. Both are reliable but as mentioned above measured at different scales. [...]*

We agree that both values are reliable. But the uncertainty of the averaged soil water content from the seven TDR measurements would further increase due to the linear interpolation. While the value from the GPR measurement is directly measured without further input errors.

(8) P8037 L19: *what is significant? Are the differences between lines are significant? Did you performed a test on significance?*

Since our approach to estimate the errors was not correct and indeed greatly overestimated the true values. The reason for this is, that we erroneously gave the uncertainty estimate for an individual measurement, while the quantities shown in Fig 10 are indeed averages over a rather large ensemble. In the new Fig 10d (see modified figure below), the differences among the lines of the clay, the valley and the ridge at corresponding dates are all significant, which are analyzed with the t-test at a level of 0.05.

The sentence is rephrased as "The differences of water volume changes at different areas are statistically significant at a p-level of 0.05, however (Fig. 10d).".

(9) P8037 L23: *which amounts do you mean?*

Text rephrased as "The amounts of the soil water content and the total water volume".

(10) P8038 L7: *please provide units if it is vol. water content.*

Done.

(11) P8039 L2-L6: *This might be only a hypothesis but I would argue that the actual ET might be also wrong, especially if calculated by such a simple equation.*

We agree with the reviewer that the actual ET might be also wrong. Since no more data are available at the site, we can only use such a simple equation. Nevertheless, here the actual ET is just used as a reference. While our discussion is mainly based on the GPR data.

(12) P8039 L21-L22: *That's an assumption only. Do you have any data supporting the assumption?*

We have done near-surface soil texture analysis with some soil samples and a time series of TDR measurements at corresponding positions (see more detailed information in Pan et al. (2012a)). Text is rephrased as "evaporation is active, uniformly across the entire soil surface as analyzed by Pan et al. (2012a)".

(13) P8039 L22: *what do you mean by loss rate?*

The loss rate means the value of the soil water loss over a certain time period. Text is rephrased as "losing the same amount of water by evaporation would lead to a higher decrease of the volumetric water content over a ridge than over a valley".

(14) P8040 L3: *"various models in the laboratory" – what you mean? Hydrological models? If yes, why laboratory?*

That means hydrological models. "in the laboratory" is deleted.

(15) P8040 L3-L7: *what do you want to say by this general statement?*

The logic of description is rephrased in the revised paper.

(16) P8040 L8: *... uncertainty ... Please add references*

The sentence is deleted.

(17) P8042 L3: *I do wonder why you do not see the same pattern in crop growth and within the GPR maps shown in Fig. 5 and 9.*

We initially took some photos and planned to do image analysis. Unfortunately, the photo quality is not so good. Alternatively, we discussed the relation between the crop growth with soil water dynamics through comparing the pattern of the crop growth along the southern boundary with the observations from GPR in the section 4.2.2.

Conclusion:

The entire conclusion needs modification. At the moments it is somehow confusing and therefore weak

One sentence is inserted as "Considering the precision and the accuracy of the measured quantities and the deduced field-scale soil water dynamics in the 3D heterogeneous soil during a short-duration infiltration event, we conclude that this method is sensitive enough to capture the spatial structure of the changing soil water content."

Reference cited in this reply that are not listed in the submitted paper:

Pan, X., Klenk, P., Roth, K., Zhang, J., Huang, P., and He, D.: Multi-channel GPR to assess the influence of shallow structural heterogeneity on spatio-temporal variations of near-surface soil

