Author Response to *Interactive comment on "Reflection tomography of time-lapse GPR data for studying dynamic unsaturated flow phenomena" by Adam R. Mangel et al.*

This response is directed toward the comments left by Anonymous Referee #2, posted to the Hydrology and Earth Systems Sciences (HESS) discussion board for manuscript **hess-2018-230** on October 23, 2018.

First and foremost, the authors would like to thank Anonymous Referee #2 (AR2) for devoting time to reviewing our manuscript and for providing a critical review of the content. Below, the authors have outlined responses to individual comments made by the reviewer.

***AR2**: In section 2.2, line 128, authors mention that 101 CMPs were collected (between y=1m and y=3m). I think there must be a typo here. It should "COPs." Otherwise, it does not make sense. If the transmitter and the receiver have moved 2cm each time, you should have 51 profiles. If each one has moved 1cm at a time, then you will have 101 profiles. Please fix and/or clarify.*

Author Response: The discussion of the data collection geometry in the manuscript has been reviewed by the corresponding author and is correct. A common-midpoint profile (CMP) was collected at 101 individual points between y = 1 m and y = 3 m (see Figure 1f in the manuscript). To collect a CMP, the transmitter and receiver are expanded or contracted about a central point. The central point locations are spaced at 2 cm intervals along the line at x = 2 m over the distance of y = 1 to 3 m. Therefore, the total transect distance of 2 meters (3 m – 1 m) is covered in 100 steps of 2 cm increments. Counting the starting position, this calculates to a total of 101 CMPs.

Of course, you could rearrange the data to give you multiple common offset profiles across the tank. The number of COPs in this case would depend on the number of offsets collected in each CMP, which for this experiment was 84. These COPs, however, would be collected with significant temporal disparity such that the traces at either end of the COP would be separated in time by 3.9 minutes. This would distort the reflectors in the COPs due to the dynamic nature of the infiltration process being monitored. The COPs are of little value to our work, however, as they do not contain the reflector moveout relationships that are used to estimate wave velocities. Thus, we only collected data in CMP configurations.

***AR2**: It is mentioned that the flux is 0.125 cm/min, but the authors did not explain how uniform the irrigation was (inside the irrigation area).*

Author Response: Lines 104-105 of the manuscript mention heterogeneity in the applied flux. This may indeed be a factor in the heterogeneity of the wetting front, but we have gone through many iterations of the irrigation equipment to minimize the problem and have made progress in homogenizing the applied flux over a prescribed area. While we continue to work on this issue, it does not impact the validity of our results give that we do not fundamentally assume homogeneity of the infiltration flux across the tank for reflection tomography to be applicable. To the contrary, our GPR and moisture probe results are both consistent with some degree of variability occurring in the applied flux. For this work, we feel that homogeneous application of water at the surface is less important than the fact that we are able to discriminate a heterogeneous response, which is more representative of real systems and points to the capability of reflection tomography for measuring heterogeneous water distributions in the environment.

***AR2**: The moisture probes were situated 0.5 m away from the line of GPR scan. Unless, the irrigation was uniform, it does not make sense to compare the results of moisture content from the GPR scans to moisture content data from the probes. I guess, we assume the sand layer was homogeneous.*

Author Response: The sand layer is homogeneous, meaning that it is all the same sand, from the same company, and was packed into the tank in a uniform manner. However, homogenous systems can exhibit heterogeneous flow responses due to small variabilities in initial and boundary conditions or very minor contrasts in sorting at the grain scale. The overall agreement between the patterns of water content change observed in the reflection tomography and probe responses suggest that the general comparison between the datasets we performed is valid, though we agree with the reviewer that over analysis of the two data sets is not warranted given this limiting factor as well as the fact that the measurements represent different scales of investigation.

The moisture probes were located off the GPR transect to avoid backscattering or the transmitted signal that would interfere with analysis of the GPR wave velocities. Though this is not an ideal setup for comparison of the moisture probe data to the GPR estimated of water content, it was necessary to ensure that high-quality reflection tomography data could be collected.

AR2*: In line 183, it is mentioned that a refraction is also observed on the CMPs. Please discuss and explain why refraction happened in this case.*

Author Response: Refraction occurs in this case because a wet low-velocity layer is present above a dry high-velocity layer. Overall, the refraction is irrelevant to this work, but the authors point it out as a rarity in the simulated GPR data. The refraction is not observed in the empirical GPR data and warrants no further discussion.

AR2*: In section 4, line 225, the error was reported for water content near the edges of the advancing plume. Please explain how the errors were calculated considering the fact that the GPR scans were collected at fixed x=2.0 m and the probes are 0.5 m away from the line of scan. How did you calculate the water content error for the central area versus the edges of the plume. Please explain.*

Author Response: Errors in the estimates of water content are calculated by comparing the difference between the soil moisture probe data and the values derived from analysis of the GPR data. We must assume homogeneity in the x-direction to directly compare these measurements which is why the errors are not discussed in greater detail in this work. Rather, the authors provide these numbers as a general metric regarding the performance of the GPR data analysis.