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Hydrology and Earth System Sciences Discussions

Interactive comment on "Temporal stability of soil moisture patterns measured by proximal ground-penetrating radar" *by* J. Minet et al.

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This study investigates temporal stability (TS) of soil moisture patterns at the field scale using GPR data and two temporal stability methods (relative difference analysis and spatial intersection of the areas showing the field-average). TS areas could be identified that partly agreed with TS sites determined from gravimetrically measured soil moisture. Since the paper is mainly well written and GPR data have not been used for temporal stability analysis before, it deserves publication in this journal. However, several important methodical and textual issues need to be addressed before publication can be recommended (see detailed comments below). Therefore, I suggest a major revision of the paper.

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General comments:

1. The GPR data used in this study should be treated more critical and possible uncertainties should be more clearly stated.

2. Gravimetric soil moisture determination is the standard measurement method; all other methods based on electromagnetic principles are sensing methods, not measurement methods. Of course it will have more or less variability depending on sample size, but it is the only reference measurement available. This fact has to be better reflected in this paper (see chapter 3.3 and 4.3). For instance, it is not adequate to write that the gravimetric samples are showing lower sensitivity to the GPR data. In fact the GPR data are showing higher variability due to measurement uncertainties.

3. It is quite obvious that the line effect is produced by soil disturbance (i.e. soil compaction) either due to the acquisition vehicle or due to farming practices. The question arises, in which way the GPR data are actually affected by this disturbance. In other words, it must be questioned whether the GPR data are still representing the true average soil moisture in the footprint of the GPR or not. In fact, the strong deviation between GPR data and gravimetric measurements especially during wet conditions shown in Fig. 5 indicate that the partly compacted soil within the GPR footprint is producing unreliable soil moisture estimates during such conditions. One reason could be that the assumption of a homogenous planar layered medium in the GPR wave propagation simulation is violated for such conditions.

4. The original GPR data is aggregated using a rectangular window before ordinary kriging is applied. Unfortunately, due to the aggregation information at the local scale is lost and therefore the support scale of is determined by the aggregation scale. The resolution of interpolated maps is not stated, but given the number of interpolated points presented in Fig. 7 a resolution of interpolated maps of $\sim$2 m can be assumed. However, the resolution of the interpolated maps must be equal or larger than the support scale (otherwise it would be disaggregation). On the other hand, the moving

window aggregation already interpolates the data thus making a subsequent kriging unnecessary. Therefore, I suggest to only apply a moving window interpolation with a defined size (e.g. 5 by 10 m) and to omit the kriging procedure, which will only produce further uncertainties.

5. The intersection method is straightforward but not generic since it largely depends on the number of acquisitions (e.g. the identified area of temporal stability (TS) will continuously decrease with the number of acquisitions or will be even vanish in case soil moisture patterns will change). In addition, the threshold value will largely determine the extent of the TS area. The authors have used a value corresponding to the measurement precision as determined by a former study; however, no justification is given why this metric is actually appropriate to the threshold value for the temporal stability method. These issues need to be discussed more comprehensively.

6. Some parts of the text are directly copied from a former paper of the same authors (e.g. chapters 2.1, 2.3). Please reformulate these sections.

Specific comments:

P4067 L4-6 This statement is rather trivial and should be omitted.

P4067 L18 Recently sensor networks on the basis of low-cost soil moisture sensors have been successfully used to determine dynamics of soil moisture pattern from the field to the catchment scale (e.g. Bogena et al. 2010; Rosenbaum et al. 2012)

P4067 L20 Actually, similar spatial resolutions can be achieved using remote sensing techniques, e.g. airborne SAR-techniques (Jagdhuber et al. 2013)

P4068 L21 Since the saturated water content becomes important in the analysis (a threshold of 0.5 m^3/m^3 that corresponds with the saturated soil water content is assumed) the average soil porosity and its standard deviation should be presented as well.

P4069 L9 "...is a function..."

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P4070 L2-4 This sentence is dispensable.

P4070 L7 In fact the GPR data used in this study has a much lesser accuracy as shown later.

P4070 L11 Choosing this value seems to be very arbitrary. How does this value relates to the actual porosity of the soil?

P4070 L12-13 This is important information since ponded water will largely effect the GPR data with respect to magnitude of soil moisture and sensing depth. Therefore also GPR data that indicate soil moisture of less than 0.5 m^3/m^3 might be affected by puddles in the GPR footprint. In addition, during saturated condition soils are becoming very unstable, which will have increased the probability of soil compaction by the vehicle.

P4070 L15 What was the size of the soil core and how many cores where taken at each location to represent small-scale variability (this is important when comparing with the GPR data that integrate over a larger footprint).

P4070 L23-24 Please provide the number of points used for the averaging.

P4073 L9 Always use the term “area” instead of “surface”

P4073 L10 So what is the consequence of this difficulty?

P4074 L2-5 This statement unnecessary and anticipates the results. Please remove.

P4074 L6 Please provide a figure showing the experimental variograms and the variogram models of all acquisitions.

P4074 L13-14 Instead of “resolution scale” use “spacing scale” for better consistency

P4074 L16-18 Unclear syntax. Please reformulate.

P4074 L18-22 A repetition test cannot determine the accuracy of the GPR data. In fact it can only reveal precision of the soil moisture acquisitions (i.e. all three data sets

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could be equally wrong). Therefore, although the precision error is low, the high nugget effect can still be caused by uncertainties in the GPR data.

P4074 L23 "...was higher during wet conditions..."

P4074 L25-28 Soil moisture variability typically decreases near saturation since it is bounded by the variability of soil porosity (see e.g. Rosenbaum et al., 2012). As the authors claim that the soil properties of the study site are rather homogenous, it is very unlikely that the soil moisture variability will increase near saturation. This discrepancy should be checked using the gravimetrically derived soil moisture data. Also the effects of possible uncertainties of the GPR data during wet conditions should be discussed.

P4076 L3 It would be more honest to present also the RMSE for each acquisition.

P4076 L6 Please provide quantitative estimates of the characterization depth of the GPR.

P4076 L7-11 I do not understand how the shallower characterization depth will produce so strong deviations especially during the wet conditions. If there is actually a strong gradient in the soil, this should also produce higher soil moisture variability for the gravimetric samples. However, the variation in soil moisture is extremely low compared to the GPR measurements. As already discussed above, I believe that the line effect is a better candidate to explain deviations with gravimetric samples.

P4076 L21-22 This statement is difficult to grasp from the presented maps. To substantiate this it would be helpful present the correlation between slope values and TS metrics.

P4077 L6-10 Clearly the lower variability of the mean relative differences in the wet range is produced by the arbitrary threshold value of 0.5 m^3/m^3. Please reformulate accordingly.

P4078 L11-12 This statement should be substantiated with quantitative metrics.

P4079 L2 Delete “where they were used”

P4079 L7 “large threshold values” instead of “large criteria”

P4079 L18-22 A comparison of this studies is problematic since they were derived from much larger scales with more pronounced topographic features.

P4079 L23-24 Please do not use the term “unprecedented soil moisture spatial resolution” since firstly similar data products are available from SAR airborne campaigns and from satellite missions (e.g. from PALSAR on ALOS) and secondly due to the need for data aggregation the actual resolution is significantly reduced.

P4081 L16-17 One important restriction of the presented method is that it uses only information on soil moisture from the top 5 cm (or even less) to determine TS areas. However, other studies have shown that soil moisture information at different depths are needed to fully characterize soil moisture variability (e.g. Rosenbaum et al., 2012) and to determine TS sites (e.g. Guber et al., 2008; Penna et al., 2013).

P4081 L18 The availability of GPR data is restricted to certain acquisition campaigns. Therefore the use of GPR data for data assimilation is restricted.

References

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