Interactive comment on “Soil water content evaluation considering time-invariant spatial pattern and space-variant temporal change” by W. Hu and B. C. Si”

We would like to thank Reviewer 1 for his/her valuable comments on our manuscript. We are going to reply all the comments as follows:

Comment 1:

With pleasure I have read this manuscript which intends to evaluate soil water content while separating it into time-invariant spatial pattern, space-invariant temporal changes and space- and time-dependent redistribution term. The manuscript is written in a proper English but should be written in a more consistent way. The manuscript is carried out in a scientifically sound way and is built upon recent scientific studies (Mittelbach and Seneviratne, 2012) and have introduced a further investigation and separation of the time-varying component of soil moisture by applying the EOF-concept. However, by introducing this further separation, the paper have to be discussed more in detail and the consistency in the paper should be increased. I very much like the idea of further investigation of the time invariant component. However applying this to a small scale experiment lead not to surprising and new results. I therefore recommend major revisions.

Response 1:

The further separation of time-varying component was made considering two aspects: (1) At a watershed scale, the space-invariant temporal change $\Delta S(j)$ and redistribution term $S_r(i, j)$, which consist of time-varying component of Mittelbach and Seneviratne (2012), are usually controlled by different factors at a watershed scale. For example, $\Delta S(j)$ may represent the average recharge or discharge amount resulted from precipitation or solar radiation that are usually relatively uniform at a watershed scale, while $S_r(i, j)$ may represent the redistribution of $\Delta S(j)$ among different locations due to the spatial variability of soil, vegetation, and topography at a watershed scale; (2) EOF method can be used to extract the common spatial structures of the redistribution term by partitioning the redistribution term into time-invariant spatial structures (EOFs) that can be multiplied by temporally-varying coefficients (ECs). In this way, soil water content (SWC) distribution can be predicted if EC of unobserved dates can be estimated by considering the possible relationship of ECs and mean SWC. Detailed discussion will be added in terms of the further separation of time-varying component of SWC in the revision.

Specific attention will be paid to the consistency of the manuscript in the revision.

We mainly made a further separation of the time-varying component of Mittelbach and Seneviratne (2012) using EOF. Thus, we guess you mean the “time-varying component” rather than “time-invariant component” by stating “I very much like the idea of further investigation of the time invariant component".

The scale in our manuscript belongs to a watershed scale, which is an intermediate scale. Soil water content measurements at a point (~1 dm^3) scale have advanced with a range of in situ sensors, while measurements at basin (2,500–25,000 km^2) and continental scales have advanced with remote sensing (Robinson et al., 2008). However, measurements at a small watershed (0.1-80 km^2) scale are still a big challenge. This is one of the motivations of this study. This point will be added in the revision.

According to the results, a reasonable improvement in predicted SWC distribution was obtained with the further separation of time-varying component and EOF analysis. In the revision, external validation will also be used to validate the new method. For external validation, the datasets (14 datasets) of the first two years were used for model calibration, and the datasets (9 dataset) of the second two years were used for model validation. The new model outperformed the conventional EOF method when soil moisture deviated from the average conditions during both cross validation (Fig. 7 in the first submission copy) and external validation (Fig. R1). The advantage of the conventional EOF method over other methods such as time stability model has been verified in Perry and Niemann (2007). Therefore, we think it is very meaningful to apply this model at a watershed scale for SWC evaluation, and outperformance of this method over previous methods was also significant, especially when SWC deviated from the average conditions.

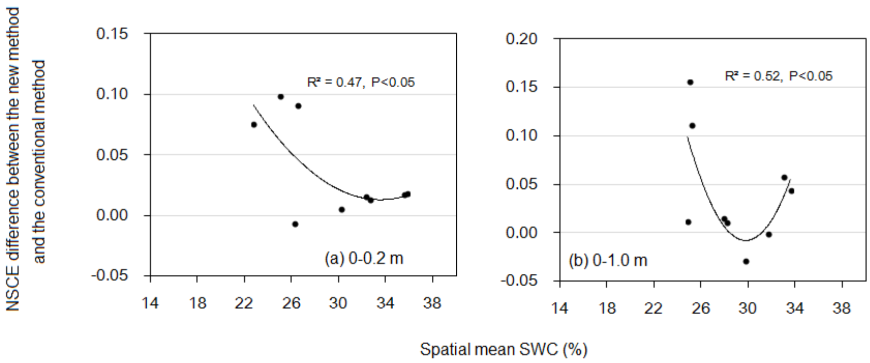

Fig. R1 Difference between Nash–Sutcliffe coefficient of efficiency (NSCE) of soil water content (SWC) evaluation using the new method and that using the conventional EOF method as a function of spatial mean SWC for (a) 0–0.2 m and (b) 0–1.0 m. A quadratic function was used to fit the associated relationship. The datasets (14 datasets) of the first two years were used for model calibration, and the datasets (9 dataset) of the second two years were used for external validation.

Reference:

Mittelbach, H., and Seneviratne, I.: A new perspective on the spatio-temporal variability of soil moisture: temporal dynamics versus time-invariant contributions. Hydrol. Earth Syst. Sci., 16, 2169-2179, 2012.

Perry, M. A. and Niemann, J. D.: Analysis and estimation of soil moisture at the catchment scale using EOFs, J. Hydrol., 334, 388–404, 2007.

Robinson, D.A., Campbell, C.S., Hopmans, J.W., Hornbuckle, B.K., Jones, S.B., Knight, R., Ogden, F., Selker, J., Wendroth, O.: Soil moisture measurement for ecological and hydrological watershed-scale observatories: A review, Vadose Zone J., 7 (1), 358-389, 2008.

Comment 2:

One main part making the readiness of the paper difficult is the nomenclature. I understand that finding the write expressions is not easy for the complex description. But the authors build upon the paper by Mittelbach and Seneviratne, 2012, so I highly recommend to use the one introduced by Mittelbach and Seneviratne, 2012 – and to extend them with respect to the redistribution term (e.g. use R_n_t instead of S_r(I,j). This gives also the possibility to see the connection and extension to this study. For better readiness I suggest to change the nomenclature and adapt the formulas.

Response 2:

Thanks for the valuable suggestion. We will rewrite $S(i,j)$, $S(i)$, $\Delta S(i,j)$, $\Delta S(j)$, $S_r(i,j)$ in Eqs.(1) and (2) to S_{tn}, M_{tn}, A_{tn}, $A_{t\hat{n}}$, R_{tn}, respectively, following Mittelbach and Seneviratne (2012). Then Eqs.(1) and (2) in the previous submission will be:

$$S_{tn} = M_{tn} + A_{tn} \qquad (1)$$

$$S_{tn} = M_{tn} + A_{t\hat{n}} + R_{tn} \qquad (2)$$

where S_{tn} refers to SWC at location *n* at time *t*, M_{tn} is the time-invariant spatial pattern, and A_{tn} refers to the temporal anomalies of SWC by removing the time-invariant spatial pattern from the original SWC series, $A_{t\hat{n}}$ is the spatial mean of A_{tn} and it is obtained by subtracting the spatial mean of M_{tn} from the spatial mean SWC at time *t*, R_{tn} is the redistribution term. The other nomenclatures in the manuscript will be changed accordingly.

Reference:

Mittelbach, H., and Seneviratne, I.: A new perspective on the spatio-temporal variability of soil moisture: temporal dynamics versus time-invariant contributions. Hydrol. Earth Syst. Sci., 16, 2169-2179, 2012.

Comment 3:

Reading the paper I associate the introduced S_r to depend on vegetation and meteorological and climate conditions, respectively. This made me very curious. However, by applying the concept to measurements at small scale (hydrological/land surface scale) and thus focusing on small scale processes results are too obvious and the innovativeness degrades. Applying the concept to a larger scale, soil properties and the respective static characteristics could most probably associated with the time-invariant spatial pattern. Thus it would be very interesting to apply the concept to larger scale or at least to soil moisture measurements across different land covers in order to identify the attribution due to vegetation and meteorological forcing. Furthermore, the difference between the “conventional EOF” and the “new method” is not really clear to me. Strengthen its added value.

Response 3:

We totally agree that the redistribution term R_{tn} ($S_r(i,j)$ in previous copy) should be related to vegetation and meteorological and climate conditions for larger scales where relatively strong variability of these factors usually exist. We also agree that it would be interesting to evaluate SWC distribution at larger scales using the proposed method. However, due to the issue of data availability, SWC evaluation at larger scales can’t be achieved at the moment and is a subject of future study. We appreciate your idea on testing the methods at larger scales. Nevertheless, we do believe that it is meaningful to apply the concept to a small watershed in this study for the following reasons: (1) in our study, the transect covers different land uses such as grass, shrub, and wetland where vegetation differs with locations. Therefore, the SWC measurements can be regarded to be made across different land covers. We would also associate the redistribution term R_{tn} to vegetation considering the significant relationship between R_{tn} and organic carbon (Table 1 in previous copy) and that the location with more organic carbon usually has more vegetation (lines 24-25 on page 12843); (2) soil water content measurements at small watershed scales have been the biggest challenge (Robinson et al,, 2008). As also suggested by reviewer #2, therefore, we will only focus on the SWC evaluation; (3) we think the outperformance of the new model over the traditional methods is independent from the scale, while we admit that the degree of outperformance may differ with scale. This is because both time stability component and part of time instability are considered in this model.

The difference between conventional EOF and new method is that EOF analysis is based on different terms, i.e., the EOF analysis was conducted on the spatial anomaly of ***time-varying component*** for the new method, while the EOF analysis was conducted on the spatial anomaly of ***original measurements*** for the conventional EOF method. Mathematically, EOF analysis was based on the following term, respectively, for the new method and conventional EOF:

$$R_{tn} = S_{tn} - M_{tn} - A_{t\hat{n}} \qquad \text{(for new method)}$$

$$Z_{tn} = S_{tn} - S_{t\hat{n}} \qquad \text{(for conventional EOF method)}$$

where Z_{tn} is the spatial anomaly of original measurements, and $S_{t\hat{n}}$ is the spatial mean SWC at a given time *t*.

Reference:

Robinson, D.A., Campbell, C.S., Hopmans, J.W., Hornbuckle, B.K., Jones, S.B., Knight, R., Ogden, F., Selker, J., Wendroth, O.: Soil moisture measurement for ecological and hydrological watershed-scale observatories: A review, Vadose Zone J.,

7 (1), 358-389, 2008.

Comment 4:

Please add in the abstract that you apply your method to a small scale experiment. Please write, e.g. in the text, which periods are recharge or discharge periods. P12833: could you implement also other reasons than the soil hydrological processes for the redistribution term. Would vegetation and meteo conditions play a role if one investigate larger scales? P12836: I do not understand why " ' " is introduced here. What are the S' and the difference to previous variables? P 12839 Paragraph 2: how high are the correlations? Significance is important but needs to be connected with the correlation value. P12841 L 27:vegetation would be interesting to implement as indicator for variability. If measurement errors are included: they have to be removed for the analyses(!). P12842 L5: Please refer to respective figure P12845: 2nd paragraph is not written in an understandable way and confusing. Please rewrite. Figure 7: is the fit of relevance? Figures in general: (i) Please locate the a) and b) in a way more often used in scientific papers, i.e. in upper left corners. (ii) some label can be more describing. E.g what are wet and dry periods? Table 1: please use SWC and not SP for soil water content Table 1, 2: Both include a lot of numbers. For better overview I suggest to write only correlation e.g. R>5 (as this is used by the authors in the text) and indicate, if they are significant.

Response 4:

We will state the study scale in the abstract.

As noted at lines 19-21 on page 12833, the recharge and discharge period in this study is a relative term which are based on the $A_{t\hat{n}}$ ($\Delta S(j)$ in the previous copy), i.e., difference between spatial mean soil water content at a given date and spatial mean of time-invariant spatial pattern term. Positive $A_{t\hat{n}}$ refers to a recharge and negative $A_{t\hat{n}}$ refers to a discharge period. From Table 2, we can easily tell which period is recharge or discharge.

As Reviewer #1 stated that other factors such as vegetation and meteorological and climate conditions may also contribute to the redistribution term at larger scales. Therefore, we will change this sentence to "The R_{tn} refers to the redistribution of $A_{t\hat{n}}$ among different locations due to topographic, soil and vegetation heterogeneity influencing soil water movement."

The symbol " ' " refers to the estimated value of a variable, and it was introduced here to distinguish the estimated value from the measured (or calculated) value for a variable. For example, $S(i,j)$ is measured SWC at location *i* and time *j*, while $S'(i,j)$ is the estimated SWC at location *i* and time *j* using models.

P12839 Paragraph 2: According to the results listed in Table 2, 68% of Rs values are significant at $p<0.05$ for both 0-0.2 and 0-1.0 m depth increments. Furthermore, 22%, 26%, and 19% of the correlations can be viewed as strong ($|Rs|\geq 0.5$), moderate ($0.3\leq|Rs|<0.5$), and weak (($0.18\leq|Rs|<0.3$) for 0-0.2 m, respectively, and 20%, 27%, and 21% of the correlations can be viewed as strong, moderate, and weak for 0-1.0 m, respectively. These will be added in the revision. In combination with the comments below, we will write S, M, W, and N to indicate strong, moderate, weak, and no correlation in Table 2 instead of writing numbers. Table 1 will be removed considering the comments of Reviewer #2.

P12841 L 27: Variability of vegetation will be added in the revision. We did not obtain the measurement error in this study. To avoid confusion, we will remove "and measurement error" in the revision.

P12842 L5: We will change this sentence to "In case all 23 datasets were included, only one significant EOF was identified for both soil layers using the conventional EOF analysis (Fig. 6)."

P12845: 2nd paragraph is intended to explain why the new method is better than the conventional method, and why the performance is better when soil water conditions are much drier or wetter than the average level. We will rewrite and make it to be clearer.

Fig. 7: we fitted the relationship between the degree of outperformance (NSCE difference between the new method and the conventional method) and spatial mean soil water content.

We will locate the a) and b) in upper left corners for all figures. We will explain the labels as detailed as possible. However, we did not mention wet or dry periods in the Figures.

Table 1: SP refers to time-invariant spatial pattern of soil water content rather than soil water content. Anyway, Table 1 will be removed according to the comments of Reviewer #2. For Table 2, we will write S, M, W, and N to indicate strong, moderate, weak, and no correlation.