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 express our thanks to Reviewer #3 for his/her detailed and useful comments on our manuscript. Responses to all comments are made below.

Comment 1:
This article describes an interesting approach to decompose the soil moisture content into a time invariant spatial pattern, space invariant temporal changes and space and time dependent redistribution. Though the ideas and the results of the paper are in my opinion interesting I think the writing of the paper can be improved. In case you manage to improve the text and mainly convey your message well, I think this article will be interesting for many scientists studying spatio-temporal variations in soil moisture contents.

Response 1:
Thank you very much for your positive comment on the value of this manuscript. We will revise the manuscript carefully based on the comments from you and the other two reviewers.

Comment 2:
(1) For example, some points to improve in the text: the reasoning behind the separation of the time varying component into the space invariant temporal change and the time dependent redistribution should be explained more clearly in the materials and methods part 2.1., as this is the main idea of this paper. **(2)** Furthermore I would recommend to move the study area and data collection description either to the beginning or to the end of the methods section, instead of in between the descriptions of the statistical analysis. **(3)** And the results start with a paragraph of the correlation between the time invariant spatial patterns and the environmental factors, where I would expect first a description of the different components of soil moisture content and how the new and the old method EOFs do for the prediction of SWC. **(4)** Then the comparison of how the different environmental factors relate to the different SWC components might be interesting to learn more about the processes which influence the soil moisture change.

Response 2:
(1) The further separation of time-varying component into the space invariant temporal change and the time dependent redistribution 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, discharge amount resulted from precipitation or evaporation due to 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 taking into account 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 an unknown EC at a time can be estimated by considering the possible relationship of ECs and mean SWC. We will incorporate this paragraph in Materials and Method Section 2.1.

(2) We will move the study area and data collection description to the beginning of the methods section.

(3) In the previous copy, we have already shown the different components of Eq. (2). Fig.1 shows the time-invariant spatial pattern of SWC; the first and last rows of Table 2 show the space-invariant temporal change, and Fig.2 shows the redistribution term for two days with contrasting soil water conditions. We will describe these components first in the result part. In combination with the comments of reviewer #2, we will show the space-invariant temporal change and spatial mean SWC in the same figure. Precipitation and air temperature will also be included to show the relationships between climate variables and space-invariant temporal change. In the figure for redistribution term (Fig.2), we will also include spatial anomaly of original measurements for those two days with contrasting soil water conditions. Our method is based on the redistribution term while the old EOF method decomposes the spatial anomaly of the original measurements. In addition, we will also stress this point in the Material and Methods part. The EOF analysis was conducted on the spatial anomaly of ***time-varying component*** (distribution term) 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*.

(4) Reviewer #2 suggested to remove the related correlation analysis by focusing

strictly on the SWC evaluation. We generally agree with his/her comment on this point. Therefore, the influences of environmental factors of different SWC components will be discussed briefly after the description of different components to add better understanding to the performance of mean SWC evaluation.

Comment 3:

With the method used in this paper the strength and direction (positive / negative) of redistribution of the soil moisture depend completely on the spatial mean soil water content. I would think that the redistribution term also strongly depends on whether the system is drying or wetting as different processes determine the soil moisture change. Therefore I think it would be worthwhile to include this in the analysis, though that may be difficult as the dataset is not very large as it is, and this would mean to divide the data in even smaller sets for the calibration/ validation. So this might be an idea for future research into the factors influencing the different space and / or time- varying components of the soil water content.

Response 3:

We agree with you on this comment. The possible influence of different processes (drying or wetting) was indicated by the spearman's rank correlation coefficients in Table 2. Take SWC of 0-0.1 m for example, the SWC of 20 April 2009 is similar to that of 29 September 2011. But the Spearman's rank correlation coefficient was significantly negative (-0.42), indicating a different distribution of redistribution term between these two days although the first day was at a wetting condition and the second day was at a drying condition. Considering the limit of data availability, we cannot do this analysis at this moment and this is a subject of future study. However, we will discuss this in the revision.

Comment 4:

p.12832, line 1-3: during evaporation period clay soils may lose more water than sandy soils, because there is more storage in clay soils? Normally the clay soils can also hold the water much stronger than the sandy soils due to capillary forces so it would depend on the time scale over which you would measure water loss. In general sandy soils lose water much more rapidly so I think the occurrence of a larger loss of water in clay soils depends on the initial water content and the time over which a soil can dry out.

Response 4:

We agree that that the occurrence of a larger loss of water in clay soils depends on the initial water content and the time over which a soil can dry out. But for our case, soil water mainly comes from snowmelt in the spring, and finer soils can store most of the snowmelt, having a higher available water storage, while coarser soils cannot. Evapotranspiration is the dominant process for water reduction in finer soil, while drainage can be also important for a coarser soil. In addition, we cannot get the SWC measurements immediately after the rainfall events due to the access issue. Therefore, it usually takes relatively long time to dry out before we can do the measurements. In this situation, drainage rate is not the limiting factor and the amount of available water determines the loss amount. This point will be discussed in the revision.

Comment 5:

Figure 1: the temporal mean soil moisture content has quite a high peak just past 100 m, going over 50 % and seeing the EOF and EC values, I estimate the redistribution value for this location is generally even positive for conditions above approx. 28% spatial mean SWC. Is that realistic?

Response 5:

The high peak point is at the distance of 121 m from the start of the transect. It just falls into the middle of a depression. The saturated water content of this position is up to 69.8% due to its low bulk density (0.8 g cm^{-3}). When the spatial mean SWC is above 28%, we do obtain positive redistribution term from EOF1 at this position. This results in SWC higher than the temporal mean values at this position. Therefore, it is easy to understand this paradox phenomenon after knowing the high saturation at this position.

Comment 6:

Figures 1 and 2: it is remarkable to see that at both extremes of the transect (i.e. from 0 to 100m and from approx. 420 m to the end) the temporally mean soil water content and the redistribution terms are much smoother and rather average values than in the stretch from 100 to 420 m. At a first glance both average SMC and redistribution terms seem to be strongly related to the elevation, except for these extreme stretches. Therefore I think it is interesting to relate these different components of soil moisture to different environmental factors to learn more about the processes which might influence the soil moisture redistribution at this scale.

Response 6:

The influences of environmental factors on time-invariant spatial pattern of SWC and EOFs of redistribution terms have been analyzed by the correlation coefficients. The related results are shown in Table 1. As you can see, both components were negatively correlated to elevation, but they were more correlated to the organic carbon and depth to $CaCO_3$ layer.

We basically agree with Reviewer #2 to focus on the SWC evaluation using the new method. But at the same time, we also think that it is interesting to relate these different components of SWC to different environmental factors. To get a balance, we will discuss the influencing factors briefly to add better understanding to the performance of mean SWC evaluation.

Comment 7:

Figure 2: here the two days selected are of course a very wet and a relatively dry day, which is a very logical choice but I would mention this in the caption, even though it

should be clear by the opposite direction of the redistribution terms.

Response 7:

We will mention the soil water condition and change the figure caption to "Redistribution terms of soil water content of (a) 0-0.2 m and (b) 0-1.0 m at a relatively wet day (13-May-11) and a relatively dry day (23-Aug-08)."

Comment 8:

Figure 3: a cosine relationship between spatial mean soil water content and EC does make sense to me, but in the case of EC1 for the top soil layer, the relationship between EC and spatial mean SWC looks quite linear. Normally I would expect the variation in soil moisture content to decrease when the soil moisture approaches saturation. Does the fact that your EC1 does not decrease with higher soil moisture content mean that your soil has a rather high porosity and the spatial mean soil moisture content never comes near saturated conditions, even when your average soil water content is near 36 Vol %? Or is your spatial variation in porosity very high? Otherwise I would expect the EC values to become negative with high soil moisture contents in case the spatial variation in porosity is low, as the spatial variation which is evident in the temporally mean soil water content would have to be counteracted with the redistribution term to get a reduced spatial variability in the soil water content.

Response 8:

First, although the relationship between EC1 and spatial mean SWC looks linear, it can be fitted better by the cosine function than by the linear function, with R^2 of 0.764 for cosine function versus 0.583 for linear function. The better performance of the cosine function indicates that the EC1 may decrease if the soil water content approached the saturation. However, in this study, we did not observe the decrease of EC1 with increasing mean SWC. As shown in Fig. R1, the spatial variability indicated by the variance increases with mean SWC. This was not due to a high spatial variability of porosity (with variance of only 38.2 $\%^2$, much less than the highest variance (about 140%) of SWC shown in Fig. R1). Instead, this was because that the measured SWC of 0-0.2 m never approached saturation (with the maximum SWC of 35.8% versus porosity of 50.9%) except for some locations in depressions. Two reasons may contribute to the absent of saturation in our measurements: (1) limited annual rainfall amount (437 mm); and (2) even the soils will approach saturation after a big rainfall, we cannot get the measurements immediately after rainfall due to the access issue. We will discuss this point considering the possible application to the situation where saturation can be approached.

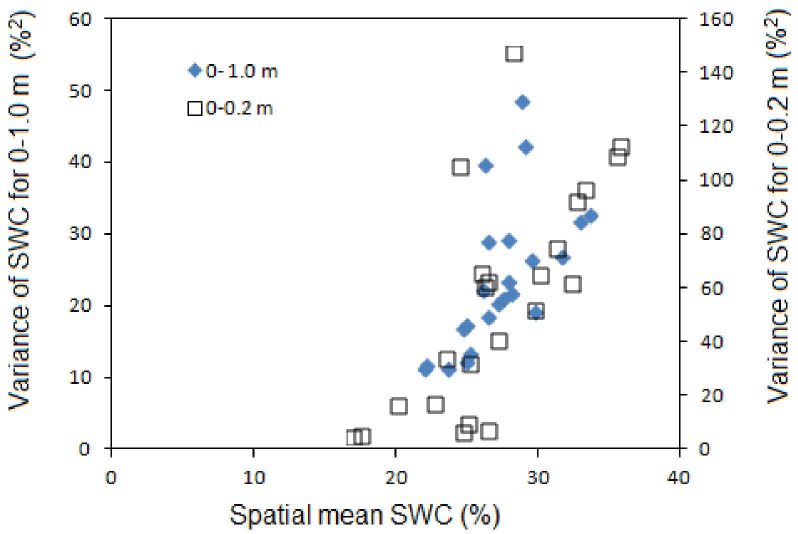

Fig. R1 Relationship between variance of SWC and spatial mean SWC for both 0-0.2 m and 0-1.0 m.