Response to Anonymous Referee #2

(1) This paper illustrates that temporally variable parameters can be estimated with EnKF. The paper can be resubmitted after major revision and I give a series of comments to be handled. The two main points are:

1) Do the found parameter variations in the real-world case show a significant trend? Why do these parameter values fluctuate so strongly?

Reply:

(a) The estimates of parameter *SC* from Wudinghe basin (Fig. 7c) show a significant increasing trend (p-value=0); while the estimated *SC* from Tongtianhe basin has no obvious trend since the correlation coefficient has an insignificance level (p-value=0.16). For parameter *C*, the results show that the estimates have no significant temporal patterns because the slopes for the trend line are near zero and the standard deviations are relatively small for the two basins (Fig. 7(a) and (b)).

(b) The fluctuations are mostly caused by the modeling and observation uncertainties (Shi et al., 2014; Meng et al., 2016). To reflect these uncertainties, the standard deviations of observations and parameters are set, respectively, shown in Table 3 and Section 2.2 (Page 11-12, Line 177-185). The results from Figures 3 to 5 show that stronger fluctuations appear when higher standard deviations are set. This is also illustrated in Page 11, Line 174-177. The set of the standard deviations is based on trial and error and the related previous studies (Moradkhani et al., 2005; Wang et al., 2009; Xie and Zhang, 2010; Nie et al., 2011; Lü et al., 2013; Samuel et al., 2014).

2) The explanation of the apparent trend in the parameters is not convincing to me. I ask the authors to provide long-term time series of precipitation and potential ET, discuss the potential role of factors like increasing water use efficiency of the vegetation and increased groundwater pumping in the area. Other data sources like trends in groundwater levels would also be helpful. It should be remembered that with this very simple hydrological model the parameters incorporate many processes and a physical interpretation is difficult.

Reply:

As the reviewer mentioned, besides the soil and water conservation measures, other potential factors such as precipitation alteration and groundwater pumping can also affect the runoff reduction (Wang and Cai.: *Detecting human interferences to low flows through base flow recession analysis*, Water Resour. Res., 2009).

The data used to illustrate the trends of parameter *SC* from Wudinghe basin is from a program report by Wang and Fan (2003) that specifically study the water and sediment changes resulted from the different factors including precipitation and human activities. This study showed that the runoff reduction are mainly caused by human activities, which were the soil and water conservation measures, i.e., land terracing, tree and grass plantation, check dam and reservoir construction. All the possible human activities have been considered in this study and the groundwater abstractions is negligible in Wudinghe basin.

The monthly water balance model used in this study is a simple conceptual model with only two parameters, i.e., evapotranspiration parameter and catchment water storage capacity. These two parameters have clear physical means. As the reviewer mentioned, these parameters are affected by multiple factors. In this manuscript, we use two study areas with different catchment characteristics to evaluate the proposed method.

The long-term time series of precipitation and potential ET have been added in the revised manuscript (Page 21, Line 346-351). We agree that other data sources like the groundwater level series would also be helpful. Unfortunately, these data are not available.

"Fig. 8 shows the long-term time series of precipitation and potential evaporation in Wudinghe basin, and the runoff reduction caused by all the soil and water conservation measures, i.e., land terracing, tree and grass plantation, check dam and reservoir construction. Fig. 8(a) shows that the yearly potential evaporation has no significant trend; while both yearly precipitation and runoff have a decreasing trend, and the trend of the yearly precipitation has a higher slope. Runoff decreases significantly while precipitation changes slightly and potential evaporation has no trend, indicating that the actual evaporation increases significantly due to impacts of human activities, i.e., the soil and water conservation measures.”

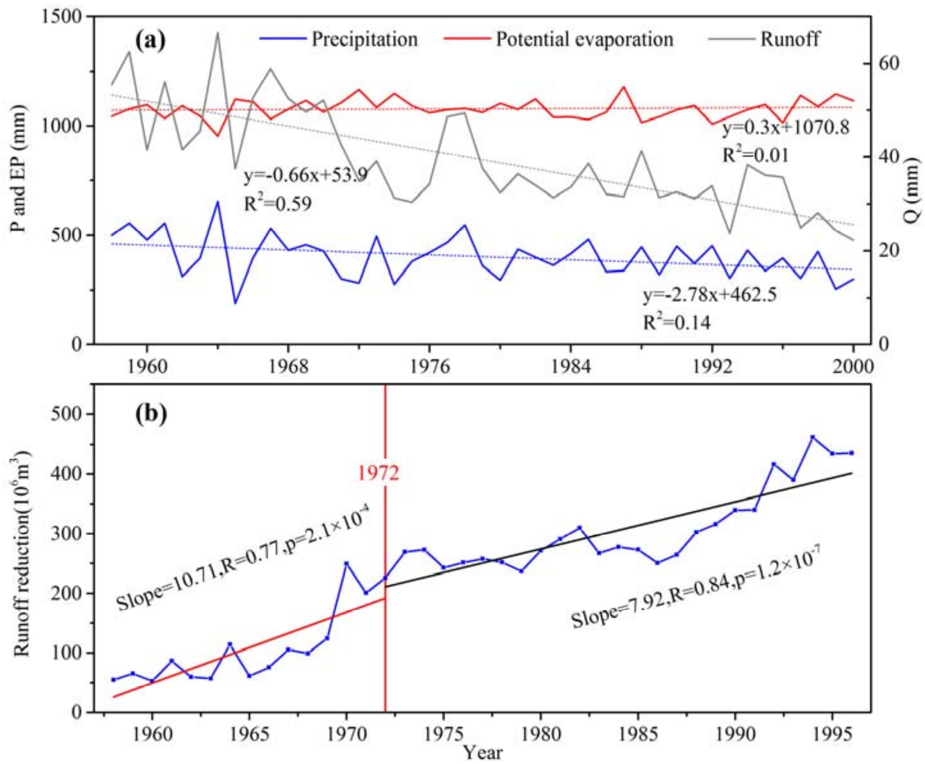

Figure 1. (a) Yearly precipitation, potential evaporation and runoff in Wudinghe basin during the period of 1958-2000; (b) Runoff reduction in Wudinghe basin caused by all the soil and water conservation measures, i.e., land terracing, tree and grass plantation, check dam and reservoir construction for the period of 1958- 1996. Note that the data is from Wang and Fan (2003) and is only available from 1956 to 1996.

(2) L52: This should not give time dependent parameters and points to a problem in the model.

Reply:

Thanks. This sentence has been modified (Page 4, Line 50-51).

“Therefore, assuming time-invariant model parameters may be unrealistic, especially for catchments with nonstationary catchment characteristics.”

(3) L62-L63: Rephrase.

Reply:

Thanks. This sentence has been rephrased (Page 5, Line 61-63).

“(1) Available historical record is divided into consecutive subsets, and parameters are calibrated separately for each subset using an optimization algorithm (Merz et al., 2011; Thirel et al., 2015);”

(4) L73: Add Kurtz et al. (2012, WRR) who performed a detailed study on modelling time dependent parameters for a hydrological system. Also Montzka et al. (2013, VZJ) estimated time dependent parameters.

Reply:

Thanks. References are added in the revised manuscript (Page 6, Line 73).

(5) L75: Please provide more details about this study as Vrugt et al. (2013) showed problems associated with estimating time dependent parameters.

Reply:

Thanks. More details about the paper by Vrugt et al. (2013) have been added (Page 6, Line 74-77).

“Vrugt et al. (2013) proposed two types of Particle-DREAM method, i.e., Particle-DREAM for time-variant parameters and time-invariant parameters, to track the evolving target distribution of HyMOD parameters, while both the results were approximately similar and statistically coherent since only three years of data were used.”

(6) L76: retrieve.

Reply:

Thanks. It has been corrected.

(7) L80: see earlier comment.

Reply:

Thanks. This sentence has been modified (Page 6, Line 80-82).

“Little attention has been paid to the identification of time-variant model parameters and the interpretation of their temporal variations based on catchment characteristics.”

(8) L117: skip typical.

Reply:

Thanks. It has been modified.

(9) L119: give original references (i.e., Evensen (1994), Burgers et al. (1998)).

Reply:

The original references have been added in the revised manuscript (Page 8, Line 121).

(10) L137: "following" instead of "followed".

Reply:

Thanks. It has been revised.

(11) L138-L139: Why is this needed? This is normally only applied for the particle filter.

Reply:

The simple random walk process is used to represent the propagation of parameters (Wang et al., 2009), i.e., small random disturbances are added to the parameter member between time steps as in equation (5).

(12) L155: give an earlier reference.

Reply:

Earlier reference has been added (Page 10, Line 157).

(13) Page 10: I think it would be better to use the standard notation like overbar for an average and C for covariance matrix.

Reply:

Thanks. The notation for average has been changed, while that for covariance matrix is kept since C is used to denote the evapotranspiration parameter (Page 11, Line 164).

(14) L178: What does this mean? Tuned? Trial and error? Parameters do not

have physical meaning.

Reply:

It is the standard deviations of the two parameters. To reflect these uncertainties, the standard deviations of observations and parameters are set, respectively. The set of the standard deviations is based on a trial and error method and the related previous studies (Moradkhani et al., 2005; Wang et al., 2009; Xie and Zhang, 2010; Nie et al., 2011; Lü et al., 2013; Samuel et al., 2014).

(15) L186: This is however usually applied for the particle filter. Is it done here?

Reply:

No, the variable variance multiplier is not used here. The description has been deleted.

(16) L228: It should be made clear and explicitly stated that these are synthetically generated parameter time series.

Reply:

Thanks. It has been modified (Page 14, Line 228).

"Time series of model parameters are synthetically generated, including the time-variant parameters and the constant parameters."

(17) L275: Reformulate.

Reply:

Thanks. The sentence has been rephrased (Page 17, Line 273-274).

"The Tongtianhe basin is rarely affected by human activities owing to the water source protection guidelines conducted by the government."

(18) L282: What about crop/vegetation data?

Reply:

The modeling time scale of this study is monthly, the corresponded crop and vegetation (e.g., monthly or yearly) data are unavailable in the study area.

(19) L291: The estimation of parameters.

Reply:

Thanks. The words have been revised.

(20) L314: skip "to".

Reply:

Thanks. It has been deleted.

(21) L321: "(...) to a certain degree"

Reply:

Thanks. It has been modified.

(22) L332: "On the other hand, the bottom panel demonstrates that (...)"

Reply:

Thanks. This sentence has been revised.

(23) L341: Is the trend slope significantly different from zero? The fluctuations are so strong that this seems not so clear. These strong fluctuations should also be explained.

Reply:

Yes, the trend slopes in Fig. 7(c) are significantly different from zero since both the p-values of the trend lines are equal to zero. The values are small because the date values are used as independent variable. The fluctuations are caused by the modeling and observation uncertainties (Shi et al., 2014; Meng et al., 2016). To reflect these uncertainties, the standard deviations of observations and parameters are set respectively. Stronger fluctuations appear when higher standard deviations are set. This is illustrated in Page 11, Line 174-177.

(24) L349-L351: Rephrase sentence.

Reply:

Thanks. The sentence has been rephrased (Page 21, Line 353-355). The sentence "The runoff reduction data is available from 1956 to 1996 (Wang and Fan, 2003)" has been moved to the caption of Fig. 8.

(25) L357-L358: Rephrase sentence. Skip "the" and "parameter" instead of "parameters".

Reply:

Thanks. The sentence has been revised (Page 22, Line 361-362).

"However, it can be treated as time-variant parameter since temporal variations exist in the estimated *C* series."

(26) L380: change to: "assimilating runoff observations".

Reply:

Thanks. It has been modified.

(27) L384: skip "drawn as follows".

Reply:

Thanks. These words have been deleted.

(28) L405: "parameter" instead of "parameters".

Reply:

Thanks. It has been modified in the revised manuscript.

(29) Figure 8: I would expect that in the long-term the water balance should be zero and if precipitation does not decrease, why would runoff reduce? Please plot in the paper also long term time series of yearly precipitation and potential evapotranspiration. Is it possible that ET reduced in relation to other factors and that the relation between actual ET, potential ET and precipitation was related to a CO2-induced change in water use efficiency of the plants? Were groundwater abstractions increased in this area?

Reply:

As the reviewer mentioned, besides the soil and water conservation measures, other factors such as precipitation and groundwater pumping can also affect the runoff reduction. While the data used to illustrate the trends of parameter *SC* is from a research report by Wang and Fan (2003) that specifically studied the water and sediment changes resulted from the different factors including precipitation and human activities (i.e., land terracing, tree and grass plantation, check dam and reservoir construction). The data used in Figure 8 is runoff reduction only caused by human activities, i.e., the soil and water conservation measures.

In the study by Wang and Fan (2003), the trends of the yearly precipitation and runoff have been analyzed, and an empirical yearly runoff model has been built to compute the runoff changes caused by precipitation and human activities, respectively. **Figure R1** shows that the yearly potential evaporation has no significant trend; while both yearly precipitation and runoff have a decreasing trend, and the trend of the yearly precipitation has a higher slope. Runoff decreases significantly while precipitation does not change much and potential evaporation has no trend, indicating that the actual evaporation increases significantly due to impacts of human activities, i.e., the soil and water conservation measures. All the possible human activities have been considered in this study and the groundwater abstractions is negligible.

The long-term time series of yearly precipitation, potential evapotranspiration and runoff have been added in the revised manuscript (Page 43, Line 641-646).

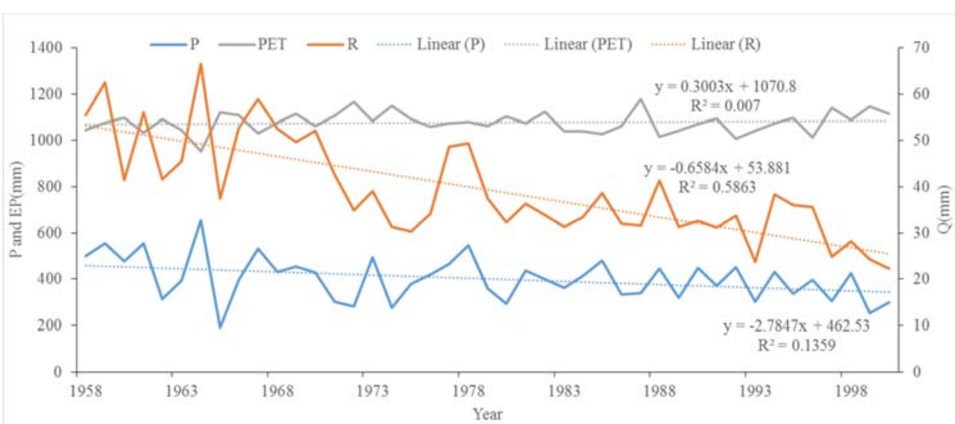

Figure R1. Yearly precipitation, potential evaporation and runoff in Wudinghe basin during the period of 1958-2000.