Response to Anonymous Referee #2

(1) Dear Authors! This paper focuses on the identification of the variability and change of model parameters with over a long time period. A parsimonious rainfall-runoff model on a monthly time step with only two model parameters was used in this study. An EnKF approach is used to update the model parameters based on the observed runoff. This method is applied for a synthetic experiment and two case studies in China. The aim of the study is to show the capability of the EnKF approach to estimate the model parameters and their change over time. In my opinion this is a very promising and important issue and additional research in this field is important.

Reply:

We thank the Anonymous Referee #2 for the constructive comments and suggestions. All the comments have been responded below, and have been incorporated into the revised manuscript.

(2) Going through this specific paper about parameter estimation I was thinking that this is more a draft or concept version of a publication, than a paper ready for submission. The introduction and the comparison with other studies should be deeper than in this version. And the benefits of the specific EnKF approach used in this study are not clearly supported by the results of the synthetic experiment and the two real case studies in China.

Reply:

We have revised the manuscript thoroughly based on the constructive comments, especially for Introduction and Results sections. More details and explanations are added to clarify the motivation of this study. Details are as follows:

The results from the synthetic experiment demonstrate that the EnKF is able to detect the temporal trend of the true parameter values by updating the state variable and parameters based on the runoff observations, although a time lag exists when the parameter C is periodic. The case study in Wudinghe basin aims to estimate the time

series of the model parameters and to provide an explanation for the parameter variation from the perspective of the physical characteristic changes. Meanwhile, a comparative study is implemented to investigate the variation of model parameters in the Tongtianhe basin, which is barely affected by human activities. The results from the Wudinghe basin show that the parameter of water storage capacity (*SC*) has a significant increasing trend for the period of 1958 to 2000, corresponding to the increase of the water holding capacity of the basin resulted from the implementation of the soil and water conservation measures, including land terracing, tree and grass plantation, and check dam and reservoir construction. While in the Tongtianhe basin, the parameter *SC* has no significant trend for the period of 1982-2013, which is consistent with the relatively stationary catchment characteristics. Therefore, the method proposed in this paper provides an effective tool for identifying time-variant model parameters for the two-parameter hydrologic model.

(3) In general my opinion about the scientific quality of this publication is in line with that of reviewer #1. A lot of additional work and analysis have to be included before this work should be published.

Reply:

The manuscript has been significantly revised based on the constructive and helpful comments from the reviewers. Please also refer to the responses to Reviewer #1.

(4) I do not go very much into the details, but my major concerns are: The introduction and literature review should be extended – broader context.

Reply:

Our paper aims to identify temporal variation of model parameters and to interpret the variations through catchment properties. Kalman filter and its extentions actually provide a method to identify the potential temporal variations of model parameters (Liu and Gupta, 2007; Xie and Zhang, 2013). Particularly, EnKF has been successfully applied in hydrology (Abaza et al., 2014; DeChant and Moradkhani, 2014; Delijani et al., 2014; Tamura et al., 2014; Xue and Zhang, 2014; Deng et al.,

2015). Several studies have used it to estimate model states and parameters under stationary conditions (Moradkhani et al., 2005; Wang et al., 2009; Xie and Zhang, 2010; Xie and Zhang, 2013; Samuel et al., 2014). In this study, we use the EnKF to detect the potential temporal variations of model parameters.

The introduction has been extended and more previous related references have been added in the revised manuscript (Page 4-6, Line 37-87).

"Parameters of conceptual hydrological models can be considered as a simplified representation of the physical characteristics in hydrologic processes. Therefore, parameter values are closely related to the catchment conditions, such as climate change, afforestation and urbanization (Peel et al., 2011)…

The data assimilation (DA) actually provides another method to identify the potential temporal variations of model parameters by updating them in real-time when observations are available (Liu and Gupta, 2007; Xie and Zhang, 2013). The DA method has been widely applied in hydrology for soil moisture estimation (Han et al., 2012; Kumar et al., 2012) and flood forecasting (Liu et al., 2013; Abaza et al., 2014). It has also been successfully used to estimate model parameters (Moradkhani et al., 2005; Panzeri et al., 2013; Vrugt et al., 2013; Xie and Zhang, 2013; Shi et al., 2014; Xie et al, 2014). For example, Vrugt et al. (2013) proposed two types of Particle-DREAM method to track the evolving target distribution of HyMOD parameters, while the true parameters were assumed to be constant. Xie and Zhang (2013) used a partitioned forecast-update scheme based on the EnKF to retrive optimal parameters in a distributed hydrological model. Although the DA method has been used to estimate model parameters, these studies are focused on the estimation of constant parameters. Little attention has been paid to the identification of time-variant model parameters and the interpretation of their temporal variations based on the climate conditions and/or catchment characteristics.

The aim of this study is to assess the capability of the DA method (i.e., the EnKF) to identify the temporal variations of the model parameters for a monthly water balance model. Thus, a synthetic experiment, including four scenarios with different parameter variations and one scenario with time-invariant parameters, is designed for

parameter estimation at different uncertainty levels. Furthermore, two case studies are implemented to estimate the model parameter series and to interpret the parameter variations in response to the changes in catchment characteristics, i.e., land use and land cover."

(5) The superior performance of the EnKF method was not obvious to me. A comparison with other sequential data assimilation techniques would have been helpful. At the other hand I didn't quite understand what the real benefit is – if the parameters are estimated from observed discharge data in the past, but the performance of the model is not tested for the "forecast" or "prediction" case when no runoff measurements are available. In my opinion this should be the most important indicator for the added value of the data assimilation routine.

Reply:

Although the DA method has been used to estimate model parameters, these studies focused on the estimation of constant parameters. Little attention has been paid to the identification of time-variant model parameters and the interpretation of their temporal variations based on the climate conditions and/or catchment characteristics. Therefore, EnKF is applied in this study for the estimation of model parameter series by using historical records of runoff. Afterwards, the parameter time series is analyzed for detecting potential temporal trend. The change of watershed characteristics are linked to the identified temporal variations of parameters. This study belongs to hydrological simulation and is an important step for achieving hydrological forecast. After the temporal pattern is identified and the impact factors are detected, we can build the function of time-variant parameters to predict the model parameters based on the factors, and further for hydrologic forecasts.

(6) Looking at figure 11, it is really not clear to me how the data assimilation approach could help to estimate appropriate model parameters when the 95% uncertainty bounds are much smaller than annual and inter annual variations of the evapotranspiration parameter C.

Reply:

Figure 11 shows the time series of the estimated *C* for the Wudinghe and Tongtianhe basins. Both the uncertainty bounds and the time series of parameters are obtained from the EnKF procedure. We focus more on the variability of the estimated parameter series, which cannot be obtained using the traditional way where optimal algorithm is applied for the estimation of the assumed constant parameter. The uncertainty bound is presented to show whether it can cover the true values of parameters in the synthetic experiment. However, the true parameters cannot be obtained in the real cases, it only shows the uncertainty level of the estimated parameters.

(7) To summarize, I suggest major revisions before this paper should be published and the benefit of the proposed method can be presented to the international scientific community.

Reply:

Thank you. We have revised the manuscript thoroughly based on the helpful comments, especially for the Introduction and Results sections, where more details and explanations are added to clarify the motivation of this study.