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Interactive comment on "A comparison between parameter regionalization and model calibration with flow duration curves for prediction in ungauged catchments" *by* D. Kim et al.

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Dear anonymous referee:

We greatly appreciate your valuable contribution to our manuscript, and thank for your comments. Accepting referee 3's constructive comments, we want to improve the manuscript. Your comments will be considered together in revision. Our main direction for restructuring the manuscript is:

(1) We will include more literatures about prediction in ungauged catchments in introduction. Additional literatures will be provided about FDC regionalization and signature-based calibration methods. We will also introduce the decade-long project

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of the IAHS in Prediction in Ungauged Basins (Blöschl et al., 2013; Hrachowitz et al., 2013).

(2) We will restructure the manuscript from gauged to ungauged catchments. First, we will show results and discussion about predictive performance and uncertainty at gauged catchment of both hydrograph- and FDC-based calibrations. Then, we will move to compare and discuss the parameter regionalization and calibration with regional FDCs.

(3) We will provide actual FDC-based calibration in combination with three flow signatures at gauged catchments. This will provide interest to readers.

Once again, we are very thankful for your contribution, and please find our response as per your comment below.

This study compares two regionalisation methods for runoff predictions: the traditional spatial proximity and the model calibration against regionalised flow duration curves. I found this study has a very limited contribution to the predictions in ungauged basins (PUB). The major reasons are as follows: 1. There are numerous studies carried out by using various methods for PUB. The hydrological modelling uses spatial proximity, physical similarity and regression to regionalize its calibrated parameter sets to ungauged catchments. There are several studies that used flow duration curve methods for runoff predictions (Shu and Ouarda, 2012; Zhang et al., 2015), which just use observed runoff and catchment attributes to predict runoff time series, but does not need to involve any hydrological modelling. This kind of research is totally ignored by the authors. These researches use the three steps to predict daily runoff: (1) building FDC method (geostatistical methods, statistical methods, etc); (2) estimating flow quantile based on some assumptions; (3) predicting runoff time series. The predictions results are very impressive (see Zhang et al., 2015).

-> We disagree that our approach has limited contribution. A FDC method can show impressive performance; however, it does not guarantee that the FDC method is always

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the best for runoff prediction. The existence of good FDC methods is not relevant to our study. We are focusing on rainfall-runoff modelling in ungauged catchments. Indeed, we never stated that the proximity-based parameter regionalization is the best approach for runoff prediction in ungauged catchments in general. In addition, FDC methods are of relative merits and shortcomings. Despite simplicity of FDC methods, they could be useless when no streamflow data available around the target catchments, except ones using duration of precipitation (e.g. Smakhtin and Masse, 2000; Kim and Kaluarachchi, 2014). In our opinion, streamflow data are generally less available than climatic forcing data (i.e. precipitation and temperatures). The objective of our study is not to directly compare between a FDC method and a parameter regionalization as did Zhang et al. (2015). The comparative study of Zhang et al. (2015) is fundamentally different from our study. We are discussing how to have parameter sets in ungauged catchments when using a frequently used conceptual model for runoff simulations. The two approaches in our study are about how to generate streamflow from atmospheric forcing. The destination of a FDC method and a rainfall runoff model is same (i.e. daily runoff estimation), but the FDC method is to transfer streamflow data at gauged to ungauged catchment. We never intended to directly transfer observed streamflow to ungauged catchments.

As we introduced, parameter calibration with regional FDCs for rainfall-runoff modeling is barely evaluated against conventional parameter regionalization. Both approaches are to have parameter sets for a rainfall-runoff model in ungauged catchments. Can we assure one is better than the other? There is no calibration process in parameter regionalization for ungauged catchments while the FDC-based calibration has it. We intended to answer this question. As you commented, there are a number of methods for runoff prediction in ungauged catchment. This fact rather makes comparative assessments (e.g., Zhang et al., 2015, Parajka et al., 2013, and our study) very important. We believe that a comparative assessment contributes to making a better selection among various methods.

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2. It is not surprise at all to see the calibration against regionalised flow duration curves performs worse than the traditional spatial proximity approach for runoff time series predictions since it does not include any runoff timing information, which is the key for runoff time series predictions.

-> We disagree that the calibration with regionalized FDCs is expected to be worse than the parameter regionalization. Regionalized parameter sets are not ones calibrated to runoff time series at outlets of ungauged catchments. Even though the parameters are calibrated to observed hydrographs at gauged catchments, they have additional uncertainty sources because of regionalization. If regionalized parameters have significant uncertainty, the calibration against regionalized FDCs could be better.

3. The sample number used here is too small. There are only 45 catchments used to evaluate regionalisation skill. Therefore, it is hard to get a generalised conclusion. Moreover, the authors only picked up 28 with good calibration of GR4J and FDC, making the sampling number extremely small.

-> We did not intend to provide general conclusions, but a case comparative study in South Korea. The number of gauged catchments is a given condition in South Korea. Indeed, some regionalization studies have less numbers of gauged catchments (see Figure 4 in Parajka et al., 2013). We believe that "extremely small" is overstating. In revision, we will use all 45 catchments for LOOCV to investigate overall uncertainty in the parameter regionalization and the FDC-based calibration.

4. The objective function. The selection of objective functions has very important implication on the conclusions. The authors used the classic NSE for hydrological modelling calibration/regionalisation. It will be inevitable that the predictions from spatial proximity regionalisation are better for high flow, but poorer for low flow. For a comprehensive evaluation, an objective function that compromises high flow and low flow (i.e. Box-Cox transformed streamflow) should be used.

-> We agreed. In revision, we will use a calibration criterion balanced between high

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and low flows as in Zhang et al. (2015). And, runoff simulations will be evaluated for high and low flows (e.g. using NSE and log NSE)

Specific comments:

1. Introduction. It is not comprehensive. Lots of methods used for building FDC in ungauged catchments are not introduced. Lots of studies using FDC to predict runoff time series are ignored (see the above-mentioned are just some examples). Lots of spatial proximity regionalisation studies are not included. The authors should have a comprehensive literature review from ISI Web of Knowledge.

-> In revision, we will provide more studies on signature-based calibration and FDC regionalization. We will make the introduction more comprehensive.

2. It is very confused for the streamflow gauges used. The authors state that the 45 streamflow gauges used in this study are with negligible regulations (river diversion and dam operation), but they also state that " . . . operationally recorded at 16 multipurpose dams for the Water Resources Management Information . . ." Is it really all the gauges are with negligible regulation?

-> In revision, we will correct the expression "operationally". It means inflows of the dams are routinely monitored for operating reservoirs for areas below the dams. Outflows are regulated, but inflows are limitedly altered. In our sense, all gauges showed natural flow regimes based on the correlation coefficient between CPI and runoff data. If human alteration is significant, we should have outliers from the correlation coefficients

3. Are all gauges not nested? Please clarify

-> Some of them are nested. For clarification, we will place catchment numbers at outlet locations in Figure 1.

4. Cross-validation and regionalisation. I am not against the cross validation (2011-2015) for model calibration and 2007-2010 for model cross validation). For regionalisa-

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tion, I suggest to use the full period of dataset. Bury in mind, there are only nine years data for each gauge.

-> We will consider the entire data period for regionalization. However, we can do nothing about data length. As explained, runoff data before 2007 have poor quality. The influence of data lengths on model calibration is a controversial topic (Seibert and Beven, 2009). Sometimes data quality is more important. During 2009-2015, Korea had significant variation in climatic conditions as shown in the time series of drought indices (Fig. 1 in this response). Thus, we could hypothesize that runoff data have adequate information for calibration though long-term topographic changes cannot be considered.

5. GR4J requires precipitation and potential evapotranspiration for model inputs. It is not clear how the potential evaporation is calculated.

-> We used the temperature-based model proposed by Oudin et al. (2005) for GR4J. We will explain this in revision.

6. Objective function. To have a comprehensive evaluation of these two methods, please also include a Box-Cox transformed streamflow objective function.

-> As replied earlier, we will use a calibration criterion that can consider both high and low flows in revision.

7. First paragraph in section 3.3.1. Please include more references for the three regionalisation approaches.

-> We will provide more related studies in revision

8. Equation (4). How is the constant 3.171 * 10ËĘ-5 derived?

-> This is a simple unit conversion from (mm yr-1 km2) to (m3 s-1). (10-3 m)×(86400×365 sec)-1×(106 m2) = 3.171×10-5 (m3 s-1).

9. The methods mixed with results. Half of section 4.2 should be moved to methodol-

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ogy

-> We will move the sentences to the methodology section.

10. Use all gauges for regionalisation. Please use all 45 gauges for the regionalisation. It makes no senses to me to exclude the 17 catchments with low NSEFDC (<0.80). You can setup prerequisite for PUB. It is not fair for another approach.

-> We will use all 45 catchments for two approaches as replied.

11. Figure captions. It is hard to follow figure captions. Please spell out all the abbreviations. I spent lots of time to figure out these abbreviations.

-> We will recheck the captions in revision.

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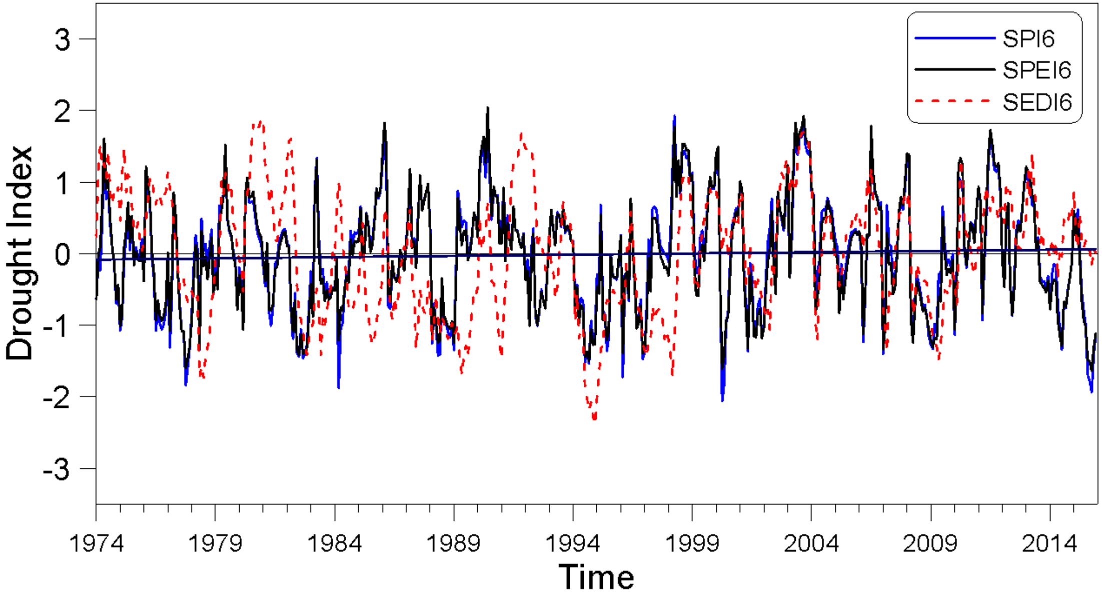

Fig. 1. Drought indices during 1974-2015 in South Korea

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