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Hydrology and Earth System Sciences
Discussions

# *Interactive comment on* "Using variograms to detect and attribute hydrological change" *by* A. Chiverton et al.

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We would like to thank the reviewer for their comments on our paper.

The background literature will be extended at the start to mention some of the other change detection methods which are used for hydrological data, and some of the reviewer's suggestions from the Geostatistics literature. However, as I am sure the reviewer is aware, change detection in hydrology is a huge research area and this cannot be reflected in an introduction. With regards to the method used in Stahl et al (2010), both the paper and a follow up paper (Hannaford et al, 2013) identified that both the magnitude and direction of change are influenced by the start and end dates, with the Thiel-Sen estimator as well as the Mann-Kendall test. This sensitivity to study period



is widely acknowledged in the change detection literature, as clear from a range of reviews of the topic (e.g. Hall et al. 2014, cited in our paper, and references therein).

In terms of the motivation to the paper (why use variograms?), I would like to refer to our response to reviewer number 2. We are going to clarify in the paper that we are detecting changes in the temporal dependence which can be thought of as an indicator of river flow. Temporal dependence is influenced by several aspects of the flow regime (identified by applying artificial changes to the river flow in Figure 4). We agree that any kind of statistic can be calculated in moving windows, and indeed they often are; but that entirely depends on the purpose of the study – Q95 would clearly be more low flow focused, for example. Our study does not set out to detect changes in extremes, rather we examine changes in variability (over a range of timescales) and temporal dependence, which the variogram captures well. We tried to set out our motivation in the introduction, but we agree that we may have focused more on identifying the weaknesses of existing approaches rather than specifying the rationale for our variogram-based approach. We will add more clarity to this, as stated also in the reply to reviewer 2.

With regards to the data transformation, as the reviewer notes, logging the data reduces the amount of variability and enables a better fit for the variogram models. A more detailed explanation is provided in the response to reviewer 1. The paper will be adapted to state this and highlight that the data does not necessarily need to be logged.

With regards to the more specific points:

1) The time resolution of the hydrological data (daily) will be stated in the paper.

2) The statement "In terms of change detection, the key advantages of variograms are: the method is based on raw daily flows" will be changed to "In terms of change detection, the key advantages of variograms are: the method uses the whole daily river flow time series"

3) In a sense, the paragraph that the reviewer highlights was where we have tried to argue the rationale behind using variograms. But in hindsight we agree that this is worded a bit more like conclusion/discussion and so doesn't sit well here. We will add more detailed information on our motivation and some background to why variograms are an appealing avenue, with references (so this section becomes more a hypothesis) in the introduction, and save the more detailed material on the merits of the approach to the conclusions.

4) The frequencies removed during the de-seasonalising are catchment dependent. The frequencies are fitted using the deseasonalize package in R, this will be stated in the paper. This is a standard approach described in Hipel and McLeod (1994) and Chandler and Scott (2011).

5) Page 11770, line 13 will be changed to the reviewers recommendation of "Based on the transformed, de-seasonalized standardized flow data".

6) The Nugget is approaching zero, particularly in groundwater dominated catchments, however, it is not zero and this will be mentioned in the paper, with some discussion on the significance of this and interpretation of the variogram parameters in Section 3.2 (see also our replies to reviewer 1 in relation to the Nugget and the Sill).

7) The time shifts are 1 year and this will be stated in the paper.

8) We will change the paragraph from: "Autocorrelation is present in the variogram parameter time-series. Whilst this will not influence the amount of bias or consistency of the precipitation characteristics, positive autocorrelation will influence the efficiency of the explanatory variables and therefore overestimate the significance. However, analysing the residuals (using the Durbin-Watson test for autocorrelation disturbance) showed no significant autocorrelation. Therefore, regressing against several precipitation variables with similar autocorrelation to the variogram parameters (both averaged over five year moving windows) series adequately removes the autocorrelation."



To: "Positive autocorrelation would influence the efficiency of the explanatory variables causing an overestimation the significance. However, analysing the residuals from the MLR between precipitation and river flow (using the Durbin–Watson test for autocorrelation disturbance) showed no significant autocorrelation. Therefore, it is deemed that, regressing against several precipitation variables with similar autocorrelation to the variogram parameters (both averaged over five year moving windows) series adequately removes the autocorrelation."

9)Temperature and hence evapotranspiration could be indeed important factors which are not included in the MLR model. We did include soil moisture deficit (which accounts for evapotranspiration to a degree) in an earlier version, but it was not felt to be meaningful when calculated over long windows. Additionally snow could be important in some years, particularly in upland catchments. More detail will be added to the discussion. At 11780, L11, we note that other meteorological characteristics could be important. We will add more detail on the possible importance of evapotranspiration and snow as an avenue for further work.

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