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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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The authors would like to thank the reviewer for their insightful comments regarding the use of geostatistical methods in a non-stationary context. These comments reflect issues around using global variograms to provide an absolute description of the temporal autocorrelation of the data. However, this paper is not aiming to provide such an absolute description for the purposes of prediction; rather, we seek to characterise temporal changes in 5 year moving windows relative to the variogram created over 30 years. We appreciate that some more detail about the assumptions of the method is needed before publication. We have addressed the reviewer's four comments below:

It is clearly difficult to test for stationarity as in all cases we only have one realisa-

tion of the variogram expressed in the data. However, if one assumes stationarity is present, then the variogram parameters in both the moving windows and the overall variogram parameters should, within some range due to random error, be coincidental. We previously developed something similar for spatial data (see Corstanje et al., 2008), in which we looked at local deviations from a global variogram behaviour. The point here is that we are not trying to ascribe the behaviour in the global variogram as the definitive expression of the autocorrelative structure, but rather we are proposing a method in which we are looking for differences between variograms at different time scales. Where we see such significant differences, then clearly the temporal autocorrelative structure has changed and this may be due to climatic change or changes in the catchment characteristics (including land management). A section will be added to the description of the variogram outlining that we are not aiming, and that the method may not be appropriate, to provide the precise autocorrelative structure of the river flow time series.

That is not entirely the case, but is true regarding the relationships between the variance components. It is the relative contribution of the variances that are affected by the transformations (as taking logs stabilises the variance) rather than their temporal dependencies. Again, we are not aiming at providing a precise characterisation of the temporal autocorrelation of the time series, rather, we are examining the change in temporal autocorrelation. These relative changes are indeed determined in a log-transformed environment, but relative to each other. The log transformation may impact the relative magnitude of the changes and this is something we will add to the discussion.

That is assuming the anomalies are structured and appear more consistently towards a particular period, which in, and of itself, is interesting and precisely what the method is set up to detect. The method is set up to detect relative differences from a postulated mean behaviour. To reiterate, if the underlying catchment is stationary in the mean and variance and the surrounding behaviour is random noise, then the moving window

statistics should correspond to the global statistics, and we are dealing with a very uninteresting catchment. If, on the other hand, we find the moving window statistics do not correspond with the overall model, then there is non-stationary behaviour, which would allude to changes in the catchment. We then look for structure in these deviations and try to understand if they are meaningful. These deviations could be related to trends in the mean or the variance.

The Sill of a variogram is the sum of the nugget and the variation which is attributed to temporal autocorrelation. There is some discussion in the literature as to whether the nugget is due to random behaviour, or whether it is attributable to behaviour at sampling intervals smaller than that considered in the study. When the variogram is 'pure nugget' then arguably one could attribute the Sill to random behaviour, but if the nugget is smaller than the Sill, then there exists a variance component that is temporally correlated. In response to the concern in that we are attributing meaning to outcomes of a process that is essentially random noise superimposed on a trend, we emphasise that we are considering here the Sill, the Range and other variogram properties. The variogram is a function of the semi variances, which do increase with an increase in magnitude (upwards trend) or decrease with a decrease in magnitude (downwards trend), and this is one of the properties we wish to pick out for the analysis (in this sense, this is no different to some of the other trend analyses such as the unit root tests – e.g. Augmented Dickey–Fuller test). But beyond the general trend, this method also allows us to determine local changes at key time intervals which general trend analysis would not be able to supply.

References Corstanje, R., Grunwald, S., and Lark, R. M.: Inferences from fluctuations in the local variogram about the assumption of stationarity in the variance, Geoderma, 143, 123-132, http://dx.doi.org/10.1016/j.geoderma.2007.10.021, 2008.

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