

***Interactive comment on “Catchments as  
space-time filters – a joint spatio-temporal  
geostatistical analysis of runoff and precipitation”  
by J. O. Skøien and G. Blöschl***

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We would like to thank Prof. Gottschalk for his very positive and helpful comments on the manuscript. We have addressed the comments as follows (referee comments in italics):

**2. DETAILED COMMENTS:**

p945

*The results are evaluated as averages over basin size classes. This approach actually assumes that all basins are non-nested. The covariance and thereby also the semi-variogram have different principal structures between nested and non-nested basins (Gottschalk, 1993a). The covariance is non-stationary with the growth of catchment*

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Discussion Paper

area along a river.

See response below.

p946

*hs is taken as the distance between the centres of gravity between catchments. For me this is not an obvious distance measure between catchments. The average over all possible distances between pairs points in the respective catchments, or shortly the Ghosh distance as I suggest to call it (Ghosh,1948) , is a more logic alternative. It behaves better when we deal with nested and non-nested catchments. Furthermore it gives a correct variance estimates for a catchment for which the distance between centres of gravity is zero while the Ghosh distance is not. It is not clear to me how nested catchments have been handled. The correlation between nested catchments is usually very high compared to non-nested ones, as was commented on above. Have the nested catchments been excluded?*

We have not excluded the nested catchments as we believe it is not necessary in the approach used in this paper. Nested catchments within the same size class typically have a small distance between their centres of gravity. This corresponds to overlapping schematic catchments in the back-calculation approach. On the other hand, non-nested catchments are represented by schematic catchments that do not overlap. The back-calculation approach as presented in this paper is hence an approximation of the variance reduction for both nested and non-nested catchments.

The Ghosh distance would indeed be a logical and viable alternative to the distance between the centres of gravity used in the paper. The reasons why we used the centres of gravity in this paper are as follows. Gosh distances, generally, are defined in two different ways, either including the contribution of the distances within each catchment or not including them. The two formulations differ significantly for the same set of catchments. As we work with regularised variances, the Ghosh distance would also have to take into account the distances within each catchment. For small catchments close to

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the centre of a much larger catchment, this formulation of the Ghosh distance would be substantially different from the distance between the centres of gravity. However, as we have divided the catchments into size classes, the difference between this version of the Ghosh distance and the distance between the centres of gravity is smaller and we believe it can be neglected in view of the other approximations involved. On the other hand, the back-calculation of the variograms is somewhat simpler if one uses the distance between the centres of gravity as compared to the Ghosh distance.

p947

*Several spatio-temporal semivariogram models have been applied in the structural analysis. The criteria for the selection are that they should satisfy the condition of conditional positive definiteness and be non-separable. The number of parameters differs between the four models selected. If I have understood it correctly, the exponential model contains 7 parameters, Cressie-Hung 8, product-sum 11 and fractal 4. The only firm conclusion drawn in the paper is that the fractal model alone does not give a sufficient good fit to the data set. So with this exception the models are flexible enough to give a good fit to the sample semivariograms. This is maybe good enough for a structural analysis.*

*What I find more problematic is to evaluate what these models really tell us about the hydrologic processes. It is very difficult to tell what the many parameters reflect. Taking the Matèrn class of covariance functions as an example we know that the two parameters of these represent scale and smoothness of the process. Covariance functions can also be derived with a starting point in partial differential equations where then the parameters of the covariance function are referred back to the parameters of these equations. It would be worthwhile to narrow the class of semivariogram models to those more process oriented and try to reduce the number of parameters. Both for the structural analysis, as well as the estimation (interpolation) it is a general observation that the results are not very sensitive to the choice of the theoretical semivariogram/covariance. It is not until we turn to simulation that we really see the effect of*

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*the theoretical model.*

The level of detail of inferring process information from variograms is indeed limited. We believe this is because of at least three reasons. First, they are second order (variance) estimators, so any higher moments are neglected. Second, the point variogram is a downscaling of the observed variances at the catchment scale, so there will be a limit to the amount of information on hydrologic processes at the point scale that can be inferred. Third, if the variogram contains a large number of parameters, it may be difficult to estimate them from a given data set. It is the last point the comment of the reviewer refers to, we believe. In any model application, there is a trade-off with the number of parameters that can be estimated. If the number of parameters is too large, there are issues with identifiability and the parameters will be uncertain. On the other hand, if the number of parameters is too small, the model will be too coarse an approximation to the data. Clearly, the optimum choice of the number of parameters depends, among other things, on the amount of data that is available (see Grayson and Blöschl (2000), for example). The amount of data used here is immense ( $>10^8$  individual data values), so we felt that up to 13 parameters may be a sensible choice. It is also true, however, that the uncertainty of some of the parameters is large (Table 6). We have experimented with different types of variogram models with fewer parameters but preliminary analyses suggested that the fits were not very good. The poor fit of the fractal model is also, partly, related to the small number of parameters which may be lower than the optimum in the trade-off mentioned above. It may be of interest to examine a wider class of variogram models as suggested by the reviewer. However, we do not consider this an essential part of the current paper as three types of variogram models are already analysed.

*The scaling exponent “kappa” is a fundamental parameter in the paper, as well as the parameter “mu”. It is never shown straightforward how they are determined. I understand it as two extra parameters added to those of the theoretical semivariogram models. If so, it would be of help for a reader if they appeared in the final versions of*

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*the applied semivariogram models (eqs. 9-12).*

Yes,  $\kappa$  and  $\mu$  are indeed fundamental as they embody the space-time link of the catchment filtering. The reason these two parameters do not appear in Eqs. 9–12 is that they are not part of the point variogram models of Eqs. 9–12 but characteristics of the filter imposed on the point variogram models. Highlighting the importance of the two parameters and the way they have been estimated is useful as suggested by the reviewer. We have therefore made the following changes to the text on page 955:

“... The procedure was repeated for each variogram model and for precipitation and runoff separately. The parameters  $\kappa$  and  $\mu$  of Eq. 15 were also simultaneously fitted by this procedure, separately for each variogram model. The response time of the catchments is hence a result of the fitting procedure. The scales of the diagrams of the spatio-temporal variograms are scaled linearly in terms of the bin spacing. ...”

p949

*All semivariogram models contain fractal components for time and space to compensate for non-stationarity. Would it be sufficient with only a fractal model in space? The estimated parameter values of the fractal part of semivariogram models shown in Table 6 give a very confusing picture. They differ very much between models. What conclusions can be drawn about non-stationarity and about semi-variogram models? On page 948 it was commented that daily precipitation is almost stationary in time but not in space.*

The non-stationarities in both space and time are important for the regularisation procedure even if they are small. A fractal model in space alone would not be sufficient. This aspect has been added on page 948:

“The variograms were therefore modified to account for non-stationarity in both spatial and temporal directions. Although Skøien et al. (2003) noted that runoff was almost stationary in time, a small non-stationary part was found to be necessary for the regularisation procedure in this paper. For application ...”

The parameters of the fractal parts of the semivariogram models differ for two reasons. First, the point variograms are estimated by a sort of downscaling from the catchment runoff data, so some scatter would be expected as discussed above. Second, the parameters of the fractal parts represent the ratio of added variance to the existing variance by increasing the distance. This ratio will depend on the variogram model. In other words there will exist some interdependence between the parameters of the fractal part and the other parameters of the variogram model. For clarification, we have added a comment at the end of chapter 5.3 on page 965:

“This, again, is plausible because of the memory induced by soil moisture and local ponding. The non-stationary (fractal) parts of the variograms are more difficult to interpret. The parameters differ between the variogram models which is likely a result of the interdependence of the parameters of the fractal part and the other parameters of the variogram models. As the levels of the stationary parts of the point variograms differ, so will the non-stationary parts in the different models.”

### 3. MINOR CORRECTIONS

p949, eq (8)

*the exponent “a” should be changed to “alfa”;*

This was a typo and has been changed.

p967, line 15.

*my copy of this paper is from volume 136 and not 16.*

This was a typo and has been changed.

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## References

- [1] Grayson, R. and Blöschl, G.: Spatial modelling of catchment dynamics. Chapter 3 in: R. Grayson and G. Blöschl (Eds.) *Spatial Patterns in Catchment Hydrology: Observations and Modelling*. Cambridge University Press, Cambridge, UK, pp. 51-81, 2000.
- [2] Skøien, J. O., Blöschl, G., and Western, A. W.: Characteristic space-time scales in hydrology, *Water Resour. Res.*, 39(10), SWC111–SWC1119, doi:10.1029/2002WR001736, 2003.

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