

# ***Interactive comment on “Spatially shifting temporal points: estimating pooled within-time series variograms for scarce hydrological data” by A. K. Bhowmik and P. Cabral***

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Dear Anonymous Referee #1

We would like to thank you for the useful and inspiring comments that helped us to substantially improve the manuscript. We agree with your opinion that the advantages of our method over the existing method as well as some methodological contents were not clarified in the previous version of the manuscript and hence, led to misunderstanding. We extensively revised the manuscript addressing your comments and clarifying those contents, that you would find in the attachment. Moreover, we inserted two

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clarifying figures in the supplementary materials that we also added at the end of the revised manuscript for your convenience. Below we provide a point-by-point reply to your comments.

Given that the discussion phase will last until the end of April, we are looking forward to your comments on the revised version of the manuscript.

Best Regards Avit Kumar Bhowmik and Pedro Cabral

Reply to referee's comments:

RC 1:

In this manuscript, Bhowmik and Cabral tackle an incredibly relevant problem confronting the use of geostatistical tools in the hydrologic sciences. Namely, they seek to improve the representation of spatial structure in time series of climatic phenomenon. Their tool, spatially shifting temporal points (SSTP), allows for a representation of spatially distributed time series, which are inherently three-dimensional at least, in a single two-dimensional space. This allows for a fitting of a single variogram across both space and time. As it is, this technique is shown to be superior to the simplest technique of spatio-temporal variogram modeling, an averaging of temporally-independent variograms. The authors conclude by arguing that their technique, by expanding the number of data points in a single space, may be applicable for data-scarce regions.

Having reviewed this manuscript, I feel that it should be reconsidered pending major revision. It is a significant contribution to the development of geostatistical tools in hydrologic sciences, but I was confronted with a few significant methodological questions that should be addressed before final publication. As I will explain, my major concern is that the authors have presented their method as more convoluted than it need be. I do not dispute its effectiveness, only its conceptualization. Beyond this, there a few claims that I would ask the authors to further substantiate. I will conclude with a brief, though non-exhaustive list of technical corrections.

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In presenting their method as a technique that shifts temporal points in space, the authors inadvertently over-complicate their method. It appears to me that this approach is nothing more than a pooled variogram model. Because the authors restrict the averaging in equation (4) to spatial-lags within the limits of the maximum and minimum across time series and the spatial shift ( $d$ ) is beyond twice the largest spatial lag, none of the semivariances used to construct the empirical variogram cross between clusters in figure 2. This is, of course, as it should be. Effectively, this can be explained without the complication of spatial shifts. All that has been done is that the semivariances at each time step have been pooled together, binned and averaged to produce a single empirical variogram. If all the time series of are the same length, than SSTP and AEV would be more than just “similar”, as noted in line 9 of page 2255, rather they would be identical. By another view, if the empirical averaging of AEV were weighting by the number of points in each bin at each time step, then SSTP and AEV, I believe, would be identical. The AEV, by averaging empirical variograms rather than pooling the semivariances, simply assumes that each empirical variogram should be equally weighted. This is not the case for data sets of vary size, which the authors’ method corrects. If there is some other advantage to spatial shifting, the authors have not made it clear.

In identifying this over-complication I, in no way, intend to detract from the value of this technique. I feel that it presents as a viable tool for estimating pooled variograms. It is a relevant competitor to the methods presented by Gräler et al. (2011), and especially useful in the case of time series of different lengths. I strongly encourage the authors to reconsider their technique in this new light, revise the manuscript and resubmit. In the hopes of improving the future manuscript, I will now provide some additional, lesser concerns.

AC 1:

We appreciate your acknowledgement of the contribution of our geostatistical tool to hydrological sciences. We also agree that the advantages of SSTP over AEV was



not clarified that led to the misunderstanding. We expanded on the advantages of spatial shifting on P 6 | 19-27, P7 | 1-2 and | 11-23. Moreover, we explained the methodological differences between SSTP and AEV in the supplementary Figure S3. In fact, the major difference between SSTP and AEV is that SSTP computes a single empirical variogram for a spatial-lag by simultaneous comparison of point pairs from all time steps within a pooled time series, whereas AEV computes separate empirical variograms for individual time steps and averages them. In reply to your comment, SSTP does not pool the semivariances from years, rather pools the data points (with observations). Hence, the semivariances computed for individual time steps (using Eq. (4) of our paper) by AEV may be erratic due to a low number of comparison and in turn the averaged empirical variogram may also be erratic (described in P 3 | 15-21 and P 11 | 4-19). By contrast, SSTP simultaneously compare substantially higher number of point pairs than AEV and yield precise variograms that is only attainable by spatial shifting (regular spatial variogram computation technique is applied). The maximum spatial-lag was set as two-fold the largest spatial-lag available within a pooled series to avoid the inclusion of temporal variability as pseudo spatial variability, as described in P 8 | 1-5. Consequently, for time series of equal length SSTP computed variograms are different than AEV computed variograms and show higher precision. For the time series of varying lengths, weighted AEV improves the variogram estimation (as shown in the supplementary Figure S4) but the SSTP computed variograms are certainly not identical to AEV and SSTP indeed shows higher precision because of simultaneous and higher number of comparisons (please also see P 12 | 3-6).

RC 2:

The authors claim that AEV is the only alternative for estimating pooled variances across time, citing the work of Gräler et al. (2011) [lines 12-15, page 2246]. Firstly, Gräler et al. (2011) provide a large number of methods for variogram prediction, but it is unclear why Bhowmik and Cabral have rejected these other methods. Furthermore, it is unclear which method AEV corresponds to in Gräler et al. (2011). From the de-

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scription, it seems that the authors applied the pooled variogram model (model c in section 2.4) from Gräler et al. (2011). This is surprising as it is not the best method identified by Gräler et al. (2011). (If this is not the case, I encourage the authors to clarify which technique was applied. My discussion above assumes that AEV is Gräler et al.'s (2011) model c in section 2.4.) How does SSTP compare to something like the mean variogram (model d of section 2.4)?

AC 2:

We agree that we did not indicate the method in Gräler et al. (2011) that corresponds to AEV and did not compare SSTP with other variogram estimation methods. This was because of two reasons: (I) in this paper we particularly focused on improving pooled variogram estimation and hence only compared with existing pooled variogram estimation method (i.e. method c in Gräler et al. (2011), as you correctly identified and AEV is shown to be the only existing method for estimating pooled variances by Gräler et al. (2011)) and (ii) the other variogram estimation methods described in Gräler et al. (2011) that correspond to individual variograms (a and b), mean variograms (d and e) and spatiotemporal variograms (f, g and h) are not applicable for our data, i.e. the numbers of data points do not meet the threshold for reliable variogram estimation in any time step and lengths of time series for the data points are highly variable. We expanded on this on P 2 | 21-32 and P 3 | 1-14, and suggest the comparison of SSTP with spatiotemporal variograms as an outlook on P 14 | 7-12. Moreover, we specified the used method from Gräler et al. (2011) on P 9 | 12 and Figure S4. In addition, please note that Gräler et al. (2011) did not compare the variogram estimation methods, rather compared the spatial interpolation methods that demanded different variogram estimation methods.

RC 3:

The authors claim that SSTP improves estimates in data-scarce regions, regions with only a few small-lag or large-lag sites, but this claim is unsubstantiated. Their method

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only improves extreme-lag estimates when the time series are not of equal length. The technique, as it is, does not increase the information content at extreme lags and therefore does not seem to improve the predictability at small lags. If all of the time series were of equal length, the method would still be limited to the most extreme lags available. With this in mind, I do not think that it can be claimed that SSTP, in of itself, improves extreme-lag estimates. Consider a “data-scarce” region where all stations, with varying record lengths, are 100s of kilometer away from each other. Would SSTP really improve the small-lag estimates in this data-scarce region?

AC 3:

We agree that the claim of SSTP improving short distant spatial variability modeling was not substantiated and also led to misunderstanding. To clarify, SSTP (and pooled variogram in general) does not increase the information content for a variable (e.g. hydrological index) at small lags in the time steps where information is not available, and hence does not improve the predictability of the variable itself (as you stated). However, it increases the information content for spatial variability at short distance in time steps with large spatial lags subsidizing with the information from time steps where smaller spatial-lags are available. It is indeed inherently dependent on the availability of spatial-lags within a time series as you correctly stated and is not achievable if a small spatial-lag is available in no time step. Moreover, the spatial predictability of the hydrological variable still remains uncertain for time steps with large spatial-lags, only spatial variability can be modeled with reduced uncertainty. We expanded on this and substantiated the claim on P 2 | 31-32, P 3 | 1-5, P 6 | 26-27, P 7 | 1-2, P 8 | 1-3 and P 13 | 5-22.

RC 4:

Finally, I would ask the authors to briefly consider the issue of temporal dependence or autocorrelation. This point is less a critique on the present manuscript, and more of a consideration for future work. To my eye, the current methods (SSTP and AEV)

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do nothing to preserve the temporal structure of the data set. Would an estimated timeseries at an ungaaged site represent the correct autocorrelation structure? Surely this is of some importance in time series modeling.

AC 4:

We would like to thank you for drawing our attention on this issue and we discussed this on P 13 l 23-32 and P 14 l1-2.

RC 5:

Having presented these thoughts for your consideration, I will present a list of minor, technical corrections. Before doing so, I wish to thank the authors for a stimulating and encouraging manuscript. I sincerely look forward to their revisions or rebuttal.

Suggestions for technical corrections:

p. 2244, l. 03: "... spatial[ly] data-scarce regions..."

p. 2244, l. 04: Remove the phrase "conditional that time series are available"

p. 2244, l. 26: "..., i.e. [the] spatial variogram[,...]"

p. 2245, l. 01: strike the word "estimation" and end the sentence after the Webster citation.

p. 2245, l. 02: strike the word "while" and start a new sentence at "[T]he precision of [the estimated] variogram strongly dependes...."

p. 2245, l. 03: Insert a comma after "data points"

p. 2245, l. 07: Remove "(reliable)"

AC 5:

All technical corrections have been conducted addressing your comments.

RC 6:

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p. 2245, l. 14: Remove hyphen and insert a comma after “smallest spatial-lag”. Note, it is unclear how Sstp fixes a limitation from small lags.

p. 2245, l. 20: Insert a comma after the parenthetical and strike the word “spatial”

p. 2245, l. 21: Remove the entire ending clause “conditional that a time series of hydrological data is available”

p. 2245, l. 25: The sentence starting on this line and proceeding to (p. 2246, l. 2) should be revised. One example might be “The advantages of PTS variograms over individual variograms are: (i) The number of point pairs is considerably increased, reducing the noise in empirical semivariograms and increasing the precision with which variograms can be estimated. (ii) The smallest spatial-lag is considerably decreased by including multiple time steps. Because of the stations being operable over different periods, different time steps may possess smaller spatial lags. Pooling allows these shorter distances to play a more significant role in the fitting of a stable variogram (Schuurmans et al., 2007).” Note that this second point is the one that I contest earlier. The shorter records are handled better here, but they do not improve uncertainty in short-lags.

## AC 6:

All technical corrections have been conducted addressing your comments. Moreover, we expanded on the claim of Sstp reducing uncertainties for short distance variability modeling on P 2 l 31-32, P 3 l 1-5, P 6 l 26-27, P 7 l 1-2, P 8 l 1-3 and P 13 l 5-22.

## RC 7:

p. 2246, l. 09: Replace “numbers of data points within a” with “lengths of”

p. 2246, l. 10: Replace “while” with “and, as previously discussed, the”

p. 2246, l. 22: “... spatial[ly] data-scarce..”

p. 2246, l. 23: “sufficient”, not “insufficient”, right? p. 2246, l. 24: “outline”, not

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“outlined”

p. 2246, l. 25: “...them[. We call this] “spatially...”

p. 2246, l. 28: “... spatial[ly] data-scarce...”

p. 2247, l. 05: Where is this data from? Please describe the source in addition to providing a citation.

p. 2247, l. 06: Remove “(data points)”, revise to “...Bangladesh, classifying the...”

p. 2247, l. 07: Remove “because the number does not meet the threshold for satisfactorily precise variogram estimation”

p. 2247, l. 09: “...in 2007[, indicating variably] imprecise spatial variograms for individual ...”

p. 2247, l. 14: Remove the two commas.

p. 2247, l. 20: “in” not “on”. Combine to a single sentence “...’gstat’ (...), ‘intamap’ (...) and ‘spacetime’ (...) packages.”

p. 2248, l. 07: Remove “Hereafter,” revise to “...was [then] applied [to] the correlation...”

p. 2248, l. 09: Remove the “in” at the last sentence

p. 2248, l. 16: “check [to ensure that] the numbers of pooled...”

p. 2249, l. 01: Please wrap the coordinate x,y in parenthesis. The same can be said of s,s. As it is, the terminology is very unclear.

p. 2249, l. 08: N remains undefined.

p. 2249, l. 20: Insert a comma before “and shifts”

AC 7:

All technical corrections have been conducted addressing your comments.

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RC 8:

p. 2249, l. 25: It is unclear how the shift represent a spatially rescaled temporal distance. Please compare this to the spatially rescaled temporal distance of Gräler et al. (2011) to clarify.

AC 8:

We expanded on the spatially rescaled temporal distance and compared with Gräler et al. (2011) on P 6 l 11-14.

RC 9:

p. 2251, l. 25: “The [SSEs of] previously fitted variogram models were compared and the best-fit...”

AC 9:

The technical correction has been conducted addressing your comment.

RC 10:

p. 2252, l. 02: “model [form] was” Was the full “best-fit model” used or was the model form recalibrated using a CV routine before providing an estimate?

AC 10:

The technical correction has been conducted addressing your comment. Moreover, we expanded on the reasons behind not recalibrating model forms using cross-validation on P 9 l 5-9.

RC 11:

p. 2253, l. 18: “Consequently, the PTS variograms [estimated] by SSTP...”

p. 2253, l. 20: “... in cross-validation, [showing] higher...”

p. 2253, l. 25: Insert a comma after 2007.

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AC 11:

All technical corrections have been conducted addressing your comments.

RC 12:

p. 2253, l. 26: Note that you cannot compare SSEs between these periods, because they are sums of different numbers. Instead, you should present mean squared error. p. 2253, l. 28: The number of points is not the only difference here. As you noted earlier, the spatial structure is inherently different. It could be that one structure is more easily modeled than another, regardless of the number of points. I do not feel this claim is substantiated by SSE. It is substantiated, I believe, by MSE.

p. 2254, l. 17: Remove the entire parenthetical phrase.

p. 2255, l. 14: Cannot compare SSE, show MSE.

p. 2256, l. 25: "in" not "on"

p. 2257, l. 05: Insert a comma before "will increase..."

AC 12:

We would like to thank you for suggesting mean squared error instead of sum of squared error that we implemented in the paper. Moreover, all technical corrections have been conducted addressing your comments.

Additionally, we checked for grammatical and typographical issues throughout the manuscript and corrected where necessary.

Please also note the supplement to this comment:

<http://www.hydrol-earth-syst-sci-discuss.net/12/C820/2015/hessd-12-C820-2015-supplement.pdf>

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