

## ***Interactive comment on “The design, deployment and testing of Kriging models in GEOframe” by Marialaura Bancheri et al.***

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The authors thank the reviewer for her/his observations, which helped us to improve our manuscript. This response does not yet produce a new manuscript, which will be submitted after the closure of the review phase, upon request of the Editor. We introduce here, however, the main adjustments that we will make in the final version of the revised paper based upon the reviewer's suggestions.

General Comments Overall quality of the paper

R1: Firstly, thanks the authors for this manuscript that delivering a new software product to science world is important for diversity and productiveness. In addition, I want to remark that the review is to improve the paper. The paper presents an interpolation

C1

package for climatic and environmental variables. The objectives of the paper are to bring an alternative package, which is applicable with good performance. By using Kriging techniques, the modeling spatial distribution of hourly temperature and rainfall in an Alpine catchment located in north of Italy and leave-one-out cross validation of the model are the scope of study. And it is suitable in terms of themes of GMD journal.

A1: We thank the reviewer for this recognition.

R2: The paper is generally clear and well-written; the methods, assumptions and results are rationally structured and presented, but I think the language has some issues in the sense of fluency. In the manuscript, the structure of parenthetical sentence is overutilized. Instead of this structure, simple and short sentences with proper conjunctions must be preferred for fluency and explicitness of text. Clarity of the manuscript can be enhanced a bit more by using clear, fluent and open expressions. In addition, I do not approve the separation of word with a hyphen at the end of the line.

A2: The manuscript will go through an extended revision of the English grammar and fluency

R3: In my opinion, the paper is at good level in terms of significance, quality and reproducibility of scientific and presentation quality has a fair level. I think it could be accepted after revision of the manuscript.

Advantages of the manuscript: A new open source software product Comparison of 4 types of Kriging and 11 semivariogram models Comparison with R gstat in terms of multi-model approach

Disadvantages of the manuscript: The lack of multi-site (which have different geoclimatic characteristics) comparison Independence of validation dataset The insufficiency of rainfall data used (the modeling of a single storm event does not provide insight into the good performance)

A3: The scope of the paper is to present a new geostatistical tool, which could be a

C2

good competitor of other open-source software. The strength of our product is not only its capability to do a good Kriging interpolation but also the possibility to be used as stand alone or plugged to a hydrological model. We believe also that the engineering of our software (an aspect usually neglected in scientific reports) could be of interest for GMD readers. As stated in some of the following answers, a deeper assessment of its performance has already carried out in other works by the Authors, (Formetta et al. 2014, Abera et al. 2017). The two previous works include multi-site comparisons, modelling of different rainfall dataset and the assessing of the impact of the type of Kriging and theoretical semivariogram model on the mean annual runoff. Therefore performing here these analysis would not add very much to literature.

Specific Comments Major-minor issues (criticisms), review based sections, clarification of figures and tables, evaluation of references, questions.

(1) Against the possibility of future modifications, the title must include version number (v. 0.9.8) of the model.

The number of the version, as the reviewer said, is an important information that should be added. However, since in the title no reference is made to the SIK package, we decided to add it in the Introduction Section.

(2) In the abstract, time scale (hourly) of used data could be mentioned. Also, "2008 year hourly temperature", "rainfall storm event (11 h) in 2008" and "spatio-temporal distribution of climatic and environmental variables" expressions could be included in the abstract.

We added the suggested information about the spatio-temporal distribution of the used data.

(3) The importance of the study for hydro-meteorological studies can be processed in some more detail in the abstract and the introduction.

We added more references and details about the impact of the interpolation on hydro-

C3

meteorological studies in the introduction. In particular we added the following sentences and references, using also other reviewer's comments: " These data, besides being important by themselves, are the natural input to distributed and semi-distributed hydrological models. Their quality and precision affect the accuracy of results, (Xu and Singh, 1998; Stooksbury et al., 1999; Balme et al., 2006; Abera et al., 2017). In fact, all the surface waters models require a reliable precipitation dataset that is complete both in space and in time. Quite often, however, datasets of hydrological variables suffer from errors and missing data, therefore, filling the gaps in time series by estimating the missing values is a common approach to solve this problem, (Eischeid et al., 2000; Saghafian and Bondarabadi, 2008; Di Piazza et al., 2011; Adhikary et al., 2015)."

(4) A bit more of recent references on Kriging as itemized below can be given in introduction section. Moreover, references on Kriging open source algorithms can be added and it is provided the differences of between this paper and the current literature.

Saghafian and Bondarabadi, 2008. "Validity of regional rainfall spatial distribution methods in mountainous areas". Di Piazza et al., 2011. "Comparative analysis of different techniques for spatial interpolation of rainfall data to create a serially complete monthly time series of precipitation for Sicily, Italy". Bostan et al., 2012. "Comparison of regression and kriging techniques for mapping the average annual precipitation of Turkey". Wang et al., 2014. "Comparison of interpolation methods for estimating spatial distribution of precipitation in Ontario, Canada". Adhikary et al., 2016. "Genetic programming-based ordinary kriging for spatial interpolation of rainfall". Jin et al., 2016. "Estimating Loess Plateau average annual precipitation with multiple linear regression kriging and geographically weighted regression kriging".

As a reference, the study of titled "A statistical approach to some mine valuations and allied problems at the Witwatersrand" by Krige (1951) which is the originator of Kriging method, can be quoted within the framework of respect for labor. As you know, Kriging method is named after him.

C4

All the previous references are really interesting and worth to be mentioned in the paper. Some of the references were added in the Introduction section, as shown in the previous answer. However, since the principle aim of our work is not to assess the Kriging interpolation but to present a new package, open source, Java-based, well integrated in a hydrological model, in the perspective of reproducible research, a comparison between the previous papers and ours is out of the scope of the paper.

(5) Kriging methods are geostatistical methods that consider the spatial autocorrelation of sample data. Due to be based on stochastic process, Kriging assumes that sample data is stationary and normally distributed. And the data needs the de-trending and de-clustering processes. In this context, fit of normal distribution and autocorrelation function are analysed. Normal distribution and spatial autocorrelation of residuals are even investigated. Within this context, detailed information about the processes of outlier treatment, normalization, detrending, declustering, optimization of semivariogram model and neighbourhood search must be provided.

One of the major comments of the Referee #2 is that we dedicated too much space to the description of the theoretical basis of the kriging and to the analysis of the results in Section 5. Therefore, according to his/her reviews, we will try to shorten the theoretical and the result parts, to give more space to the informatics description. Some of the previous information (treatment of the outliers, neighbourhood search, optimization of semivariogram) are already given in the related sections of the paper and, according to us, add further parts would make the paper less readable and our contents less effective. For example, in the Setup subsection the description of the treatment of the outliers, the choice of the number of bins of distances, the information on the neighbourhood search were discussed.

(6) In introduction, some open source geostatistical tools are given. In addition to them, software products such as; GRASS ([grass.osgeo.org](http://grass.osgeo.org)) GSLIB ([www.gslib.com](http://www.gslib.com)) Surfpack ([dakota.sandia.gov/content/surfpack](http://dakota.sandia.gov/content/surfpack)) jk3d ([sourceforge.net/projects/jk3d](http://sourceforge.net/projects/jk3d)) Map Window ([mapwindow.org](http://mapwindow.org)) SGeMS ([sgems.sourceforge.net](http://sgems.sourceforge.net)) GitHub Py Krige

C5

([github.com/bsmurphy/PyKrige](https://github.com/bsmurphy/PyKrige)) QGIS ([qgis.org](http://qgis.org)) uDig ([udig.refractor.net](http://udig.refractor.net)) GeoDa ([spatial.uchicago.edu/software](http://spatial.uchicago.edu/software)) ArcGIS ([arcgis.com](http://arcgis.com)) -even it can be counted from the point of view of integrating open source codes -can be indicated.

The Authors thank the reviewer for this list of alternative software. Some of these packages are actually open source, easy to import into a custom script and actively developed. Between them, it is worth mentioning: PyKrige: a documented and actively developed python package. It covers both 2D and 3D ordinary and universal Kriging; Dakota (Surfpack): well documented and actively developed C++ software. These represent very good competitors of the SIK package, as well as gstat. However, SIK is the only Java and component-based software. QGIS and GRASS (v.kriging) krigitings are both encapsulated into GIS software and are easy to include into scripts leveraging GIS capabilities. Making them part of a modeling solution is pretty cumbersome though. Map Windows is yet open source, available on github and actively developed but it is GIS-based and mainly Windows OS oriented. The other packages are old, hardly accessible or poorly documented. Eventually, ArcGIS is not open source.

(7) The study contains continuous modeling of temperature and event based modeling of rainfall by SIK package. Temperature outputs are also compared with R gstat. Although temperature is more stable climatic variable in according to the spatial distribution, precipitation is more changeable that has more the spatial variance. Thus, I think continuous modeling and comparison with different package results of precipitation make greater contribution to this paper.

According to the reviewer suggestions, we added also a comparison of the results of precipitation interpolation.

(8) It is stated that plug-in to a hydrological model of the SIK model is easy. Entering more details about this will be good. Furthermore, the SIK results can be inputted into a hydrological model and the performance of hydrological model can be assessed.

C6

Regarding the easiness of the SIK package to plug-in to a hydrological model, we added more information in the Introduction and in the Design of the SIK package section. In particular, in the Introduction, the following sentences were added: " SIK inherits some previous code used, for instance, in Formetta et al. (2014) and Abera et al. (2017). In particular Abera et al. (2017) assessed the effect of the interpolation of precipitation on long-term mean annual runoff. To make the code more flexible, easily extensible, maintainable, SIK was completely refactored and a systematic use of Design Patterns (DP), (Gamma, 1994; Freeman et al., 2004), was introduced. " As stated in the previous sentences, the assessment of the performances on the SIK package on the hydrological results has already been presented in Abera et al. 2017, where a previous version of the component, based on the same algorithms, was used. The main difference between that version and the present one is mainly the refactoring of the software with a new, more flexible design and the addition of more choices for variograms and Kriging alternatives. Moreover, a component for the automatic leave-one-out error estimation was added. Therefore the required assessment was already performed and does not require to be done again. However, in "Design of the SIK package" section, besides the two modelling solution already presented in the previous manuscript, we added a further flow chart, which shows how to plug-in the SIK components to GEOframe-NewAGE.

(9) In some parts of the paper, it is specified that the data of 97 meteorological stations are used, but there are 93 stations in Appendix D. More than this, there are 81 stations in Figure 4; 57 stations in Figure 8. In short, an inconsistency in number of stations is in existence.

The total number of stations is 97. In Appendix, D 4 stations were missing for a mistake. All the stations are reported in figure 4 but due to visualization problems (the scale is too big), some of them overlap. The same visualization problems are present in figure 8, were some of the stations overlap.

(10) When examining Figure 8, I have doubts about a manipulation for high perfor-

C7

mance. Please enlighten me about this matter.

Regarding the manipulation for high performance, and also the doubts about the number of the stations, it is easy to check that nothing was made on the results, since all the simulations, inputs and outputs are available in the OSF project. We highly believe in the reproducibility of research and that's why we put the entire SIK project online. This helped also us to easily check and correct the mistake about the number of the stations.

(11) To get to the clarification of figures, I think Figure 3 and 5 must be made smaller, due to they are nonsensically very big.

We reduced the size of the two figures and we will further improve this aspect in the final version of the paper.

(12) In Figure 4, basin boundary and river network should be shown for more understanding of the study area. In the legend of Fig. 4, the ranges of elevation must be like "210.1-850, 850-1500, 1500-2100, 2100-2750, 2750-3388" with round numbers as an example.

The figure was changed accordingly to the suggestions.

(13) For Figure 5 and 9, please give an explanation of X and Y axis in the relevant places of the text.

The two explanations were added in the text.

(14) In the legend of Figure 5, please illustrate experimental semivariance as only black dot without line and the others as only line without dot.

The legend was correct.

(15) In Figure 6, size of dots can be smaller in terms of clearly view of each semivariogram model.

C8

We tried to change the size of the dots but they overlaps anyway. Therefore, we decided to change the figure, showing only a comparison between the 4 types of Kriging, as suggested by the Reviewer #2.

(16) A scale bar (km) must be added on Figure 7 where the intervals of temperature must be as "-6-0, 0-5, 5-10, 10-15, 15-19" with round values.

The legend was correct and the scale bar added.

(17) Likewise, A scale bar and north arrow must be placed in Figure 8 which has two same legends of elevation, one of them must be removed.

The scale and the north were added.

(18) In comparison of spatial data, same color scale must be used for spatial layers. In this respect, Figure 7 (temperature scale) and 8 (elevation scale) are good examples. However, sizes of RMSE plots are not same in Figure 8. In despite of the authors allege the visualization reasons as excuse, I do not accept this situation. For a reasonable comparison, same size scale of RMSE must be used. I suggest the followed intervals for RMSE in both OK and DK output layers of June 2008. "0-1, 1-2, 2-3, 3-6, 6-9, >9 with max value". A conspicuous another issue about Figure 8 is that max RMSE value is 9 in spite of given as 11.95 in the text.

The figure was changed and also merged to figure 7, to shorten the Results section according to the Reviewer #2 suggestion.

(19) The measured rainfall is not shown as black dashed line in the legend of Figure 10.

Corrected

(20) In Figure 11, the color scale of precipitation is changed from white to dark blue. But the colors of precipitation classes are very close to each other, because of this situation the transition of precipitation surface is not distinguished exactly. To remove

C9

this problem, selection of a more colorful scale will be suitable. For instance; red, yellow, sea green, light and dark blue, purple. It changes respectively from dry and wet. Two raster layers (DEM and precipitation), both of which contain white color, are overlapped using transparency feature of the layers in the same figure; but this is caused the confusion with regard to understanding of the figure. If the presentation of elevation layer is as contour lines, the confusion dies. The intervals of the precipitation and DEM must be respectively as "2.21-2.7, 2.7-3.2, 3.2, 3.7, 3.7-4.2, 4.2-4.7, 4.7-5.2, 5.2-5.7, 5.7-6.02" and "0-300, 300-2900, 2900-3388". Figure 11 also needs a scale bar.

The plot was changed accordingly to the reviewer suggestions.

(21) Together with NSE; R2, RMSE and PBIAS values of DK and similarly all the performance criteria of OK methods can be given in Figure 12.

According to the reviewer suggestions, we modified the plot and added also the R2, RMSE and PBIAS in the comparison between the two software.

(22) And all, the captions of the figures can be shortened as follows and the required explanations relating to the figures should be stated in the relevant places of the text. In all the figures, writings and titles of chart and axis must be had standard font size. Figure 1. Flow chart of modeling process. Figure 2. Flow chart of validation process. Figure 1. Flow chart of modeling and validation processes. (Figure 1 and 2 can be combined into one) Figure 4. Geo-location of study area and position of meteorological stations. Figure 5. Fitting of the experimental semivariogram for 15th June 2008 12:00 CET. Figure 6. Monthly variation of the NSE index over entire hourly temperature dataset. Figure 7. Maps and histograms of spatialized temperature for 15th February 2008 and 15th June 2008. Figure 8. Bubble plots of the RMSE obtained using OK and DK. Figure 9. Boxplots of the semivariograms of the precipitation event of 29th and 30th June 2008. Figure 10. Comparison between the four types of Kriging and the measured rainfall. Figure 11. Spatial interpolation of the precipitation applying OK and

C10

the linear semivariogram model.

The captions were shortened according to reviewer suggestions

(23) A little more information such as slope, land cover, vegetation, hypsometric elevation and river discharge about the study area can be given. Basin characteristics are important in understanding and evaluation of hydro-meteorological modeling in particular type and distribution of precipitation for this study.

More information was added to the general description.

(24) Info of DEM is not presented in the paper. Please provide source of DEM.

The source of the DEM was added.

(24) Please give definitions, explanations and formulations of the performance criteria used (NSE, R2, RMSE, PBIAS) in the paper. For NSE, it is referred to Nash and Sutcliffe (1970).

- The definitions and references of the GOFs are now in a related Appendix.

(25) The headers of the tables can be changed as below because of they are also overlong. The statements about the tables can be presented in the relevant parts of the text not in the table header.

Changed accordingly

(26) It is emphasized that Bessel semivariogram model is the best in according to Table 1. How was this information reached? How was the integration of 4 criteria (NSE, R2, RMSE, PBIAS) achieved?

The integration of the 4 criteria was obtained using the R package "hydroGOF", which computes the GOFs between the measured and simulated values (in this case experimental semivariance and theoretical semivariance).

(26) Logarithmic model results also look pretty good, why was not the logarithmic model

C11

in the best 5 of the authors? How were the best 5 determined? In my opinion, the logarithmic model is candidate for the best and Bessel, logarithmic, exponential, linear and spherical models are the best 5 semivariograms. Please clarify this matter.

This is true. The five best models are Bessel, logarithmic, exponential, linear and spherical. However, to be in line with the paper of Abera et al. (2017), and according to the suggestions of the Reviwer #2, we decided to keep only the results obtained using the Bessel model. In Abera et al. (2017), as well as in Haberlandt, 2007, it is stated that "the main difference is observed between the kriging methods, not between the semivariogram fitting within a single model". Therefore, we could have added also the results for the logarithmic model, but without obtaining valuable differences in the interpolation results. Nevertheless, the statement "All the models gave satisfactory results and, therefore, we chose to use the best 5: Bessel, Exponential, Gaussian, Linear and Spherical for the interpolation of the temperature dataset" was changed to " All the semivariogram models gave satisfactory results, with high values of NSE (0.72:0.92) and R2 (0.73:0.92), low values of RMSE (2.14 °C : 3.99 °C ) and PBIAS (-3.80% : -7.90%), confirming the accuracy of the calibration procedure. In order to assess the goodness of the of the interpolation, we performed the leave-one-out cross validation using the optimized hourly values of sill, nugget and range for the Bessel model, which is one of the best semivariograms according to the previous results."

(27) In Table 2, mean of performance criteria values of all the stations can be given for 4 types of Kriging.

According to the Authors, the Table is coherent with the text, since the results of the interpolation in the two station considered are compared.

(28) Table 1. Performance results of semivariogram models used Table 2. Results in terms of goodness of fit indices between the measured and interpolated rainfall values for two stations

Changed accordingly

C12

(29) In the manuscript, it is stated that the overall performances of both SIK and gstat tools are good. I don't think gstat has good performance in according to Figure 12. Please research the success limits of NSE values in the literature. In this context, please rewrite the related parts and the last sentence of the abstract. In plain words, I did not expect it to be so different. SIK has almost overwhelming superiority. I have some suspicions in this regard. Please inform about the optimization of gstat, is it performed sensitively? How do you describe this failure and explain it?

We checked the results and we found an error in the comparison of the time series obtained with the two software (there was an inversion of the ID of two stations, which caused an offset of all the IDs). The plot was corrected and now the GOFs are really good for both software. The following part was added to the section: "Figure 12 shows the results of the temperature interpolation done with SIK and gstat, in terms of NSE, RMSE, PBIAS and R<sup>2</sup>: the overall performances of both tools are very good. The NSE are always above the 0.65, while the RMSE are always lower than 2 °C. Figure 13 shows the results of the precipitation interpolation done with SIK and gstat, in terms of NSE, RMSE, PBIAS, R<sup>2</sup> and cumulative volume. Also in this case, both software are able to reproduce the rainfall event, well simulating the peaks. The results obtained for station ID 1152 are very good for both software, with a NSE >0.9. Both software show slightly worse results for station ID 2170, with lower values of NSE and R<sup>2</sup>, higher RMSE, and an overestimation of the total rainfall (19 mm with gstat and 20 mm with SIK, compared to the 16 mm recorded by the gauges)."

(30) In conclusion section, resolution of interpolation grid data (100 m) can be mentioned because of the resolution is an important issue for the hydrological model results.

Added

(31) The following abbreviations and symbols must be added to Appendix B: PSO: particle swarm optimization OK: ordinary kriging LOK: local ordinary kriging DK: de-

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trended kriging LDK: local detrended kriging SIK: spatial interpolation kriging OMS3: object modeling system v.3 MS: modeling solutions DP: design patterns LOO: leave-one-out GIS: geographical information systems a.s.l. : above sea level CET: central European time DEM: digital elevation model DOI: digital object identifier  $\Gamma$ : matrix of the two point variograms  $\Lambda$ : N-uple of the unknown weights  $\hat{S}$ : N-uple containing the variograms among the ungauged site and the measured sites

Changed accordingly

(32) In most of the equations in Appendix C, multiplication is indicated by a dot. I think there is no need to use these dots.

All the dots were deleted.

(33) In Appendix D, sorting of the stations by elevation not station ID becomes more meaningful due to the strong relationship between the elevation and temperature or precipitation. Giving of mean and median elevation values of the all stations would be better.

All the info about the stations is going to be moved in a complementary material (according to the suggestions of the Reviewer #2).

(34) In appendix of code availability, the authors specify that the documentation of SIK components is available. Is a detailed user manual provided?

Yes. The link is present in the OSF project in the section "Documentation".

(35) The sentence of "Lastly, the authors declare that they have no conflict of interest." should be placed at the end of author contribution appendix.

The sentence was added.

Technical Corrections Corrections, typing errors

(36) In some parts of the paper, it is specified that the data of 97 meteorological stations

C14

and 10 semivariograms are used, but there are 93 stations in Appendix D and 11 semivariogram models in Figure 5/Table 1.

The mistakes were corrected.

(37) P1 L7-P8 L14- P11 L8- P20 L18: "97" → "93"

Changed accordingly

(38) P1 L5-P20 L20-P22 L2: "ten" → "eleven"

Changed accordingly

(39) P10 L6-P10 L14-P11 in Fig. 5 caption-P11 L2-P12 in Table 1 header-P20 L2: "10" → "11"

Changed accordingly

(40) P1 L3: "in a hydrological model" → "to a hydrological model"

Changed accordingly

(41) P1 L8: "compared to the results" → "compared to the results of temperature"

Changed accordingly

(42) P1 L11+: "These data, besides being important by themselves, are the natural input to distributed and semi-distributed hydrological models, where their quality and precision affect the accuracy of results." → Please give a few references.

References were added accordingly.

(43) P1 L15+-P1 L19-P1 L22-P3 L5+-P5 L5-P7 L17: The references aren't chronologically presented, please chronologize.

Changed accordingly

(44) P1 L18: "anong" → "among"

C15

Changed accordingly

(45) P1 L20: "shown" → "showed"

Changed accordingly

(46) P2 L25: "(Formetta et al., 2014).In order" → "(Formetta et al., 2014). In order". No space after point.

Changed accordingly

(47) P3 L13-P3 L15-P3 L27: The ordering of in-equation parenthesis is not appropriate. The correct ordering is "{ [ ( ) ] }".

Changed accordingly

(48) P3 L9-P3 L22-P 3 L23: "N-ple" → "N-uple" Changed accordingly

(49) P3 L26-P5 L21-P7 L11: "e.g." → "e.g.," Changed accordingly

(50) P3 L27: ":= " → " = "

Changed accordingly

(51) P4 L2-P4 L3: "i.e." → "i.e.,"

Changed accordingly

(52) P4 L19: "are the local" → "are respectively the local"

Changed accordingly

(53) P4 L28: "interpolate a theoretical model for the semivariogram" → "fit a theoretical model to the semivariogram"

Changed accordingly

(54) P4 L30: "produce maps" → "produce continuous surface maps"

C16



Changed accordingly

(55) P5 L7: "Efron and Efron" → "Efron"

Changed accordingly

(56) P5 L10: "produced" → "performed"

Changed accordingly

(57) P5 L16: "granularity whose rational" → "detail whose logic"

Changed accordingly

(58) P5 L17: "that, for the reader convenience are presented in A" → "presented in Appendix A for the reader convenience"

Changed accordingly

(59) P5 L19: "Object Modelling System v3 (OMS3)" → "OMS3". Previously presented as open.

Changed accordingly

(60) P5 L20: "here" → "are"

Changed accordingly

(61) P5 L22: "Modelling Solutions (MS)" → "MS". Previously presented as open.

Changed accordingly

(62) P5 L22: "complicate" → "complicated"

Changed accordingly

(63) P5 L25: "particular cares from the researcher who programs them" → "any special effort of the computer programmer of them"

C17

Changed accordingly

(64) P5 L29+: "in various components, and inserted in MS as alternatives, thus opening the way to compare, inside the same chain of tools" → "various components inserted in MS as alternatives. Thus inside the same chain of tools, it enables to compare"

Changed accordingly

(65) P5 L31: "in Formetta et al. (2014) and in Bancheri (2017)" → "Formetta et al. (2014) and Bancheri (2017)"

Changed accordingly

(66) P6 L12: "Particle swarm" → "Particle swarm optimization (PSO) technique"

Changed accordingly

(67) P6 L16-P11 L7-P14 L2-P17 L2: "show" → "shows"

Changed accordingly

(68) P7 L10: "addition(" → " addition (". No space before parenthesis.

Changed accordingly

(69) P7 L11: "Design Patterns (DPs," → "DP". Previously presented as open.

Changed accordingly

(70) P7 L13-P7 L14-P7 L15: "DPs" → "DP"

Changed accordingly

(71) P8 L13-P20 L11: "modeling solutions" → "MS". Previously presented as open.

Changed accordingly

(72) P9 in Fig. 4-P18 in Fig. 11: "Meteo\_stations" → "Meteorological stations" P9 in Fig. 4: "DEM" → "DEM (m)" P18 in Fig. 11: "DEM" → "Contour lines (m)". In Fig.

C18

11, contour lines must be used instead of DEM.

Changed accordingly

(73) P9 L9: "out-layers" → "outliers"

Changed accordingly

(74) P9 L10-P10 L3: "asses" → "assess"

Changed accordingly

(75) P10 L1+: "nor too low or too high" → "neither too low nor too high"

Changed accordingly

(76) P10 L10: "their performances" → "performances"

Changed accordingly

(77) P11 L1: "the correlation coefficient" → "the coefficient of determination"

Changed accordingly

(78) P11 L5: "4 typer of Kriging, OK, LOK, DK, LDK," → "4 types of Kriging"

Changed accordingly

(79) P11 L9: It is specified that the two local cases were performed using the ten closest stations to the interpolation point. Why 10 stations? Has neighborhood analysis ever carried out?

The local cases have been performed using a fixed number of closest stations. In the case of temperature, this number was set equal to ten, since it was the right compromise between the mean distance among the stations and the number of recording stations for each time step.

(80) P11 L10: "meaning" → "it means"

C19

Changed accordingly

(81) P11 L12: "exists" → "exist" Changed accordingly

(82) P12 in Table 1: Please sort the semivariograms by the performance.

We prefer to leave the alphabetical order of the semivariograms since, in this way, it is coherent with Figure 5 and Appendix E.

(83) P13 in Fig. 6: Please remove expression of "hourly temperature" from the chart titles as it is expressed in the caption.

Changed accordingly

(84) P14 L2: "7" → "Figure 7"

Changed accordingly

(85) P14 L3: "during" → "in"

Changed accordingly

(86) P15 L1: "alms" → "m a.s.l."

Changed accordingly

(87) P15 L2: "1.83 oC" → "1.83 oC in the DK method" Changed accordingly

(88) P15 in Fig. 8: Please remove expression of "monthly mean temperature" from the map titles.

Changed accordingly

(89) The altitude legend scale has not min and max values, please add these.

Changed accordingly

(90) P16 in Fig. 9 chart title: "30 h" → "11 h"

C20

Changed accordingly

(91) P16 L2: "953 m" → "943 m". According to Appendix D.

Changed accordingly

(92) P16 L6: "local ordinary kriging" → "LOK". Previously presented as open.

Changed accordingly

(93) P16 L7: "ID 2170" → "ID 1270" Changed accordingly

(94) P16 L6-P16 L8: It is stated that the LOK computed using the 5 closer stations. Is it determined with manual calibration of the neighborhood? If search of neighbor numbers was performed, it must be specified in the text. If not, explain that how it was determined. In addition to, the number of closest neighbor stations is 10 for temperature and 5 for rainfall. Please interpret this.

In the case of precipitation, the number of closest stations was set equal to five, given the prevalent convective nature of summer precipitation phenomena and the lower number of active gauge stations for each time step. A description of the analysis of the data, the treatment of the outliers, the choice of the number of the bins and of the closest stations is reported in the section Setup.

(95) P17 L1: "DEM (100 m resolution)" → "DEM"

Changed accordingly

(96) P17 L3: "[mm/h]" → "(mm/h)"

Changed accordingly

(97) P19 L4: "design pattern" → "DS". Previously presented as open.

Changed accordingly

(98) P19 L4: "figure 3" → "Figure 3"

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Changed accordingly

(99) P19 L7: "opertion" → "operation"

Changed accordingly

(100) P19 L10: "offers" → "offer"

Changed accordingly

(101) P19 L11+: "the same number of bins and the same cutoff distance" → "the same number of bins and cutoff distance"

Changed accordingly

(102) P19 in Fig. 12 legend: "SI component" → "SIK component"

Changed accordingly

(103) P19 in Fig. 12 caption: "package" → "packages"

Changed accordingly

(104) P19 in Fig. 12: NSE value 1.0 is not found in the figure.

Changed accordingly

(105) P20 L13: "design patterns" → "DS". Previously presented as open.

Changed accordingly

(106) P20 L18+: "Both the interpolation of the temperature and the interpolation of the rainfall" → "Both the interpolation of the temperature and the rainfall"

Changed accordingly

(107) P20 L22: "detrended Kriging" → "DK". Previously presented as open.

Changed accordingly

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(108) P20 L22: "Single event rainfall, on the contrary do not" → "On the contrary, single event rainfall did not"

Changed accordingly

(109) P20 L26: "GPL v3" → "GPL v3 ([www.gnu.org/licenses/gpl-3.0.en.html](http://www.gnu.org/licenses/gpl-3.0.en.html))"

Changed accordingly

(110) P20 L27: "a a-personal" → "a-personal"

Changed accordingly (111) P20 L28: "thus"

Changed accordingly

(112) P21 L1: "instead, for instance, of Mercurial," → "instead of for instance Mercurial"

Changed accordingly

(113) P21 L1: "found at" → "found at followed link"

Changed accordingly

(114) P21 L5: "includes" → "include"

Changed accordingly

(115) P21 L7: "Maven and Gradle, in particular" → "in particular Maven and Gradle"

Changed accordingly

(116) P21 L7+: "Our favor, among the possibilities, was for" → "Our favor among the possibilities was"

Changed accordingly

(117) P21 L12: "instead than another All of them" → "than another. All of them"

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Changed accordingly

(118) P21 L13: "programmers' community, but are" → "community of programmers, but they are"

Changed accordingly

(119) P21 L13+: "scientists making increasingly difficult for them maintain their own code" → "scientists who are increasingly struggling against difficulties to maintain their own code"

Changed accordingly

(120) P21 L18: "and run all the software" → "and all the software"

Changed accordingly

(121) P21 L20: "GPL v3 license ([www.gnu.org/licenses/gpl-3.0.en.html](http://www.gnu.org/licenses/gpl-3.0.en.html))" → "GPL v3 license"

Changed accordingly

(122) P21 L22: "alternatives are, among others," → "alternatives among others are"

Changed accordingly

(123) P21 L25: "our" → "ours"

Changed accordingly

(124) P22 in Appendix B: "Percent bias" → "percent bias"

Changed accordingly

(125) P22 in Appendix B: "Coefficient of determination" → "coefficient of determination"

Changed accordingly

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(126) P22 in Appendix B: "Root mean square error" → "root mean square error"

Changed accordingly

(127) P25 in Appendix D: The elevation of station 90145 is 3399 m as given in Appendix D and P15 L1. However the max elevation value of study area is 3388 m in Fig. 4. Here, there is a mistake (3399>3388), please correct it.

Changed accordingly

(128) P29 L5: "Fisheries research" → "Fisheries Research"

Changed accordingly

(129) P29 L25-P29 L37-P30 L10: "Oxford university press" → "Oxford University Press"

Changed accordingly

(130) P29 L29: "Efron, B. and Efron, B."

Changed accordingly

(131) P29 L36: "Springer Publishing" must be added.

Changed accordingly

(132) P30 L2: "Journal of hydrology" → "Journal of Hydrology"

Changed accordingly

(133) P30 L7: "Journal of applied meteorology" → "Journal of Applied Meteorology"

Changed accordingly

(134) P30 L8: "International journal of geographical information systems" → "International Journal of Geographical Information Systems" Changed accordingly

(135) P30 L21: "Biotechnol. Agron. Soc. Environ., vol. 17(2), 392-406" must be added.

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Changed accordingly

(136) P30 L27: "Mathematical geology" → "Mathematical Geology"

Changed accordingly

(137) P30 L31: "Publ. Climatol., 46" must be added.

Changed accordingly

(138) P30 L35: "JAWRA Journal of the American Water Resources Association, 21(3), 365–380" must be added.

Changed accordingly

(139) P30 L36: "Monthly weather review" → "Monthly Weather Review"

Changed accordingly

(140) The references in P30 L22 and P30 L24 must be replaced due to the chronological order.

The order depends on the second author name.

(141) P31 L3: "Agricultural systems" → "Agricultural Systems"

Changed accordingly

(142) P31 L6: "Data Acquisition And Processing, Analysis, Forecasting And Other Applications, (WMO No.168)" must be added.

Changed accordingly

Recommendations

The validation of SIK component can be performed with remote sensed data (radar and satellite products) besides of ground based data (earth observation stations).

The climatic and environmental variables can be analyzed at different time scales as

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daily, monthly, seasonal and annual.

The interpolation performance can be evaluated in different areas in point of multi-site approach.

Co-Kriging using secondary data as elevation, vegetation and temperature can be embodied into the SIK.

Kling-Gupta Efficiency (KGE) criteria whose advantages over NSE are stated in Gupta et al., 2009, can be added as performance benchmark.

Interpolated temperature and rainfall data can be inputted into a hydrological model. And accuracy and reliability of interpolation can be tested in terms of performance of hydrological model.

In assessment of interpolation performance, jack knife and k-fold cross validation can be utilized for independent data set of validation procedure.

Fit of normal distribution of residuals can be tested due to Kriging modeling is a stochastic process.

Uncertainty analysis can be carried out. Comparison based on pixels of raster layer can be implemented.

Comparison in terms of lowland-highland, underestimate-overestimate, density of stations and representation of low-high rainfall.

All the previous recommendations are great ideas for future versions of the software and we put it in the wish list of improvements to do, in the Github repository of the component. Various case studies using remote sensed data have been already performed using the GEOframe-NewAGE infrastructure and SIK performances will be going to appear also in future papers. The software has been also intensively used for educational purposes with students of the Hydrology class in Trento, a sort of a crash test, which was successfully accomplished. The integration of Co-Kriging, given the software de-

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sign of the SIK package, is easy and straightforward, and the interested researcher could find the “How to do” in our repository in Github. However, these are not efforts we can afford at present without delaying too much the final review of this paper, whose scope has, as well as all the papers, a limited scope.

References Adhikary, S. K., Muttill, N. and Yilmaz, A. G., 2016. Genetic programming-based ordinary kriging for spatial interpolation of rainfall. *J. Hydrol. Eng.*, 21 (2), -1–1. Bostan, P. A., Heuvelink, G. B. M. and Akyurek, S. Z., 2012. Comparison of regression and kriging techniques for mapping the average annual precipitation of Turkey. *Int. J. of Applied Earth Observation and Geoinformation*, 19, 115-126. Di Piazza, A., Lo Conti, F., Noto, L. V., Viola, F. and La Loggia, G., 2011. Comparative analysis of different techniques for spatial interpolation of rainfall data to create a serially complete monthly time series of precipitation for Sicily, Italy. *Int. J. of Applied Earth Observation and Geoinformation*, 13, 396-408. Gupta, H. V., Kling, H., Yilmaz, K. K. and Martinez, G. F., 2009. Decomposition of the mean squared error and NSE performance criteria: Implications for improving hydrological modelling. *Journal of Hydrology*, 377, 80-91. Jin Q., Zhang J., Shi M. and Huang J., 2016, Estimating Loess Plateau average annual precipitation with multiple linear regression kriging and geographically weighted regression kriging. *Water*, 8, 266, 1-20. Krige, D. G., 1951. A statistical approach to some mine valuations and allied problems at the Witwatersrand. MSc Thesis of the University of Witwatersrand. Nash, J. E., and Sutcliffe, J. V., 1970. River flow forecasting through conceptual models. Part I-A discussion of principles. *Journal of Hydrology*, 10(3), 282-290. Saghafian, B. and Bondarabadi, S. R., 2008. Validity of regional rainfall spatial distribution methods in mountainous areas. *J. of Hydrol. Eng.*, 13 (7), 531-540. Wang, S., Huang, G. H., Lin, Q. G., Li, Z., Zhang, H. and Fan, Y. R., 2014. Comparison of interpolation methods for estimating spatial distribution of precipitation in Ontario, Canada. *Int. J. Climatol.*, 34: 3745-3751.

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