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Interactive comment on "Comparison of approaches to interpolating climate observations in steep terrains with low-density gauging networks" *by* Juan Ossa-Moreno et al.

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Comparison of approaches to interpolating climate observations in steep terrains with low-density gauging networks Response to comments by Reviewers We are very grateful with the two anonymous reviewers who have provided very valuable feedback to improve the manuscript. We are glad that both of them highlighted that the topic of the manuscript is interesting, valuable and within the scope of HESS. We are also happy that reviewer 1 highlighted the value of the temperature results.

Overall, the key requirements from reviewers involve: reorganising the content of some sections, better explaining the results obtained by the referenced authors on the in-

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Discussion paper

terpolation of climate variables in mountain areas, providing more information of the general climate in the case study and giving a better explanation of the main method used to interpolate the variables. Furthermore, we will do the extra analysis suggested by reviewer 1 in his last comment, to have a better idea of how the WCA method could be applied to the CHIRPS dataset. We address all the comments of the reviewers below. We are grateful for comments received, as they will improve considerably the quality of the paper, however, since none of the comments involves major changes, we are confident we will be able to fully address all of them and re-submit the manuscript within two months. We will present as follows the corrections that have been done up to date, and the plan to address the rest.

Reviewer 1 Specific Comments

1. Section 2.1 - Separate the description of the geographical and climate settings.

The description of the geography was moved to the beginning of Section 2, while the climate settings were kept in Section 2.1.

a. Climate setting would deserve a more extensive description

The description of the climate settings in Section 2.1 was considerably increased, to provide more details of the broader climate phenomena affecting the case study, the sources of inter-annual variability (including ENSO and a brief comment on the Pacific Decadal Oscillation), and temperature fluctuations. Further references were included. A comment on glaciers was also added, including two references which provide further details. We did not go deeper on the subject of glaciers, as their presence is restricted to the highest elevation areas of some of the sub-catchments in the case study. Furthermore, one of the references highlights that, although challenging to quantify, their role in catchment flows seems to be only relevant during dry years, and only for the very upper sub-catchments (Ohlanders et al., 2013). This means that the overall relevance of glaciers in the case study is not that high, thus, we do not consider pertinent to provide much more detail about them.

b. Eliminate large map from Figure 1. Enlarge the small one. Clearly define the case study. Change colour of catchment delineation.

The catchment delineation colour has been changed so it is easy to identify it. The whole figure has been enlarged. None of the figures was eliminated as we think they all are useful to clearly locate the catchment.

c. Include comments on glaciers in the area.

See 1a.

2. Section 2.2 – Clearly state the total number of time-series and the maximum time-span covered by the considered time-series.

This information was provided in the Appendix, however, we acknowledge that a better explanation was required in the text. Thus, the third paragraph of Section 2.2 was reworded to better link the text with the information provided in the Appendix. This paragraph is included as follows: "A total of 41 gauges were used in the project, 17 of them measured precipitation only, 23 measured temperature only and 1 measured both variables. The location of the temperature and precipitation gauges is shown in Figure 1, while further details of the gauges (including the periods with information available and the percentage of missing values) are provided in Table A1 in the Appendix."

a. Merge Figure 2 and 3 in a two panel figure.

We acknowledge that the large number of figures was an issue in the previous version. This was caused by the fact that our original latex text was not in Copernicus format and included several files for the same figure (i.e. the files of figures 2 and 3 were merged in latex into one figure). However, having several files for the same figure is not allowed in Copernicus format, thus we separated all files into different figures, without realising the negative consequences in the paper All files that were part of the same figure were merged in R, as to create one file only, and in this way there is only one figure, for the previous figure 2 and figure 3. The large number of figures was an issue in the previous version. Each figure that we planned to be a multiplot had to be split to follow the Copernicus Latex format, they were presented as multiple separate figures. Now, image files were merged prior to their inclusion in Latex so that many figures are now merged appropriately, including figure 2 and figure 3.

3. Section 2.3 – Lines 27-29 include references of studies that have evidenced decreased skill of remote sensed products in the mountain environment.

The references were already included in the previous sentence (Dinku et al., 2010, Manz et al., 2016, Thiemig et al., 2012). However, they were repeated to make it more explicit that they provide the evidence of the decreased skill of remote sensed products to work in mountain areas or with extreme weather conditions, when compared to flat regions. The new paragraph is presented as follows: "To complement the point observations, the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) satellite product (Funk et al., 2015) was used. Including remotely sensed data to analyse climate variables is increasingly popular amongst researchers, and several examples exist for precipitation in the Andes (Dinku et al., 2010, Zambrano-Bigiarini et al., 2016, Manz et al., 2016, Álvarez Villa et al., 2011) and beyond (Nikolopoulos et al., 2013, Thiemig et al., 2012, Dinku et al., 2014). Based on these experiences in mountain regions, it could be said that generally, satellite products tend to be good at detecting precipitation and its overall spatial variability, but struggle to predict the magnitudes of the events, particularly heavy precipitation events, and for daily and subdaily resolutions (Dinku et al., 2010, Manz et al., 2016, Thiemig et al., 2012). This is usually a consequence of orographic effects and convective precipitation events."

a. Merge Figure 4 and 5 in a 2 panel figure.

Figures have been merged. See answer to comment 2a.

b. Specify what is the DEM used for.

The DEM was used to define the elevation at all points in the catchment, as this variable is required for some of the interpolation approaches. The first part of this paragraph in section 2.3 was adjusted to include this as follows: "The third spatial data set used was a Digital Elevation Model (DEM) based on the Shuttle Radar Topography Mission (SRTM) (Jarvis et al., 2008), with a spatial resolution of 90 m. The DEM was used to define the elevation, which is an input variable in some of the interpolation approaches."

c. Consider including a plot of MEI index to discuss el nino or la nina events during the period of analysis. Given the short length of the used time series, it could be difficult to have enough ENSO cycles to get a significant correlation between observations and MEI index.

We considered this and concluded that there would not be too much added value by including this plot. As the reviewer highlights, the period of analysis is relatively short compared to the frequency of the ENSO events, and this may have hindered finding a better correlation between the MEI index and the climate variables. This, however, is clearly stated in section 4, where we describe the correlation analysis between variables and covariates.

4. Section 3 – It is not clear if in the first paragraph the authors discuss literature or the methods

We have moved most of the content in the beginning of Section 3 to the introduction, and kept only one paragraph explaining the reason for using the GLMM in this project.

a. Include at the beginning a structured list of the methods, possibly including literature on advantages/drawbacks.

We will include a list (i.e. perhaps as a table) at the beginning of this section, providing references, and potential advantages and disadvantages of all methods used.

b. Discuss in more detail why the GLMM is potentially good for this application.

We consider this is one of the key comments from reviewers, and we will make sure to provide a more in-depth explanation of the GLMM and on the added value of this method, compared to alternatives in hydrology. We think we did not overlook this, but in the original manuscript we focused more on providing details of the mathematics (Section 3.1), rather than on the description of the benefits.

c. Be more clear on what type of data was used for each method.

We thought sufficient details of each source of data was provided in Section 2, however, we will make sure to clarify the specific data requirements of each method (i.e. what data was used on each method).

d. Provide details of the resolution of the climate outputs.

This will be provided at the end of section 3.

5. Section 3.1 – Clearly state in Section 2.2 and abstract that monthly precipitation data was used.

Done

a. If monthly precipitation data was used, why including FAR and POD?

Although POD and FAR are more commonly used for daily analyses, the large numbers of months without precipitation in the catchment make the calculation of these two categorical statistics valuable. This reason was made explicit in the article with the following paragraph: "Furthermore, two categorical statistics, the False Alarm Ratio (FAR) and the Probability of Detection (POD), were used to assess to what extent the model is able to predict precipitation occurrence (see Table 2)(Zambrano-Bigiarini et al., 2016). The latter is relevant, even at a monthly time-scale, taking into account that in the case study, there are several months without any precipitation (above the defined significance threshold), thus properly simulating its occurrence is not a trivial exercise."

6. Section 3.2 – Is WCA based on IDW using both station data and WorldClim maps?

Yes, WCA is based on using IDW to interpolate the residuals between the WorldClim maps and the station data. We thought this was clear enough; however, we reworded the explanation to further clarify. Two references explaining a similar method were included in the revised version, in case the reader wants to have more details about this procedure. “The WCA method attempts to couple the benefits of the spatial variability of the WC maps and those of the temporal resolution of the observations in a simple way. This approach is similar to the RIDW in (Manz et al., 2016) or the bias adjustment in (Dinku et al., 2014), but in this case using WC maps. The residual between observations and WC maps is computed at each gauge location, these residuals are interpolated using Inverse Distance Weighting (IDW) to each point in the catchment, and this interpolated surface is added back to the original WC map. This procedure is repeated for every time-step (monthly for precipitation and daily for temperature).”

a. Merge figures 6 and 7

To address the previous comment we reviewed again some papers where similar methods were applied, and realised that none of them included this kind of figures, but only a brief explanation with the steps followed. Taking this into account, figure 6 and 7 were eliminated and the explanation of the method was improved by providing a more specific explanation, and some references to obtain further details about the approach.

7. Section 3.3 – Divide LOOCV and sensitivity tests.

The explanation of the LOOCV and the sensitivity test was divided. The first paragraph in Section 3.3 explains the LOOCV while the next two explain the sensitivity tests. LOOCV and sensitivity results in section 4 will also be separated.

a. Be more clear why for the GLMM it was required to use the expected value as opposed to the others (GLMM is a stochastic method, the others are not). Explain this in a better way for all methods.

Further details of this were provided in the fourth paragraph of Section 3.3, as follows: For all tests, the average Root Mean Squared Error (RMSE) of the validation group was used to assess the performance of temperature and precipitation predictions, following similar comparisons (Cameletti et al., 2013, Manz et al., 2016, Nerini et al., 2015). Being a stochastic method, for the GLMM this involved the analysis of the expected values of each variable for each time-step (y in Equations 5 and yP in Equation 8). On the other hand, the other three methods are deterministic, thus the single set of values at each time-step (e.g. y in Equation 11) were used for the RMSE computations.

b. Be more specific of the comparisons of raw WC maps and temperature data, and discuss its small RMSE.

We thought sufficient details had been provided, however, we will make sure to discuss in more detail the small RMSE for raw WC maps. Furthermore, with the changes in the explanation of the WCA method (See comments 6 and 6a), we hope it is more clear how the comparison between WC maps and temperature data was done.

8. Include a paragraph in the methods section discussing the correlation analysis.

A paragraph has been included at the end of Section 3.1, briefly describing the correlation analysis and its purpose. The more in-depth discussion of the results was kept in the first paragraph of the results section (Section 4). The paragraph included is as follows: "Furthermore, before including the covariate data in the GLMM (e.g. WC, elevation, CHIRPS), an analysis of their correlation with the climate variables was done. This included plotting temperature and precipitation observations versus the covariates, and computing Pearson Correlation coefficients. This analysis was used to define what covariates to include in each GLMM."

a. Merge Fig 8-13 in a 6 panel figure.

The figures have been merged. See answer to comment 2a.

9. Section 4.1 – Explain how and why the 5 yrs daily average was calculated, and explain that this was for plotting purposes only in Figs 14-16.

This aggregation was done for illustration purposes only. Our goal with these figures was to show: what methods over and under-estimate observations, by approximately how much, how this changed as a function of the period of the year, and how this changed as a function of different types of stations. The 5-year series of daily data contained too much variability to visually assess the trends, which was achieved using the averaged series. For the same reason, to facilitate the visualisation of the main trends, values were also smoothed using the LOESS method. Briefly, the method analyses data nearby a point X (how much data is included is a user defined parameter), and does a simple regression using this data. The value of X is adjusted to the value predicted by this regression. Although this may eliminate day-to-day fluctuations, the overall trend over several days is shown much more clearly, as the noise is reduced. The LOESS is just one of the several methods that could be used to do this (a simple moving average could have also been used). A reference was provided so the reader can have access to more details (Jacoby, 2000). This information was not provided in the previous version because we did not consider it to be very relevant, taking into account that the method is only used for illustration purposes. We will provide more detail about the purpose of this aggregation and the method in the text.

a. Merge these three in a three panel figure.

The figures have been merged. See answer to comment 2a.

10. Why CHIRPS data was not analysed in the same way as WC? Or be more clear how the CHIRPS data was merged with observations.

Chirps was not applied in the same way as WC because Chirps does not include temperature data. However, it is possible to apply Chirps in the same way as WC to interpolate precipitation data. We understood the comment from the reviewer and realised that it would be valuable to show how CHIRPS would behave with this method, taking into account its better performance than WC. This will included in the revised manuscript.

a. Merge figures 17 and 23. 19 and 21. 18 and 22.

The figures have been merged. See answer to comment 2a.

Reviewer 2 Specific Comments Introduction

How have other authors addressed this topic? There is a strong discourse on this issue and a large number of researchers developing precipitation products as MSWEP, CHIRPS and CR2 have dealt with this problem. Please elaborate on the findings of other authors working with high elevation data. Also how do authors deal with missing information in hydrological modelling, which interpolation methods have worked and which were the results of evaluating different satellite based and combined precipitation data sets in data scarce Andean regions? Although you mention some authors, their findings are not described or compared. Ideally, these should help to justify your objectives.

We did an extensive review of similar analyses, both in terms of interpolation techniques and merging of satellite data with observations, and many of these references were included in the original paper. We acknowledge, however, that the findings of these authors could be described in further detail in the introduction section. Based on this we can conclude what the gaps in knowledge are, in order to justify the objectives of this paper.

Data The data (input, validation..) should be presented in the main text. Otherwise the numbers in the map are useless. Also in the map, it would help to enlarge it and use other colours for elevation and delineate a stronger catchment area to make the map understandable even in black and white. Numbers in the map should also be visible in Figures 2 and 3.

We are not sure about what the reviewer means by including the "data (input,validation..)" in the main text. We have tried to follow general practice from similar papers working with similar data, which commonly include: âĂć A map of the region being analysed including the location of the gauges. âĂć A list, usually in an appendix, of the stations analysed, providing detailed information of the location, variables measured and availability of observations (this is not included when analyses involve a very large number of stations e.g. > 100). âĂć General statistics of the stations (e.g. mean and range), plus some figures of some stations or from a region, describing general trends of the data (e.g. seasonality). Furthermore, we are not sure how we could differentiate validation stations, as a leave-one-out cross validation method was used, which means that all stations were both used for calibration and validation in different runs of the model. The map has been updated following the comments from both reviewers, to make sure that the catchment is easy to identify, terrain elevation is easy to differentiate and the location of the stations is clearer. Figures 2 and 3 were updated as well following comments from reviewers. Also, a CHIRPS figure was provided for the reader to visualise this product and compare it with the WC data, particularly the resolution of both within the area of analysis. We did not think about comparing it with observations as did not see the purpose of a single month comparison, however, we will include the average values of CHIRPS and WC in Figure 2 to facilitate a more robust comparison of data.

It is not well explained why you only used such a short period. There are enough data available to fill gaps (CR2 P dataset, Chirps, MSWEPv2.2, etc.). Temperature of course is difficult but at least different time periods could be compared. The main variable of interest should be precipitation. - Why do you present a spatial distribution of Chirps in May 2009 instead of comparing it with values from observed data?

We were interested in analysing both temperature and precipitation in the catchment over the same period. We obtained 5 years of valuable data, previously not used for research, from a company operating in the area, who installed multiple weather stations around 2008, thus we started our analysis in that year. We acknowledge that there are precipitation stations in the lowlands (government gauges which we obtained from CR2) and one in the mountains, which have been continuously measuring precipitation for decades. However, the availability of multiple gauges in the mountains for the 5 year period starting on 2008 was decisive in terms of the quality of the research. The temporal infilling using these products could have been inappropriate for creating a data set for assessing the spatial interpolation methods. We thought that the spatial interpolation methods would be better assessed using observations from gauges. The use of alternative spatial data sets is useful when used as inputs to the spatial interpolation methods, which he have done, as long as available observations from gauges are used to assess their proficiency. We used datasets such as the ones that the reviewer suggests, e.g. we used CHIRPS and WC maps, however, the scope of the paper was not to use all of the data sets available for the case study but to analyse the interpolation approaches. We would like to further stress that we have never attempted to claim that the results in the paper are valid for long term trends, nor that the conclusions are valid under all circumstances. We have been cautious highlighting that our findings are restricted by the limitations of the study, however, this does not mean that they are not useful. We think that they provide valuable information of the performance of some methods, under a complex climatic region with few observation gauges. We will explain all of this in much more detail in all sections of the revised manuscript.

Methods section 3: The first paragraphs of this section should be part of the introduction as they deal with the general state of the art. - The advantage of using GLMMs and its exact output in this context is not clear to me. - There should be a conceptual figure explaining the methodology, input data and outputs - You use station data and as Covariates Chirps and ENSO as model input to test different interpolation methods. Then in the results section you correlate station data with Chirps and other data products for the station pixel? This part should be shifted to the data section and justify the method and data input (or not?). - 4.1 difference between input data and validation data not presented.

Following the comments from both reviewers, we have moved some of the information from the methods section to introduction, and we will describe the advantages of the GLMM in a much better way. Furthermore, we will better describe this method, its inputs and outputs in the list of methods we will include in section (see answer 4a to the comments from the first reviewer). We will make sure to explain here what information was used as covariates/input for each method.

As suggested by reviewer 1, we included a new paragraph in Section 3 better describing the correlation analysis between climate variables and covariates. However, we consider that it is better to keep the outcomes of this analysis in the results section, as they are part of the process to build the GLM (i.e. defining the covariates to use).

We are not sure what the reviewer means by differences between input data and validation data. By using a leave-on-out cross validation (Manz et al., 2016), we believe we go a step ahead of using one part of the data for estimation purposes, and the rest for validation. We run each method several times, and in each of them we remove one station at a time, to validate the results of that specific run. We repeat this process for all stations, which means that all stations were used for estimation purposes, but at the same time each of them was used once for validation purposes. The overall output is the average results of all validation stations (i.e. all stations, but only when they were used for validation). Perhaps we are not very clear with this, thus we will make sure to provide a better description in the revised manuscript.

Results: In light of the above described missing information regarding the data input, validation data and output variables, it is difficult to understand the results and their interpretation. Overall presentation structure and language are still very poor. There are too many figures with little information content. Please focus on the main findings and try to present them in fewer self-explanatory figures.

Once more, we are not clear what the reviewer means by issues with data input and validation data (see previous answer), but we will make sure to better explain the leave-one-out cross validation in the revised manuscript. If this was more related to the fact that it is not clear what sets of inputs/covariates were used in each method, we will make sure to clarify this as well in Section 3.

We have improved the structure of the manuscript taking into account the comments from reviewers, particularly in the introduction, data and methods section. We will make sure to double check potential language issues.

The large number of figures was an issue in the previous version and we acknowledge this decreased the presentation quality of that version. As explained in the answer to the comment 2A of reviewer 1, we have solved this issue by merging lots of figures in multi-plots.

For the revised version, we will make sure to focus on the valuable outcomes of the paper and present them in a clearer way.

References

ÁLVAREZ VILLA, O. D., VÉLEZ, J. I. & POVEDA, G. 2011. Improved longâĂŘterm mean annual rainfall fields for Colombia. International Journal of Climatology, 31, 2194-2212. CAMELETTI, M., LINDGREN, F., SIMPSON, D. & RUE, H. 2013. Spatio-temporal modeling of particulate matter concentration through the SPDE approach. AStA Advances in Statistical Analysis, 97, 109-131. DINKU, T., HAILEMARIAM, K., MAIDMENT, R., TARNAVSKY, E. & CONNOR, S. 2014. Combined use of satellite estimates and rain gauge observations to generate highâĂŘquality historical rainfall time series over Ethiopia. International Journal of Climatology, 34, 2489-2504. DINKU, T., RUIZ, F., CONNOR, S. & CECCATO, P. 2010. Validation and Intercomparison of Satellite Rainfall Estimates over Colombia. Journal of Applied Meteorology and Climatology, 49. FUNK, C., PETERSON, P., LANDSFELD, M., PEDREROS, D., VERDIN, J., SHUKLA, S., HUSAK, G., ROWLAND, J., HARRISON, L. & HOELL, A. 2015. The climate hazards infrared precipitation with stations–a new environmental record for monitoring extremes. Scientific data, 2. JACOBY, W. G. 2000. Loess:: a nonparametric, graphical tool for depicting relationships between variables. Electoral Studies, 19, 577-613. JARVIS, A., REUTER, H. I., NELSON, A. & GUEVARA, E. 2008. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM

90m Database. MANZ, B., BUYTAERT, W., ZULKAFLI, Z., LAVADO, W., WILLEMS, B., ROBLES, L. A. & RODRIGUEZâĂŘSANCHEZ, J. P. 2016. HighâĂŘresolution satelliteâĂŘgauge merged precipitation climatologies of the Tropical Andes. Journal of Geophysical Research: Atmospheres, 121, 1190-1207. NERINI, D., ZULKAFLI, Z., WANG, L.-P., ONOF, C., BUYTAERT, W., LAVADO, W. & GUYOT, J.-L. 2015. A comparative analysis of TRMM-rain gauge data merging techniques at the daily time scale for distributed rainfall-runoff modelling applications. Journal of Hydrometeorology. NIKOLOPOULOS, E. I., ANAGNOSTOU, E. N. & BORGA, M. 2013. Using high-resolution satellite rainfall products to simulate a major flash flood event in northern Italy. Journal of Hydrometeorology, 14, 171-185 %@ 1525-755X. OHLANDERS, N., RODRIGUEZ, M. & MC PHEE TORRES, J. 2013. Stable water isotope variation in a Central Andean watershed dominated by glacier and snowmelt. Hydrology and Earth System Sciences, 9. THIEMIG, V., ROJAS, R., ZAMBRANO-BIGIARINI, M., LEVIZZANI, V. & DE ROO, A. 2012. Validation of satellite-based precipitation products over sparsely gauged African river basins. Journal of Hydrometeorology, 13, 1760-1783. ZAMBRANO-BIGIARINI, M., NAUDITT, A., BIRKEL, C., VERBIST, K. & RIBBE, L. 2016. Temporal and spatial evaluation of satellite-based rainfall estimates across the complex topographical and climatic gradients of Chile. Hydrology and Earth System Sciences.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-505/hess-2018-505-AC1-supplement.pdf

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