**Response to reviewer #2 of "The role of morphology on the spatial distribution of short-duration rainfall extremes in Italy" by Mazzoglio et al.**

**C:** The authors here investigate short-duration rainfall extremes in Italy focusing on improving simple relationships with elevation. The form national multiple regression equations exploiting several geomorphological covariates and one climatic. At the national level this did not really led to significantly improvements and thus the authors proceed to several localized spatial clustering approaches identifying this need given the clear spatial pattern in local bias. The paper was joy to read, clearly written, easy to follow and offers an addition to the literature. Therefore, my comments are only minor and optional since the paper fulfills its goal as is.

***R:*** *We thank the reviewer for appreciating our work.*

**C:** In general, there are different definition on what is considered extremes. There so many references on extremes, and sub daily extremes, mean extremes, etc. in the introduction but it is not crystal clear what these extremes are. Are POT values, annual/seasonal maxima, etc? Please clarify.

***R:*** *We thank the reviewer for this comment. In our work we used annual maximum rainfall depths recorded in different intervals (durations). For the sake of clarity, we will replace the word "extremes" with "annual maximum rainfall depths" or with "index rainfall" when we introduce the average of the annual maxima, according to the literature standards.*

**C:** Section 2.2. Can you show the fitting the Equations 3-6? Especially the nonlinear 5-6.

***R:*** *The fitting of the four regression models (Avanzi et al. and this paper) will be introduced in the Supplementary material and is visible in Figure 1 of this document.*

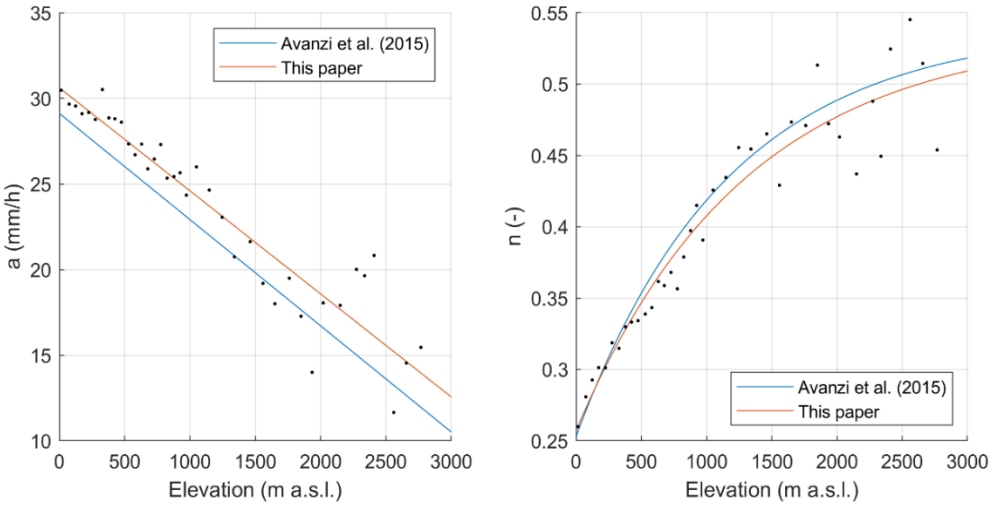


*Figure 1. Fitting of the four equation on $I^2$-RED data.*

**C:** Fig 2 please try to use the minus symbol for minus and not the dash as the "--" is not clear and it should be "- −".

***R:*** *We will correct this issue in the new version.*

**C:** Out of curiosity, have the authors tried to see if there's potential in using the temperature as a climatological variable?

***R:*** *We have evaluated the possibility of including the mean temperature as an additional covariate in a preliminary step: this step is not documented in the paper, as the temperature comes out highly correlated with the elevation, as expected. In the subsequent analyses we retained only the elevation as an active covariate, considering that the multicollinearity tests were not passed by the equations that contain both the variables temperature and elevation.*

**C:** The authors might be interested in the Moccia et al. 2021 (10.1016/j.ejrh.2021.100906) study (though at daily scale) analyzing a fine resolution gridded product over Italy and investigating extremes. The bivariate choropleth in Fig13 also shows elevation-rainfall depth relationship.

***R:*** *We thank the reviewer for this valuable suggestion. This reference will be very useful in a follow-up work we are carrying out, as the suggested paper is based on the use of CHIRPS data (satellite + ground data). In the case of the present paper we intended to focus only on literature work carried out using annual maximum data recorded by rain gauges.*

**C:** Is beta-i a vector in Eq7?

***R:*** *Beta is a vector while beta_i is an element of the beta vector. We will correct this in the new version.*

**C:** Was there some preliminary examination in leading to select a multiple linear model? Maybe pair-wise scatter plots would give valuable information and might actually lead in selecting nonlinear relationships at least for some of the covariates. It might worth creating these scatter plots. Also, yes the test showed no collinearity, but let's see this also in scatter plots.

***R:*** *In Figure 2 and Figure 3 of this document we reported the scatter plots of the mean of the extremes in 1h and 24h taken in each Italian station, against different covariates. No dominant covariate emerges from these plots: this suggests to proceed towards multiple linear regression models. Their effectiveness is confirmed by the increase of the adjusted coefficient of determination ($R^2_{adj}$) with the increase of the number of covariates (as reported in rows 200-201 and in Supplement n°1).*

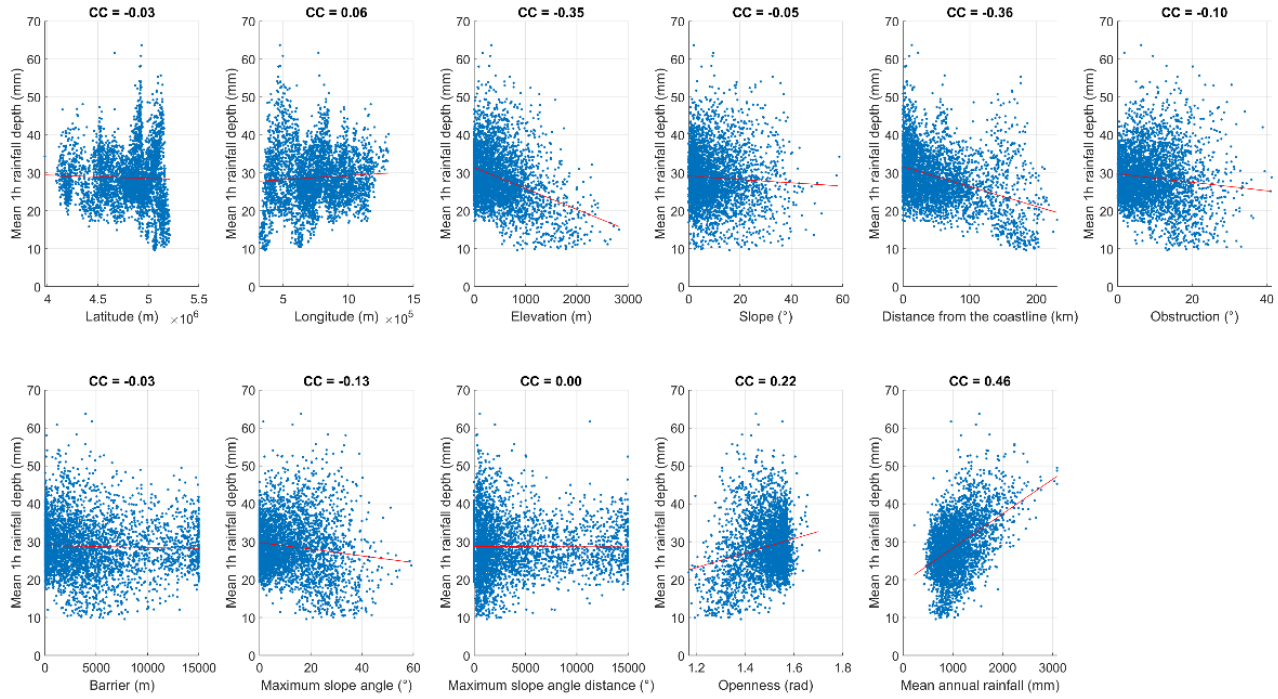


*Figure 2. Scatter plots of the mean of the extremes in 1-hour duration against different covariates.*

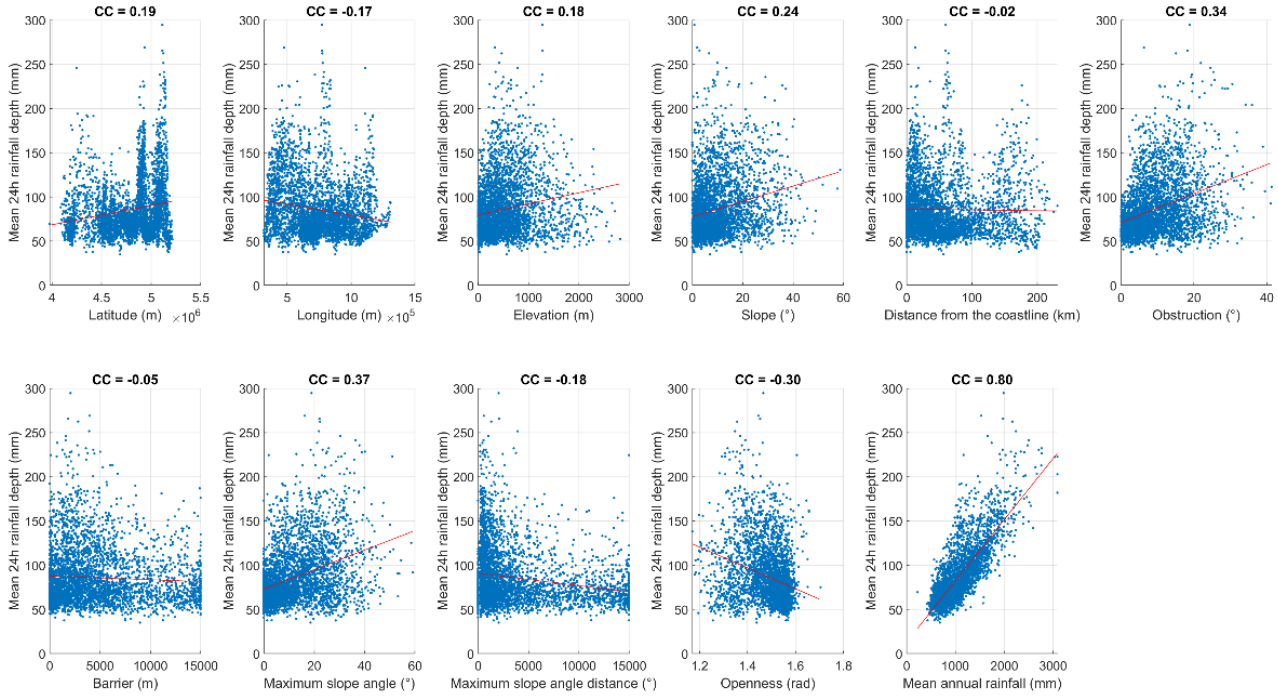


*Figure 3. Scatter plots of the mean of the extremes in 24-hour duration against different covariates.*

**C:** 210. So in essence MAR acts as a proxy of elevation, right? What is the correlation between MAR and elevation?

***R:*** *The correlation between mean annual rainfall (MAR) and elevation is significant, but it is not high enough to be detected by the VIF test. So, equations with both variables are possible. In particular, over the entire nation the correlation coefficient (C.C.) between MAR and elevation is equal to 0.27. If we separately consider the Alps and the rest of Italy we obtain C.C. = -0.24 over the Alps and C.C. = 0.37 over the complementary part. For the whole area of the coastal belt within 20 km from the coastline we obtained the highest correlation, i.e. C.C. = 0.48.*

**C:** Maybe creating subnational regions would be improved by using generic spatial clustering algorithms. I mean based on some statistical properties and not necessarily based on the geomorphological classifications. There are many of them in the literature and could offer an alternative detailed assessment on the optimal number of subregions and on their extend. I hope I have not missed this, but have the authors considered creating such region by applying spatial clustering algorithms to the bias maps?

***R:*** *We thank the reviewer for this comment.*

*We have indeed considered the possibility of using spatial clustering algorithms. Drawbacks of these algorithms are that they would create regions with complex shapes (twisted, elongated, etc) that need to be iteratively identified with a high detail level. This is quite difficult if considering that different areas can have very different rain gauge density. Another source of complexity is that a cluster-based approach is based on the definition of some parameters that have to be preset, as the number of clusters and the maximum number of iterations; however, the results obtained are sensitive to the number of clusters and also to outliers (Xu et al., 2015), which makes the preset choices an iterative procedure. Ramos (2001) suggests that it could be useful to use more than one clustering criterion to extract as much information as possible. Bernard et al. (2013) argue that clustering algorithms based on k-means principle is suited when the variable follows a mixture of normal distributions, posing major problems in the analysis of hourly precipitation amounts, that are generally highly skewed. Considering all these degrees of freedom and shortcomings to tackle in a clustering analysis, it would be the matter of an entire new paper but with a quite different approach to undertake as compared to the one proposed here.*

**C:** Summarizing this is a nice paper, adding to the literature and deserves publication.

***R:*** *Thank you again for the valuable comments and for having appreciated this work.*

***References:***

*Bernard, E., Naveau P., Vrac M., and Mestre O.: Clustering of maxima: spatial dependencies among heavy rainfall in France, Journal of Climate, 26(20), 7929-7937, https://doi.org/10.1175/JCLI-D-12-00836.1, 2013.*

*Ramos M.C.: Divisive and hierarchical clustering techniques to analyse variability of rainfall distribution patterns in a Mediterranean region, Atmospheric Research, 57(2), 123-138, https://doi.org/10.1016/S0169-8095(01)00065-5, 2001.*

*Xu, D. and Tian, Y.: A comprehensive survey of clustering algorithms, Ann. Data. Sci., 2, 165–193, https://doi.org/10.1007/s40745-015-0040-1, 2015.*