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Interactive comment on "Return Levels of Temperature Extremes in Southern Pakistan" *by* Maida Zahid et al.

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The authors would like to thank Sylvie Parey (Referee # 2) for the careful review and comments that helped us to improve our manuscript. Our responses to the comments are as follows.

1. Line 28 p3, it is stated "If the ERA Interim dataset characterizes well the extremes: : :".This is very unlikely, since re-analysis has a too low spatial resolution to represent adequately local extremes, this is not the aim of reanalysis

Ans: It is in principle not obvious that ERA data can simulate well meteorological extremes, as reanalysis are constructed in such a way that typical conditions are well reproduced. This is why we look at how well ERA data performs in the target area against observations. Note that Cornes and Jones, (2013) reported that the ERA-

Interim reanalysis data are generally very good at replicating trends in percentile-based measures of temperature extremes. However, ERA-Interim is weak in capturing the extreme temperatures in complex terrains, but our study area has simple terrain.

2. Lines 31 to 35 p4: it is true that stationarity is a requirement to perform POT, but stationarity means that the distribution is invariant by translation in time, not the autocorrelation is weak. Autocorrelation is rather linked to independence, and must be handled too. Maybe here stationarity refers to the iid (independent and identically distributed) condition, then this section deals with independence, but not with identical distribution. However, identical distribution needs to be checked as well, just because of seasonality. Has seasonality been checked? Is the occurrence of the highest values restricted to the summer season or identically distributed throughout the year? If a season appears as favoring high temperature values, then the analysis should be restricted to this season, otherwise the occurrences are not distributed according to a homogenous Poisson process and the frequency of occurrence is biased. Not only seasonality can disturb the identical distribution, trends can too. There is no discussion about possible trends. Maybe it is possible to neglect the trends over the relatively short 1980-2013 period, but this could be checked.

Ans: We agree with the reviewer. We note that one can see non-stationarity and presence of trends as the presence of long-time correlation in the data. Clearly, extreme temperature and extreme heat indices are realized in summer conditions, so the analysis is restricted to summer season. Including the other seasons would make no sense. We have tested that trends are not significant in such a short time interval. Short-time correlations are studied by computing the extremal index θ in all time series and treated using the associated standard declustering technique.

Additionally, the strict stationarity means that the distribution of the random process is invariant to time shifts. Weak stationarity concerns only the invariance in time of the first and second order moments of the random process, i.e. mean and auto-covariance function (or autocorrelations). However, if the process is Gaussian, then strict stationar-

ity and weak stationarity are equivalent. Nevertheless, weak stationarity and ergodicity are sufficient conditions in time series which allows (when the number of time periods is quite large) to consider the observations 'as if' they were i.i.d. That is why we just check for covariance stationarity (and assume the process is ergodic, i.e. the process has not a long memory: autocovariances decay to 0 for very large time lags). Moreover, when we run the unit-root test (test for stationarity), we check for the presence of a stochastic trend. So, actually, before running the POT analysis it is definitely discussed in the paper the possible presence of a trend.

3. When computing TWmax, are we sure that Tmax and RHmax occur in the same time?

Ans: The occurrence of TWmax takes place in general in different dates than Tmax or RHmax, because one could have a day with high temperature but low humidity and vice versa. Since our study area is next to the Arabian Sea the level of Tmax and RHmax remains constantly high during summer.

4. Some considerations on independence are given again between lines 15 and 22 p6,but no indications are given on how this is used and applied in the study

Ans: Computing the extremal index θ allows for studying the degree of clustering of extremes. The inverse of θ gives the average length of a cluster. Usually θ = 0 means strong clustering and dependence, θ = 1 absence of clusters and independence. The extremal index value in all the time series is $\leq$ 0.5 referring to dependence. Therefore, it is necessary to decluster the extremes by choosing the largest event in each cluster, before fitting it to the GPD. Note that this is the practical strategy commonly adopted by practitioner as well as the rigorous prescription suggested by mathematics.

5. In section 3.2 concerning the GPD fits, one can read "if the higher quantiles are neglected, then the stations like : : : show that the exceedances fit very well". But in an extreme value analysis, the higher quantiles are the targeted ones!

Ans: By saying neglected we did not mean to neglect the higher quantiles. We wanted to say if the higher quantiles are disregarded or unnoticed. We have replaced the word "neglected", as it can be misleading for the readers.

6. In the conclusion, it is stated that: "This paper contains novel and beneficial information: : :, which would help the local administration to prioritize the regions in terms of adaptation". What does adaptation mean here? The estimated levels are based on observations, thus these are rare levels which could occur even if there were no additional warming. It is not clear in the paper if this distinction is made. The notion of return level is defined for stationary time series, that is without any cycles nor trends, and is devoted to the estimation of very rare levels which could happen (once every N years in average), but may not yet have been observed. Climate warming brings other difficulties in their estimation: the definition of a return level has to be changed because a past and a future period are not prone to experience the same temperature levels, and the estimation is complicated. Different papers are devoted to this problem, for example: Cheng, L., AghaKouchak, A., Gilleland, E., & Katz, R. W. (2014). Non-stationary extreme value analysis in a changing climate. Climatic change, 127(2), 353-369 Du, T., Xiong, L., Xu, C. Y., Gippel, C. J., Guo, S., & Liu, P. (2015). Return period and risk analysis of nonstationary low-flow series under climate change. Journal of Hydrology, 527, 234-250 Obeysekera, J., & Salas, J. D. (2016). Frequency of Recurrent Extremes under Nonstationarity. Journal of Hydrologic Engineering, 21(5), 04016005 Parey, S., Malek, F., Laurent, C., Dacunha-Castelle, D. (2007). Trends and climate evolutions: statistical approach for very high temperatures in France. Clim.Change, 81, 331–352. Parey, S., Hoang, R.T.H., Dacunha-Castelle, D. (2010). Different ways to compute temperature return levels in the climate change context. Environmetrics, 21, 698–718.

Ans: Adaptation means preparation of baseline contingency plans for dealing with strong heat waves based on the current climatology. Such measures are not yet present in the territory and lead to many casualties each year. We wish to remark that the study domain is one of the hottest region in the world as mentioned in the

paper with the highest record-breaking temperature of 52°C in 2010. This region is a hub of agriculture activities and 50% of the population work outdoors. The local administrations have limited resources, therefore they want to prioritize the region for the adaptions like, early warning systems, introducing new the temperature tolerant crops, water management and providing shelters for the outdoors workers etc. Therefore, the information of return levels is good for the planning and adaptation strategies. So, a stationary analysis is already a pretty relevant contribution for the region. Moreover, we consider the stationary extreme value analysis due to short duration of the data (33 years) and to have reliable estimates with less uncertainty. Clearly, considering non-stationarity is a good idea for future work. We might consider using the centennial NCEP reanalysis [Compo et al., 2011], and looking at non-stationary extreme events using the methodology proposed in e.g. Parey et al. (2007) or Cheng et al. (2014).

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