

# ***Interactive comment on “Uncertainty analysis of the rate of change of quantile due to global warming using uncertainty analysis of non-stationary frequency model of peak-over-threshold series” by Okjeong Lee et al.***

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Comment #1

The current manuscript presents the nonstationary frequency analysis based on the POT precipitation data. The presented manuscript sounds interesting and contains the novelty. However, the assumption they made was not clearly explained and its still further explanation must be included. Therefore, I recommend that the current manuscript needs major revisions before publication. Detailed comments are attached.

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Your detailed comments were very helpful in making a better manuscript. The authors would like to express great gratitude for this. The main additions are as follows. First, data from 11 sites, which began to be observed in 1961, were further analyzed. That is, a total of 13 sites were used in this study, including 2 sites that were previously applied. As a covariate, analysis was performed by adding surface air temperature in addition to the dew point temperature. The results of applying the added sites and an added covariate were prepared in the form of Supplementary Material and included in the revised manuscript. Also, as a figure showing the final result, Figure 7 of the revised manuscript was newly added. This further analysis may dispel concerns about whether the method proposed in this study applies only to two sites or is not valid only for dew point temperature. In addition, further analysis results will increase the representativeness of the results derived from this study and provide local insights into Korea. More specific details of how and where the manuscript has been revised are described in response to the comments presented below.

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Figure 7(a) shows the values of the negative log likelihood function of the stationary model and the non-stationary models at 13 sites. The stationary model, the SAT-based non-stationary model, and the DAT-based non-stationary model were found to have no significant difference in the fit performance with the observed POT excesses. Figure 7(b) shows the h-factor of rainfall quantile corresponding to the return level of 100-year. When all the values of covariate observed on the day of POT excesses are considered ("DPT" and "SAT" in Figure 7(b)), at all sites except Mokpo site, the non-stationary h-factor is greater than the stationary h-factor. However, when the reference covariate is applied, the non-stationary h-factor is smaller than the stationary h-factor. Results from 13 sites and most of the non-stationary models using SAT or DPT as a covariate indicate that how to determine the appropriate value of the covariate corresponding to the rainfall quantile plays an important role in securing the reliability of the non-stationary frequency analysis.

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Comment #2

[L111] Specific information and references must be added to support the selection of DPF as a covariate. Physical relation must be also included between dpt and extreme rainfall.

We will add information and related references that support DPT or SAT as the covariate to the revised manuscript below. We also included a description of the physical relationship between DPT or SAT and rainfall extreme.

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In this study, a non-stationary frequency analysis using dew point temperature (DPT) or surface air temperature (SAT) as a covariate is performed. As can be seen from Leopore et al. (2014), there is a strong scaling relationship between rainfall extreme and DPT or rainfall extreme and SAT. In addition, changes in DPT and SAT can directly affect the atmospheric moisture retention governed by the Clausius-Clapeyron equation, and in warmer climates, the moisture content of the atmosphere increases and the intensity of precipitation increases at a similar rate (Trenberth et. al., 2003; Giorgi et al., 2019). That is, according to the Clausius-Clapeyron relationship, the amount of moisture in the atmosphere increases exponentially as the temperature increases, and the amount of moisture in the atmosphere represents an increase rate of 6 - 7 %/K when other atmospheric conditions are kept constant. To obtain a necessary understanding of the relationship between daily rainfall and DPT and daily rainfall and SAT in Korea, two prior studies have been conducted (Sim et al., 2019; Lee et al., 2020). Sim et al. (2019) analyzed the effects of DPT and SAT on daily rainfall extremes. Their results indicated that even if there was some cooling effect in the event of summer rainfall (Ali and Mishra, 2017), daily rainfall extremes in Korea were very sensitive to DPT and SAT. Lee et al. (2020) presented a procedure for performing non-stationary frequency analysis using DPT or SAT as a covariate. They revealed that non-stationary

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frequency analysis using future DPT or SAT could yield more reasonable and persuasive projections of future rainfall extremes. The purpose of this study is to focus on the uncertainty of covariate-based non-stationary frequency analysis using DPT or SAT. (Additional references) Ali, H. and Mishra, V. (2017) Contrasting response of rainfall extremes to increase in surface air and dewpoint temperatures at urban locations in India. Scientific Report, 7, 1228, DOI:10.1038/s41598-017-01306-1. Giorgi, F., Raffaele, F. and Coppola, E. (2019) The response of precipitation characteristics to global warming from climate projections. Earth System Dynamics, 10, pp. 73-89. Lepore, C., Veneziano, D. and Molini, A. (2014) Temperature and CAPE dependence of rainfall extremes in the eastern United States, Geophysical Research Letters, 42, pp. 74–83. Trenberth, K., Dai, A., Rasmussen, R. and Parsons, D. (2003) The changing character of precipitation. Bulletin of the American Meteorological Society, 84, pp. 1205-1218.

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### Comment #3

[L158-162] please make it italic and also for  $x$  throughout the paper. All the symbols must be italic unless matrix or vector.

We will modify all the formulas in the text in italics.

### Comment #4

[L172] This one paragraph is not sufficient to set nonstationary model only for shape parameter. Detailed description must be included with more references.

There is a typo. The parameter mentioned here is the scale parameter. We will accept the opinions of the referee and add the following explanation to the revised manuscript.

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In non-stationary frequency analysis, temporally changing parameters are applied to the probability distribution function (PDF). Various types of functions are applied to the

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parameters that change over time. In general, the shape parameter is often set to constant (Lopez and Frances, 2013), but location or scale parameters are often considered functions of time or covariate. Ali and Mishra (2017) applied covariate to the location parameter of GEV, and Agilan and Umamahesh (2017) applied covariate to location and scale parameters of GEV. Non-stationary features in GP distribution are generally implemented by the scale parameter (Coles, 2001; Khaliq et al., 2006). Although non-stationarity can be expressed using the shape parameter, it is not a common practice since it is difficult to estimate the shape parameter, especially when considering covariates (Renard et al., 2006; Pujol et al., 2007). Although studies considering the non-stationarity of the threshold of the POT series have been conducted (Tramblay et al., 2012), in this study, the non-stationarity was given only to the scale parameters of the GP distribution as follows (Um et al., 2017): (Additional references) Khaliq, M., Ouarda, T., Ondo, J., Gachon, P. and Bobee, B. (2006) Frequency analysis of a sequence of dependent and/or non-stationary hydro-meteorological observations: A review. *Journal of Hydrology*, 329, pp. 534–552. Pujol, N., Neppel, L. and Sabatier, R. (2007) Regional tests for trend detection in maximum precipitation series in the French Mediterranean region. *Hydrological Sciences Journal*, 52, pp. 956–973. Renard, B., Lang, M. and Bois, P. (2006) Statistical analysis of extreme events in a nonstationary context via a Bayesian framework. Case study with peak-over-threshold data. *Stochastic Environmental Research and Risk Assessment*, 21, pp. 97–112.

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## Comment #5

[L194] detailed description and references must be added to validate that these factors are meaningful.

It seems to be related to L294. We will explain the meaning of m-factor and h-factor in more detail, and add necessary references to the revised manuscript as follows:

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In fact, m-factor and h-factor can be seen as quantification of confidence intervals of ensembles simulated by MCMC. That is, the m-factor and h-factor of the estimated value indicate how accurate the estimate is or how much uncertainty is (Odura et al., 2020). The greater the uncertainty of the parameter or rainfall quantile, the greater the value of 95 PPU. That is, the quantitation factors of uncertainty expressed by m-factor and h-factor reflect the diffusion or lack of precision of the ensemble sampled from the posterior distribution (Motavita et al., 2019). (Additional reference) Motavita, D, Chow, R., Guthkea, A. and Nowaka, W. (2019) The comprehensive differential split-sample test: A stress-test for hydrological model robustness under climate variability. Journal of Hydrology, 573, pp. 501–515.

## Comment #6

[L331-334] The sentence must be improved.

We will revise the relevant sentences as follows:

The above results indicate that although the non-stationary model is better in fitting performance for the observed samples, it is difficult to admit that the non-stationary model is more reliable than the stationary model due to the influence of extreme values of the covariate when estimating rainfall quantile. Ouarda et al (2020) also produced similar results using the annual maximum rainfall series and the non-stationary GEV distribution.

## Comment #7

L804 The range for (a) and (c) must be changed as shorter than 0-100. It seems that scale parameter has very accurate and small variance. However, in reality it is not.

The horizontal axis range in Figure 3 was set to visually indicate the range of prior-distribution. In fact, comparing the ensembles of scale and shape parameters, we can see that the scale parameters are relatively more accurate and show less coefficient of variation. For further explanation of this fact, we will add a description of the part corresponding to the revised manuscript as follows:

Table 1 shows the final estimated parameters at Busan and Seoul sites. The parameter estimation value of the MH algorithm was defined as the ensemble average of samples extracted by MCMC from the posterior distribution as mentioned in Eq. (7). The parentheses of the parameter estimation values by the MH algorithm in Table 1 are the coefficient of variation of the parameter. It can be found that the PWM and MH algorithms give similar parameter values for both scale and shape parameters. The negative logarithm likelihood (nllh) was also calculated similarly. From the above results, it can be recognized that when the POT series is to be fit to the GP distribution, parameter estimation by the MH algorithm is applicable, and information about the uncertainty of the estimated parameters is also obtainable. It can also be found that the coefficient of variation of the ensemble of scale parameters sampled by MCMC is less than 10 %, while the coefficient of variation of the ensemble of shape parameters is around 40 %. This means that the uncertainty of the shape parameters is relatively higher. Results for other sites tend to be similar to those obtained at Busan and Seoul sites. Results for other sites are shown in Table S1 of Supplemental Material.

Comment #8

[L829] is y-axis 'relative frequency' or pdf? 'relative frequency'= $n_i/N$  while pdf= $n_i/(N \cdot dx)$ . Check it.

As a result of checking, the PDF is correct. We will replace the vertical axis label of

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Figure 5 with PDF.

Comment #9

[L840] circle black line and blue line are not explained properly. F(DPT) does not seem to be empirical cumulative probabilities (see blue and red lines). It is just cumulative distribution function.

As in the reviewer's opinion, the F(PDF) of the original manuscript is correct. However, we will revise Figure 6 as shown below:

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The formula for rainfall quantile  $X_T$  corresponding to the return level of T-year in the non-stationary GP distribution using covariate is as follows:

$$X_T = x_o + 1/k e^{(\alpha_1 + \alpha_2 Z)} [1 - (1/\lambda T)^k]. \quad (5)$$

From Eq. (5), rainfall quantile  $X_T$  appears as a function of covariate Z. That is, Eq. (5) shows that various rainfall quantiles are calculated depending on the value of the covariate even at the same return level. Therefore, one of the problems to be solved in the non-stationary frequency analysis using a covariate is how to set the value of the covariate corresponding to a specific quantile. Since it is often required to have a single design rainfall depth in practice, it is very cumbersome to give a result of calculating rainfall quantiles of various values depending on a change in a covariate. From Eq. (5), the DPT value (i.e., reference DPT) of the non-stationary GP distribution that returns the rainfall quantile equal to the stationary GP distribution can be calculated (reference SAT can be calculated in the same way). Figure 6 shows an example of determining a reference DPT. The results of calculating the reference DPT at Busan and Seoul sites indicate that the reference DPT increases as the return level increases. The right figure in Figure 6(a) and (b) shows the histogram of DPT corresponding to POT excesses. The distribution of DPT is slightly distorted to the left. It can be found that the reference DPT corresponding to various return levels at Busan and Seoul sites is similar



to the location of the mode of the DPT distribution. This fact reveals that covariate values that deviate significantly from the reference covariate (i.e., some extreme values of the covariate) amplify the uncertainty of rainfall quantile from the non-stationary frequency analysis. From the results of regression analysis of rainfall quantile for various return levels and the corresponding reference DPT, the relationship of  $DPT = 18.8589RL^{0.01555}$  (where RL is the return level in year and the unit of DPT is °C) was obtained at Busan site. At Seoul site, a relationship of  $DPT = 19.8540RL^{0.01728}$  was obtained. The coefficient of determination of the regression analysis was 0.99 or higher at Busan and Seoul sites. From these results, the reference DPT corresponding to the return level of 100-year at Busan site could be applied to 20.2567 °C and Seoul site to 21.4958 °C. As shown in Figure 6 and Figures S3 and S4 of Supplementary Material, the value of the reference covariate is almost completely dependent on the return level. It should be noted that the return level and the reference covariate are proportional to each other at some sites, and are inversely proportional to other sites. This means that it is not easy to identify a single covariate value corresponding to a rainfall quantile. In this study, we tried to overcome the problem of random sampling of covariates by introducing the concept of reference covariate when estimating rainfall quantile estimation and its uncertainty from non-stationary frequency analysis based on covariate. From a practical point of view, how to set the value of the reference covariate may be an important research topic in the covariate-based non-stationary frequency analysis.

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Please also note the supplement to this comment:

<https://www.hydrol-earth-syst-sci-discuss.net/hess-2020-167/hess-2020-167-AC3-supplement.zip>

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