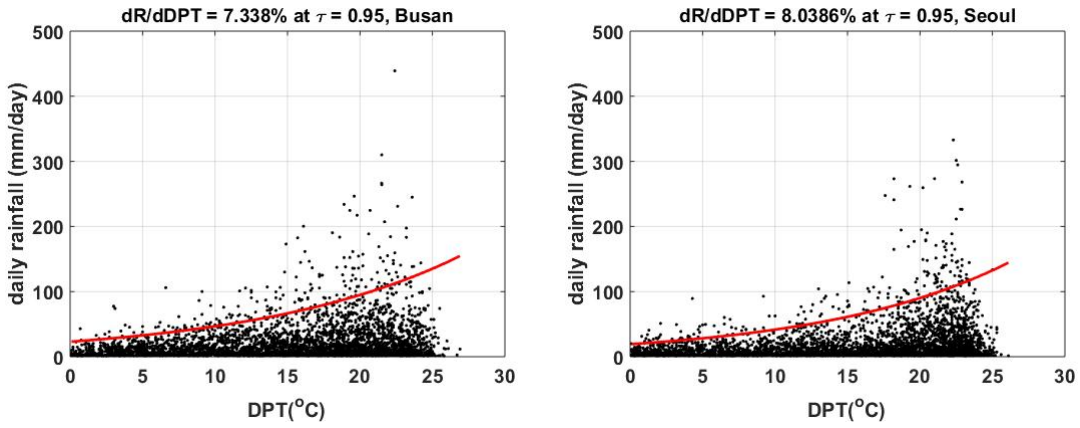
Table 1. Parameter estimation of stationary GP distribution at Busan and Seoul sites

Site	Parameter	PWM	MH
Busan	α	33.5972	33.966 (8.54 %)
	k	-0.1423	-0.1477 (47.44 %)
	nllh	1630.38	1630.42
Seoul	α	34.9666	35.1785 (8.93 %)
	k	-0.1633	-0.1772 (38.59 %)
	nllh	1340.82	1340.87

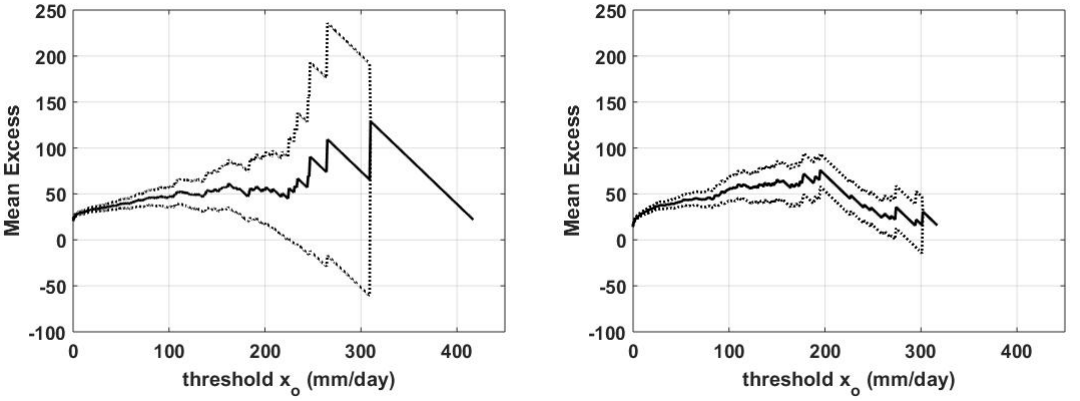
Table 2. Uncertainty of stationary and DPT-based non-stationary frequency analysis at Busan and Seoul sites

Site	factor	Parameter	stationary	non-stationary
Busan	m − factor	α_1	0.3278	0.5463
		α_2		0.8700
		α		0.2920
		k	1.7507	1.5717
	h − factor	100-yr	0.7595	0.4771 (1.0274)
Seoul	m − factor	α_1	0.3407	0.7127
		α_2		0.8588
		α		0.3349
		k	1.4204	1.5613
	h − factor	100-yr	0.7421	0.5331 (1.0273)



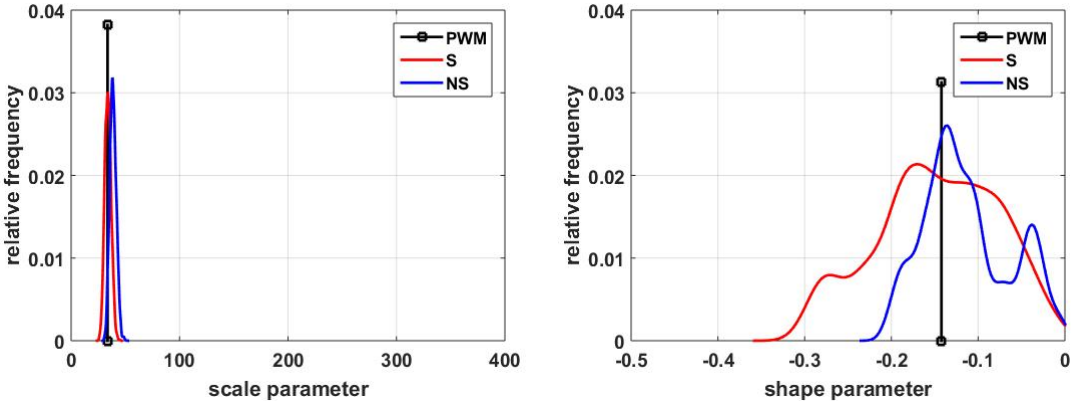
(a) (b)

Figure 1. Sensitivity of 95 % daily rainfall depth to dew-point temperature at (a) Busan and (b) Seoul sites.



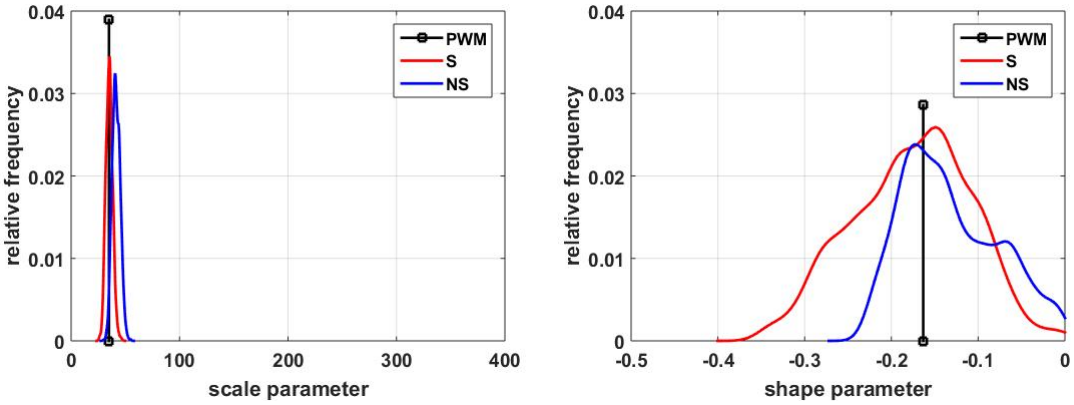
(a) (b)

Figure 2. Mean residual life plot at (a) Busan and (b) Seoul sites.



(a)

(b)



(c)

(d)

Figure 3. Posterior distribution of parameters of stationary and non-stationary GP distribution. (a) Scale and (b) shape parameters at Busan site, and (c) scale and (d) shape parameters at Seoul site. The black vertical lines are a parameter calculated by PWM, which is expressed as a single value. The posterior distribution of parameters for the stationary GP distribution sampled using the MH algorithm is indicated by red lines. The posterior distribution of parameters for the non-stationary GP distribution is indicated by blue lines. The scale parameter of the non-stationary GP distribution using covariate is defined as a function of DPT. Therefore, the posterior distribution of the scale parameters were derived on the assumption that DPT was given at 20.2567 ℃ (Busan site) and 21.4958 ℃ (Seoul site), respectively.

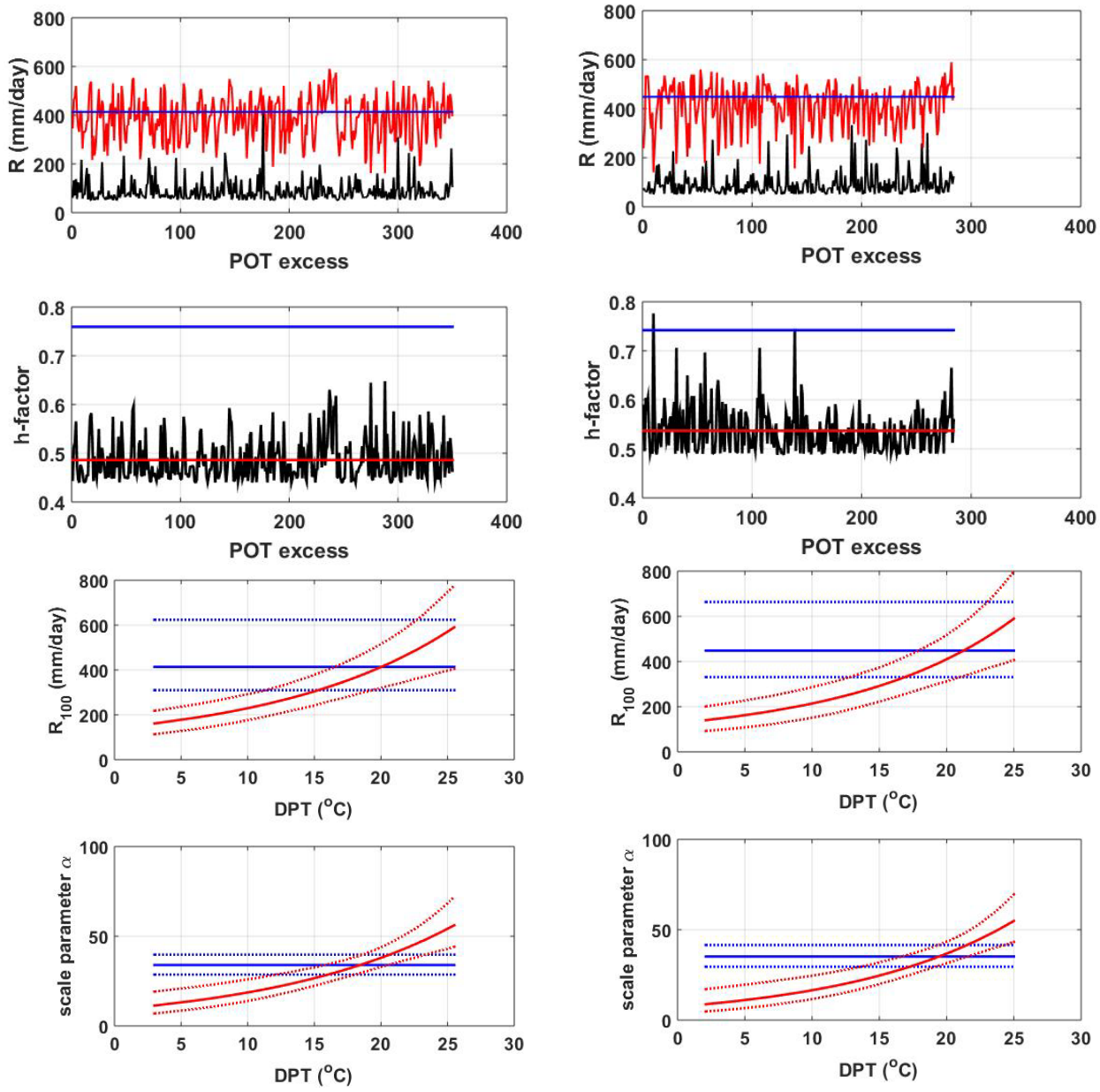
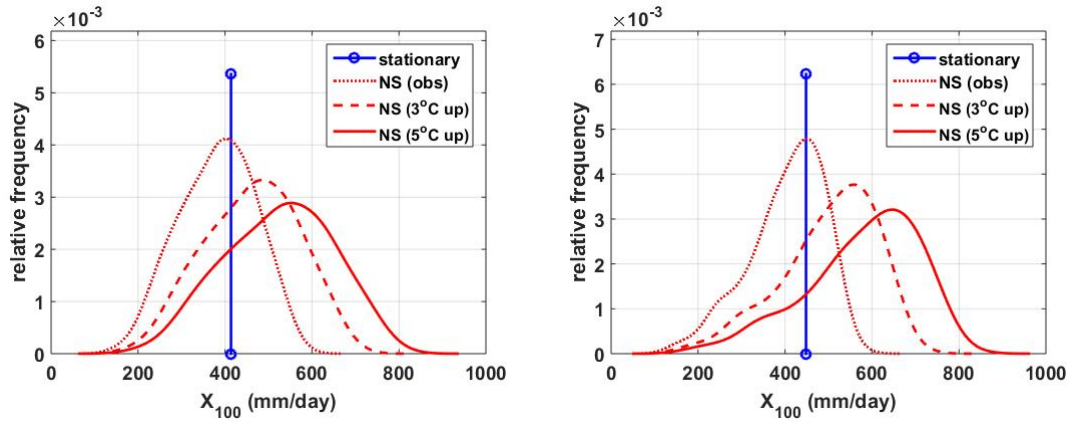
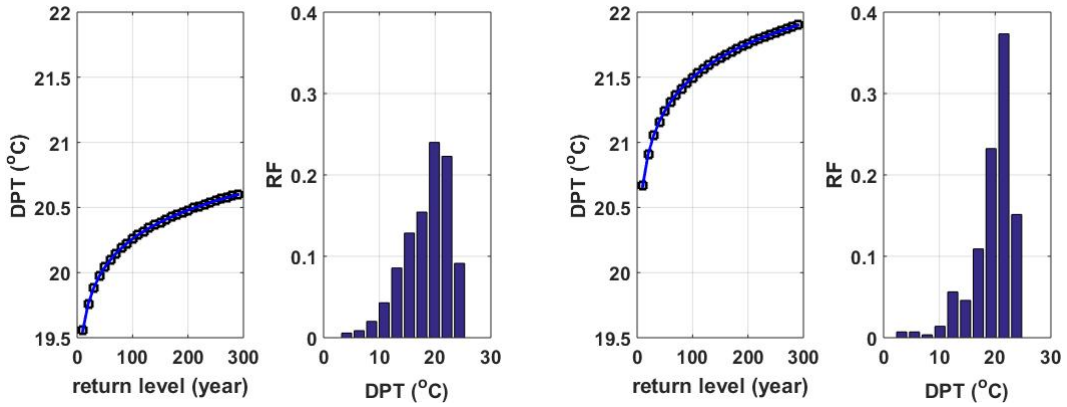


Figure 4. Changes in uncertainty for co-variate at (a) Busan and (b) Seoul sites. The upper left figures in Figure 4(a) and (b) show the POT series (blank line), and the ensemble average of stationary (blue line) and non-stationary (red line) rainfall quantile corresponding to the return level of 100-year. In the upper right figures, the ensemble average (blue line for stationary model, and red line for non-stationary model), and 95PPU of the stationary (blue dotted line) and non-stationary (red dotted line) rainfall quantile for the return level of 100-year are shown. The lower left figures show the h-factor of the stationary (blue line) and non-stationary (black line) rainfall quantile corresponding to the return level of 100-year. Red lines mean the average of black line. The lower right figures show the ensemble average (blue line for stationary model, and red line for non-stationary model), and 95PPU of the stationary (blue dotted line) and non-stationary (red dotted line) scale parameter.



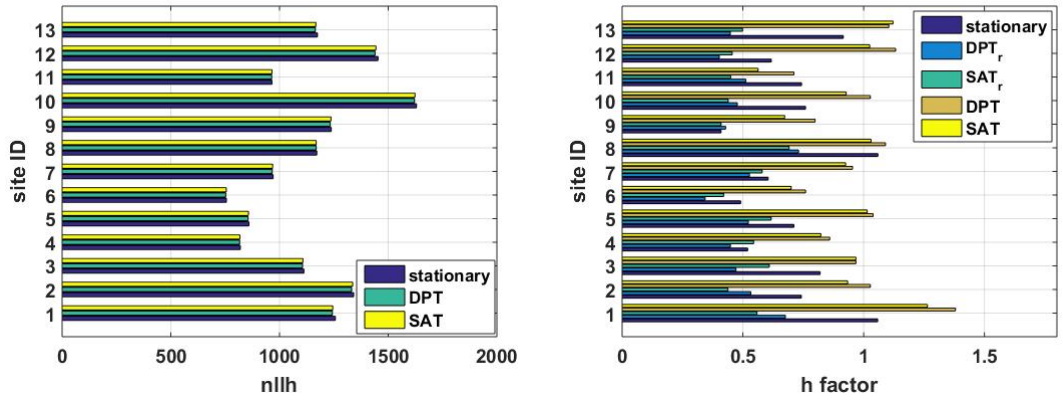
(a) (b)

Figure 5. Rainfall quantile estimates at (a) Busan, and (b) Seoul sites for return level of 100-year using observed dew-point temperature and global warming scenarios. The stationary rainfall quantile is indicated as a blue vertical line since it is a single value. The non-stationary rainfall quantiles were calculated using the average of the parameter ensemble sampled by MCMC and the DPT observed on the day of POT excesses (red dotted line). In this figures, 'NS (3 ℃ up)' is an empirical distribution of rainfall quantile derived using DPTs that add 3 ℃ to DPTs observed on the day of POT excesses. Likewise, 'NS (5 ℃ up)' is an empirical distribution of rainfall quantile under the scenario condition where DPT has risen 5 ℃ due to global warming.



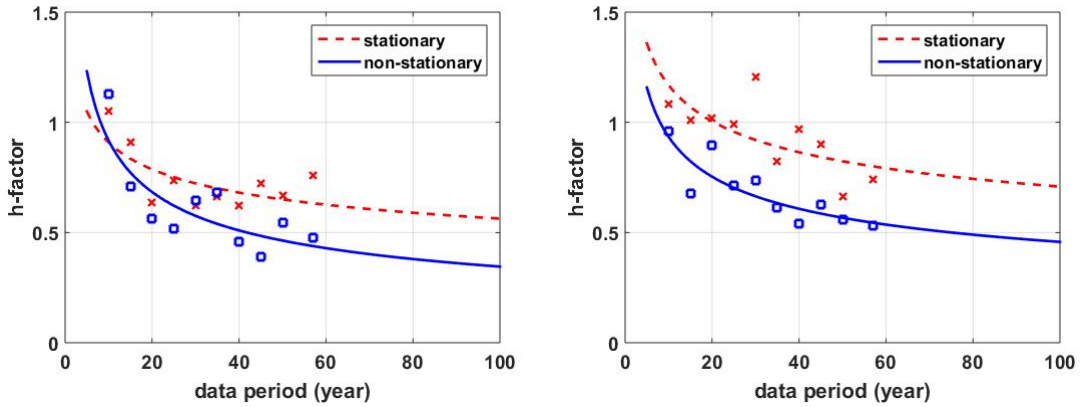
(a) Busan (b) Seoul

Figure 6. Selection of reference dew-point temperature for estimating rainfall quantiles at (a) Busan and (b) Seoul sites. In this figure, 'RF' refers to the empirical relative frequency of DPT on the day of POT excess.



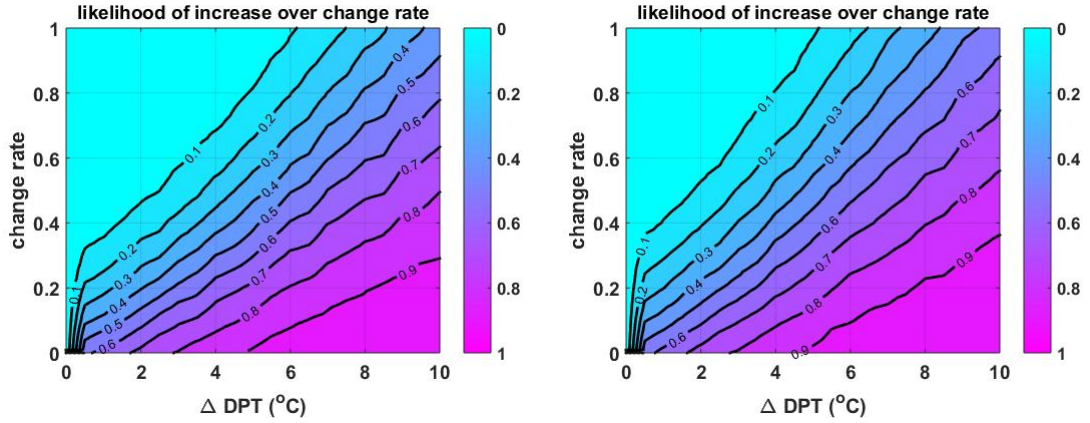
(a) negative log likelihood (b) h factor

Figure 7. Performance of stationary and non-stationary frequency analysis models. At Site ID, 1: Ghangreung, 2: Seoul, 3: Incheon, 4: Chupungryeong, 5: Pohang, 6: Daegu, 7: Jeonju, 8: Ulsan, 9: Ghwangju, 10: Busan, 11: Mokpo, 12: Yeosu and 13: Jeju site.



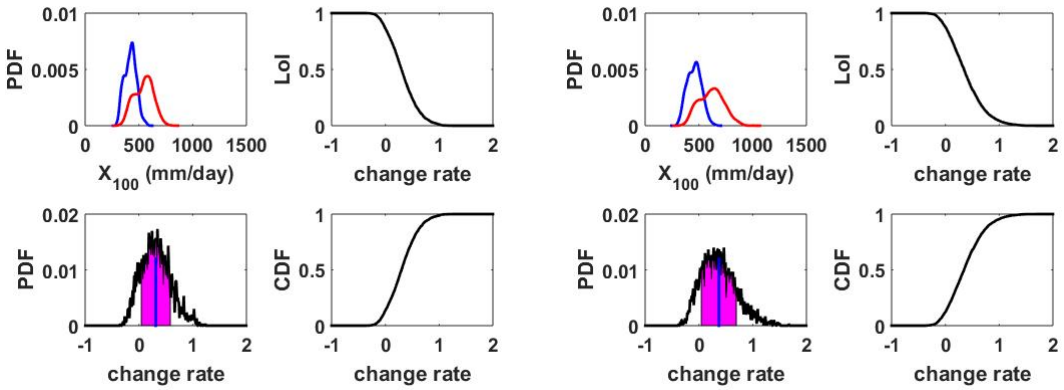
(a) Busan (b) Seoul

Figure 8. Effect of the number of samples on the uncertainty of rainfall quantile using reference dew-point temperature.



(a) Busan (b) Seoul

Figure 9. Likelihood of increase over change rate of rainfall quantile for return level of 100-year.



(a) Busan (b) Seoul

Figure 10. Procedure for analyzing uncertainty in rate of change. In upper left figures, the blue line is the probability distribution of X_p^T in the present condition, and the red line is the probability distribution of X_f^T in the DPT 4 ℃ rising condition. In the lower left figures, the section of the standard deviation was colored in pink.