Estimation of Extreme Rainfall Quantiles using CMIP6 Multi-Model Ensemble at the Wolsong Nuclear Power Plant

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1. Introduction

The safety of critical infrastructure is very important, as it impacts public safety and property. In particular, the safety management of nuclear power plants is especially critical due to the potentially severe consequences of an accident compared to other facilities. Therefore, conducting safety reviews of external hazards, such as seismic and extreme rainfall events, is essential for the safety of nuclear power plants. Climate change is driving an increase in the frequency and intensity of extreme rainfall events globally, leading to significant changes in rainfall patterns. These changes can pose serious threats to the safety management and operation of nuclear power plants. This study aims to estimate the extreme probability rainfall at the Wolsong Nuclear Power Plant (NPP-WS) using CMIP6 multi-model ensemble data, thereby contributing to the enhancement of safety measures for nuclear power plant operations.

2. Data and Methods

To utilize the global climate model (GCM) data provided by CMIP6, techniques for downscaling were applied to increase the resolution of the original data both spatially and temporally. Based on the downscaled data, frequency analysis techniques were employed to estimate extreme rainfall probabilities.

2.1 GCM models and climate change indices

This study employs 23 GCM models from CMIP6 used in the IPCC Sixth Assessment Report (AR6). The scenario used is the SSP585 scenario. The spatial resolution varies by model and the temporal resolution is daily. The Expert team on climate change detection and indices (ETCCDI) was used to analyze and review the data from the GCM models [1]. Table 1 summarizes the models and ETCCDI used in this study.

Table I: Summary of climate change models and indices

Category	Details
Model/Scenario	GCM/SSP5-8.5
Variable/Resolution	Precipitation/Day
PRCPTOT	Annual total precipitation
Rx1day	Max 1-day precipitation
Rx5day	Max 5-day precipitation

2.2 Spatial downscaling

Due to the low resolution of GCM data, the Inverse Distance Weighting (IDW) method [2] was employed using location information from OBS observation stations to perform spatial downscaling. The IDW method interpolates values based on their distances from the observation points. The formula for IDW is as follows.

$$Z(x) = \frac{\sum_{i=1}^{N} \frac{z_i}{d_i^p}}{\sum_{i=1}^{N} \frac{1}{d_i^p}} \qquad (1)$$

where $Z(x)$ is the interpolated value at location (x), (Z_i) is the value at the i-th known point, d_i is the distance from the i-th known point to the location x, and p is the power parameter that influences the weighting. A higher value of p gives more weight to closer points. Fig. 1 illustrates the spatial downscaling and results of calculating IDW using Equation 1.

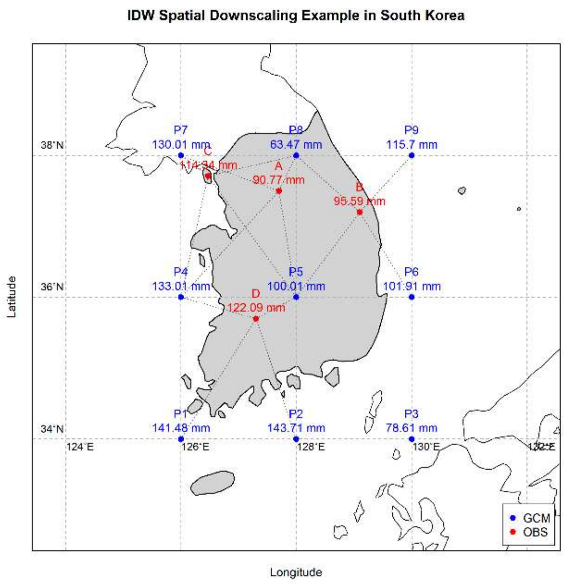


Fig. 1. Example of spatial downscaling using IDW method

2.3 Temporal downscaling

Temporal downscaling was conducted to convert GCM daily data to hourly data using the scale property in the observed hourly rainfall data. Using this scale property, the first to fifth moments for various durations were calculated to determine the scale exponent. The scaling property is defined by the relationship [3]:

$$x_T(\lambda t) = \lambda^e x_T(t) \qquad (2)$$

where, x_T is the observed rainfall for duration T, λ is the scale factor, and e is the scale exponent. The scaling exponent can be calculated from the slope of the linear regression of the moments of the observations by duration.

2.4 Generalized extreme value (GEV) model

In this study, the GEV model was employed to estimate the probabilities of extreme rainfall. The GEV distributions are widely used to model extreme rainfall, floods, high-speed winds, and other extreme phenomena. They have also been widely used to analyze extreme rainfall events in Korea [4~6]. In this study, the probability quantiles were estimated with the GEV model using the observed annual maximum rainfall data around the NPP-WS site and the annual maximum rainfall data from 23 GCM models.

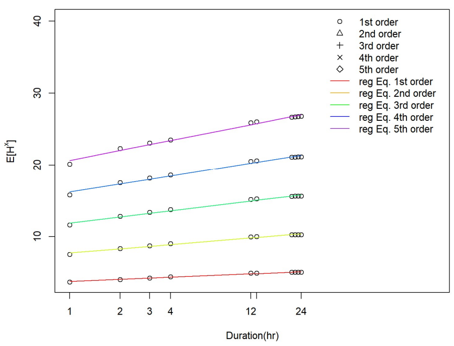
$$f(x) = \frac{1}{\sigma}\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi-1} exp\left(-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right) \qquad (3)$$

$$F(x) = exp\left(-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right) \qquad (4)$$

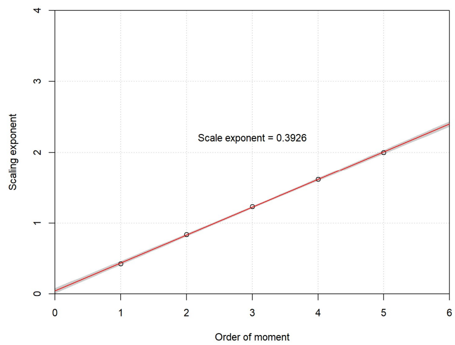
where μ is the location parameter, σ is the scale parameter, and ξ is the shape parameter.

3. Results

In this study, the spatial downscaling using the IDW method was performed using the grid-scale projection results of 23 GCM models provided by CMIP6 and the location information of the station near the NPP-WS site, and the temporal downscaling was performed by increasing the resolution of the daily climate change scenario data to hourly data using the observation data and the scale property. Fig. 2 shows the results of the calculation of the 1st to 5th order moment values by each duration data obtained from the observations around the NPP-WS site and the resulting scale exponent values. Based on the spatial and temporal downscaling of the 23 GCM model data, the future daily rainfall was estimated, and the annual maximum rainfall was calculated, and the variability of the value was analyzed. The GEV distribution model and the multi-model ensemble were used to estimate the extreme rainfall quantiles for each return period. The variation trend of the annual maximum rainfall(AMR) for each model is shown in Fig. 3(a), and the results of the multi-model ensemble(MME) for each return period are shown in Fig. 3(b).

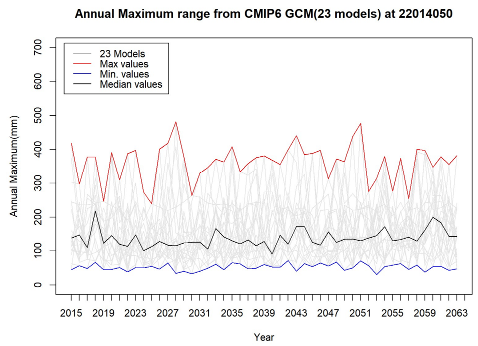


(a)

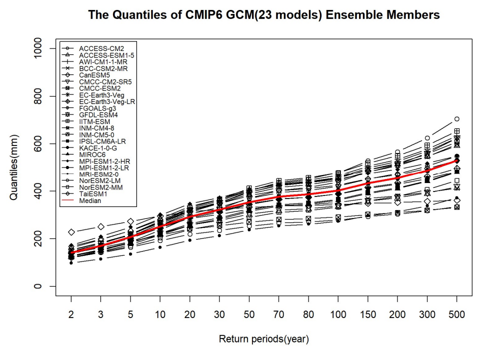


(b)

Fig. 2. Results of (a) raw moment each rainfall duration and (b) scale exponent at NPP-WS



(a)



(b)

Fig. 3. The (a) AMR and (b) MME results from GCM models

We also compared the GEV model using observations with another GEV model using GCM data for the NPP-WS site. Fig. 4 shows the annual maximum rainfall values (histograms) and PDF curves of the GEV model.

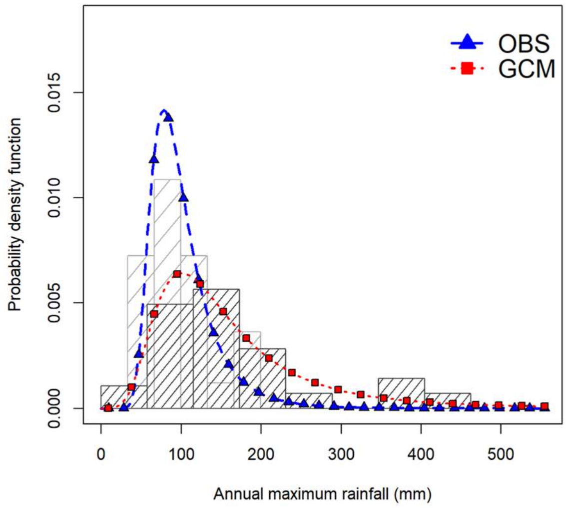


Fig. 4. Comparison of GEV model PDFs from observed and GCM data

4. Conclusions

In this study, to consider climate change, extreme rainfall quantiles for the NPP-WS site were estimated using 23 GCM models with the SSP585 scenario. The authors expect this study to enhance the understanding of using future climate change scenario data for nuclear power plant sites and to serve as a reference for the analysis and assessment of external hazards, such as extreme rainfall.

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