In late June 2021, the Pacific Northwest (PNW) experienced an unprecedented heatwave, setting historical temperature records that led to severe adverse impacts. Many areas in the western United States and Canada recorded extreme temperatures (e.g., 47°C in Portland and 42°C in Seattle). This heatwave had a substantial impact on human health, infrastructure, and the environment. There was a surge in heat-related cases in emergency rooms (Schramm et al., 2021), resulting in over 500 deaths (Popovich & Choi-Schagrin, 2021), and it caused road distortions, crop damage, and increased wildfire occurrences (Griggs, 2021; Overland, 2021). Although this heatwave was shorter in duration than the heatwaves in Europe in 2003 and Russia in 2010, the extent of its record-breaking temperatures and the abnormal temperature deviations were particularly significant (Thompson et al., 2022). The severity of this event has sparked widespread discussion regarding its causes and the impact of climate change.

The 2021 heatwave in the Pacific Northwest set all-time high temperature records, indicating the growing significance of climate change on extreme weather events. Research shows that global warming has increased temperatures during this heatwave by approximately 0.8°C to 1°C. If global warming continues, it is projected that heatwave temperatures may rise by about 5°C by the end of the 21st century (Bercos-Hickey et al., 2022). The severity of such extreme weather is partly attributed to the interaction of slow and fast atmospheric circulation, coupled with a lack of regional soil moisture. Further analysis revealed that land-atmosphere feedback mechanisms, along with long-term regional warming and drought, amplified the intensity of this heatwave (Bartusek et al., 2022). Since the 1950s, global warming has shifted the occurrence of such extreme heat events from nearly impossible to approximately once every 200 years, with projections suggesting that these heatwaves could occur every 10 years in the future due to ongoing climate warming (Bartusek et al., 2022).

This study conducted a repeated non-stationary Generalized Extreme Value (GEV) analysis on single-site data from 1950 to 2020, using a linear location parameter correlated with total greenhouse gas forcing. The analysis indicated that the high-temperature values of 2021 exceeded the expected range of the GEV model, with a return period exceeding 2000 years, demonstrating the model's inadequacy in describing the 2021 PNW heatwave. Statistical results support the conclusion that these temperatures would have been nearly impossible under past meteorological conditions. To explain the causes of the 2021 heatwave, the study employed a retrospective attribution approach, simulating conditions under different climatic backgrounds using numerical weather prediction models. The study utilized the Weather Research and Forecasting (WRF) model and the Regional Climate Model (RegCM) for retrospective simulations, finding that event simulations were more effective at higher horizontal resolutions. While traditional attribution methods have limitations, human-induced climate change likely had a significant impact on the 2021 PNW heatwave.

The methodology of Bercos-Hickey et al. in non-stationary GEV analysis is similar to that used by Risser and Wehner, both incorporating time as a covariate in the GEV model. The distinction lies in the former considering specific sites, while the latter focuses on specific regions.

As climate warming continues, the frequency, intensity, and duration of heatwaves will significantly increase, profoundly affecting ecosystems, human health, and the economy. The rise in extreme high-temperature events may lead to the loss of habitats for plants and animals, affecting the survival and reproduction of species, particularly those sensitive to temperature changes. Additionally, the risks of drought and water scarcity will intensify, threatening agricultural production and aquatic ecosystems. In terms of human health, heatwaves will lead to increased health issues such as heat stroke, dehydration, and cardiovascular diseases, especially impacting the elderly and those with pre-existing health conditions. Economically, agriculture and energy sectors will be adversely affected, with decreased crop yields and increased electricity demand potentially resulting in economic losses. In urban areas, the urban heat island effect will exacerbate the impacts of high temperatures, and declining air quality will increase health risks for residents.

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