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Extreme temperature scenarios in Mexicali, Mexico under climate change conditions

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RESUMEN

Los eventos climáticos extremos pueden tener consecuencias graves en la población y el medio ambiente, por lo que en este artículo para la ciudad de Mexicali, México, con una serie de tiempo de 1950 a 2010, se analizan las tendencias anuales de temperaturas extremas; asimismo, se estiman los periodos de retorno de 5 a 100 años mediante la modelación de la temperatura máxima estival y la temperatura mínima invernal. Para determinar las tendencias temporales se aplicaron la prueba no paramétrica tau de Kendall y el estimador de pendiente de Sen. También se aplicaron la distribución generalizada de valores extremos (GVE) a la aproximación de máximo por bloques, y la distribución generalizada de Pareto (DGP) a valores sobre un umbral determinado previamente. Debido a las características no estacionarias de la serie de valores de temperatura, se incluyó la tendencia temporal como covariable en el parámetro de ubicación, observándose mejoras sustanciales, sobre todo respecto a la temperatura mínima extrema en comparación con lo obtenido con la distribución GVE sin covariable y con la DGP. Se encontró una tendencia positiva estadísticamente significativa para ambas temperaturas extremas: máxima estival y mínima invernal. Hacia finales del siglo XXI la temperatura máxima extrema podría ser de 2 a 3 ºC más alta que la actual, y el invierno podría ser menos severo, ya que el modelo probabilístico sugiere incrementos de 7 a 9 ºC en la temperatura mínima extrema respecto del periodo de base estudiado. Se analizan las posibles consecuencias de lo anterior en la ciudad de Mexicali.

ABSTRACT

Extreme weather events can have severe consequences for the population and the environment. Therefore, in this study a temporal trend of annual temperatures was built with a time series from 1950 to 2010 for Mexicali, Mexico, and estimates of 5- to 100-year return periods are provided by modeling of summer maximum and winter minimum temperatures. A non-parametric Kendall's tau test and the Sen's slope estimator were used to compute trends. The generalized extreme value (GEV) distribution was applied to the approximation of block maxima and the generalized Pareto distribution (GPD) to values over a predetermined threshold. Due to the non-stationary characteristic of the series of temperature values, the temporal trend was included as a covariable in the location parameter and substantial improvements were observed, particularly with the extreme minimum temperature, compared to that obtained with the GEV with no covariable and with the GPD. A positive and significant statistically trend in both summer maximum temperature and winter minimum temperature was found. By the end of 21st century the extreme maximum temperature could be 2 to 3 ºC higher than current, and the winter could be less severe, as the probabilistic model suggests increases of 7 to 9 ºC in the extreme minimum temperature with respect to the base period. The foreseeable consequences on Mexicali city are discussed.

Keywords: Generalized extreme value distribution; generalized Pareto distribution; maximum temperature; minimum temperature; Mexicali, Mexico.

1. Introduction

Various studies have indicated that changes in the frequency and intensity of extreme climate events, such as heat waves, droughts, and floods, can be expected in several parts of the world due to global climate change (IPCC, 2007). Changes in these extreme events are particularly important for society and the environment because, by definition, they occur outside the usual range of adaptability; therefore, they can have severe impacts and significant negative economic effects (Kharin *et al*., 2007). Variations in temperature extremes are of particular importance due to their relationship to biodiversity and human thermal comfort, as well as their use in climate variability and climate change impact assessments in sectors such as agriculture and energy demand. In the period from 1906 to 2005, the increase in average terrestrial temperature was estimated at 0.74 ± 0.18 ºC, and although the value is small, visible effects were observed on many physical and biological systems (IPCC, 2007). According to some projections, extreme heat and cold events may increase during this century, resulting in increased mortality (Curriero *et al.*, 2002; Qian and Lin, 2004).

Studies related to the analysis and modeling of extreme climate events use general circulation models (GCMs) and the extreme value theory (EVT) as essential tools. In particular, EVT models the behavior of extreme observations, *i.e.*, maxima or minima. Its application to climate studies is recent (Naveau *et al.*, 2005), but studies are increasingly using EVT for events related to weather and climate and their impacts on human society and ecosystems (Dixon *et al.*, 2005; Katz *et al.*, 2005; Unkašević and Tošić, 2009; Furió and Meneu, 2011; Constantino, 2011; García-Cueto and Santillán, 2012).

Mexico is vulnerable to the climate change phenomenon, but the impacts may not be uniformly distributed. The IPCC (2007) has shown that water shortages will be exacerbated due to temperature increases and reduced precipitation in the northern Mexico and southern United States regions. According to national climate scenarios, the greatest increases in the average annual temperature in Mexico will occur in the northern part of the country, with greater increases in the northwest than in the northeast (Magaña *et al.*, 2012). Increases for the period 2070-2099 will be approximately 3.5 ºC in the northwest and approximately 3 ºC in the northeast, under the A2 scenario. Tejeda-Martínez *et al.* (2008) estimated future scenarios for the extreme maximum temperature during the month of July in Mexico. They found that changes in the extreme maximum temperature, compared with the 1961-1990 baseline period, varied from +0.5 ºC in the 2020s to +9 ºC in the 2050s; the extreme minimum temperature varied between +0.5 º C in the 2020s and +7 º C in the 2050s. The increases depended on socioeconomic development and the region of the country.

Extreme temperature studies in Mexico have shown that in the last decades of the 20th century (post-1970), there was a significantly higher rate of increase in maximum temperatures than for minimum temperatures, with contrasting trends between northwestern and central Mexico compared with the rest of the country (Englehart and Douglas, 2005; Pavía *et al.*, 2008; Gutiérrez-Ruacho *et al.*, 2010). Regional analyses, such as those conducted by Herrera (2011) for the state of Nuevo León, Vázquez-Aguirre *et al.* (2008) for the state of Veracruz, and Peralta-Hernández *et al.* (2009) for southern Mexico, found a significant upward trend in maximum temperature and the frequency of hot days. In the city of Mexicali, Baja California, García-Cueto *et al.* (2010) found that there are currently 2.3 times as many heat waves compared with the early 1970s, and both their duration and intensity have increased. Regarding minimum temperatures, Weiss and Overpeck (2005) reported an increase in the duration of the frost-free period in the northern Sonoran Desert, although the frost-free period also shortened in the extreme southeast of this desert. For the Laguna District, significant negative trends were also reported for the monthly minimum temperature (Inzunza-López *et al.*, 2011). Only the study by Ríos-Alejandro (2011) applied EVT to model minimum winter temperatures in the city of Monterrey, Nuevo León, using the Gumbel distribution, and estimated some return periods.

The above discussion confirms that studies conducted at the regional level in Mexico have focused predominantly on studying *trends* in temperature extremes. The evidence of changes depends on the region considered, the method of analysis, and the available data period. It is clear that with an increasingly urban population, people, infrastructure, and urban ecosystems will become more vulnerable to extreme temperature events due to the limited number of prospective extreme climate events studies. Therefore, the