Physics and Chemistry of the Earth xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

Temperature and heat wave trends in northwest Mexico

Polioptro F. Martínez-Austria *, Erick R. Bandala, Carlos Patiño-Gómez

Posgrado en Ciencias del Agua, Universidad de las Américas Puebla, Sta. Catarina Mártir, Cholula, 72810 Puebla, Mexico

ARTICLE INFO

Article history:
Received 19 April 2015
Accepted 22 July 2015
Available online xxxx

Keywords:
Heat waves
Climate change
Temperature trends
Climate extremes

ABSTRACT

Increase in temperature extremes is one of the main expected impacts of climate change, as well as one of the first signs of its occurrence. Nevertheless, results emerging from General Circulation Models, while sufficient for large scales, are not enough for forecasting local trends and, hence, the IPCC has called for local studies based on on-site data. Indeed, it is expected that climate extremes will be detected much earlier than changes in climate averages. Heat waves are among the most important and least studied climate extremes, however its occurrence has been only barely studied and even its very definition remains controversial. This paper discusses the observed changes in temperature trends and heat waves in Northwestern Mexico, one of the most vulnerable regions of the country. The climate records in two locations of the region are analyzed, including one of the cities with extreme climate in Mexico, Mexicali City in the state of Baja California and the Yaqui River basin at Sonora State using three different methodologies. Results showed clear trends on temperature increase and occurrence of heat waves in both of the study zones using the three methodologies proposed. As result, some policy making suggestion are included in order to increase the adaptability of the studied regions to climate change, particularly related with heat wave occurrence.

1. Introduction

According with the most recent climate change report by the Intergovernmental Panel on Climate Change (IPCC, 2014), human influence on climate is undeniable and many of its consequences are now observed in several regions of the world. Particularly, climatic extremes had shown to be pervasive and, among them, heat waves are responsible of some of the worst recent climate-related human deceases. From the Annual Disaster Statistical Review 2013 (Guha-Sapir et al., 2014) it is found that three, among the ten worst natural disaster -by the number of deaths- during 2013 were caused by heat waves (see Table 1).

Modern societies are striving, without much success so far, to mitigate the global warming effects by reducing the greenhouse gas emissions produced by insatiably consumption of oil, gas and carbon. The concentration of greenhouse gases, however, continues increasing. According with the US National Oceanic and Atmospheric Administration (NOOA), in May 2014 carbon dioxide concentration in the atmosphere reached 402.85 ppm at the Mauna Loa observatory. The increase rate of CO_2 concentrations not only has not been reduced, but rather continues to increase reaching, in 2013, 2.62 ppm/year. As result, NASA has reported 2014 as the warmest year registered, confirming the increasing temperature trend. According with IPCC, the regions located in middle and high latitudes will experiment some of the highest temperature increases. In the course of this century, a mean global temperature increase is expected to occur reaching up to 4 °C (IPCC, 2013).

These predictions are supported on the results of general circulation models. The IPCC has estimated the performance of these models by making a comparison of their results with the climate observed during the 1980–1999 period. With respect to temperature, when multi-model results (i.e. the average of 23 general circulation models) are analyzed, the estimation error (i.e. the difference between observed and model estimated data), is rarely greater than 2 °C, although individual models can show errors close to 3 °C (Randall and Word, 2007). Nevertheless, the IPCC have noticed that the largest-scale features of climate are more accurately simulated than regional- and small-scale features.

The analysis of climate change impact and vulnerability should therefore be soundly based on observational evidence. Accordingly, the fourth and fifth IPCC Assessment Reports (IPCC, 2007, 2013) are not solely based nor predominantly on the results of general circulation models, but also on observational evidence. However, the latest report notes a lack of geographic balance in data and literature on observed changes, with marked scarcity in low and middle income countries. Furthermore, the reported trends and forecasts

* Corresponding author.
E-mail address: polioptro.martinez@udlap.mx (P.F. Martínez-Austria).

http://dx.doi.org/10.1016/j.pce.2015.07.005
1474-7065/

Table 1
Ten most deadly natural disasters in 2013 (Guha-Sapir et al., 2014).

Event/date	Country	Deceases number
Cyclone (Haiyan), November	Philippines	7354
Flood, June	India	6054
Heat wave, July	UK	760
Heat wave, April–June	India	557
Earthquake, September	Pakistan	399
Heat wave, May–September	Japan	338
Flood, August	Pakistan	234
Flood, July	China	233
Earthquake, October	Philippines	230
Flood, September–October	Cambodia	200
	Total	16,359

from general circulation models focus particularly on average values (IPCC, 2008). For instance, there are average temperature forecasts for several scenarios, but no general forecasts for extreme temperatures are available. Nevertheless, the IPCC Fifth Assessment Report has pointed out that the number of cold days and nights has already decreased globally, and the number of heat waves has increased in Europe and North America (IPCC, 2013). Forecasting mean temperature changes at local scale is a difficult task, although forecasting extreme temperatures is much more difficult since it depends almost entirely on observational evidence. Therefore, the analysis of the occurrence of heat waves is relevant, especially in vulnerable areas, such as Northwestern Mexico. The aim of this work is hence to show the observational evidence of warming trends and increasing of heat waves in the most vulnerable region of Mexico to climate change.

2. Heat waves

The importance of heat waves lie mainly on their effects on human health. Heat waves produce disorders causing minor alterations or even the collapse of body's capacity for regulating its temperature through changes in blood circulation or sweating. In extreme cases, those health effects can lead to death. The population segments particularly vulnerable to heat waves are elderly and small children (Gronlund et al., 2014; Kovats and Ebi, 2006; Pinacho-Velázquez, 2014). In the last few decades, occurrence of record temperatures during particularly dangerous heat waves have caused human deceases, even at developed countries with good public health services. Worth to noting are the heat wave at Chicago in 1995, causing 514 heat-related deaths (Whitman et al., 1997) and the heat wave during 2003 in Europe, affecting mainly France, caused almost 15,000 deaths (Hémon and Jougla, 2003; Le Tertre et al., 2006).

A heat wave can be defined qualitatively as a period, usually lasting several days, of temperatures significantly higher than average. Nevertheless, there is not a universal quantitative definition mainly because it is relative to a specific area and a certain time of year. Accordingly, there are different thresholds to determine the presence of a heat wave. For instance, the UK Met Office establishes a regional system with an average threshold of 30 °C by day and 15 °C overnight for more than two consecutive days (METT, 2015). The NOOA establishes thresholds considering maximum temperatures and ambient humidity, which comes closer to the measurement of apparent temperature. Mexico lacks of a general definition in use. Some authors (Jáuregui, 2009) suggested for Mexico City that a heat waves happens when temperature values above 30 °C were observed for three or more days, associated to a mean temperature of 24 °C or more. Díaz-Lázaro (2011) recommended a temperature threshold over the 96th percentile of the maximum recorded by at least one day. Another definition suggested by the World Meteorological Organization, with no direct association to health effects, established heat wave as the condition with temperatures 5 °C higher than the mean maximum temperature in the area recorded during five or more consecutive days (Campell, 2009).

3. Methodology

3.1. Temperature trends and heat waves in Northwestern Mexico

The statistics of heat waves, and the resulting diseases and deceases, are uncommonly recorded in Mexico. Usually, the heat wave produced diseases are not diagnosed as "heat stroke", but as one or another of its effects. In this regard, it has been well documented that the increase in extreme temperatures produces a significant increase in diseases caused by respiratory and renal malfunction (i.e. Anderson et al., 2013; Gronlund et al., 2014). On the other hand, in our country, many of those persons affected by heat waves have no access to health services, resulting in the absence of disease registers at all (Knowlton et al., 2009).

According to Díaz Caravante et al. (2014) in the 2002–2010 period, 393 people died in Mexico related to "excessive heat", the most of them in the Northwest of the country, in the states of Sonora and Baja California. From the latest, particularly in the municipality of Mexicali. Jaramillo Ramírez et al. (2011) reported statistics data of patients with a diagnosis of heat wave at Mexicali's General Hospital during 2006–2010. In that period, 76 patients with heat wave symptoms were admitted, 23 of them (almost on third) died. Fig. 1 shows mortality in Mexico from heat stroke in the 1979–2003 period. As it could be observed, the trend shown at Fig. 1 confirms the Northwest of the country as the region with the largest number of cases, mainly in the states of Sonora and Baja California, followed by the states located along the Gulf of Mexico, particularly Veracruz and Tabasco (INE, 2007).

Concerning climate change scenarios for Mexico, Montero Martínez et al. (2010) conducted a regionalization analysis using data from the Climate Research Unit (CRU) of the University of East Anglia, along with general circulation models. Their results indicated that temperature anomaly at Northern Mexico will become one of the highest in the country, as depicted in Fig. 2. Hence, accordingly with the aforementioned statistics analysis of heat wave diseases and considering the climatic change scenarios, we have selected two areas of study: the Lower Yaqui Valley watershed at Sonora State and Mexicali City at Baja California. The geographical location of the selected study areas are shown in Fig. 3.

3.2. Geographical description of the study zones

The Yaqui River flows from the slopes of the Sierra Madre Occidental to the Gulf of California, near to Obregon City, and constitutes one of the major river systems of Northwestern Mexico. The Yaqui River basin is considered climatically vulnerable, subject to frequent and severe droughts. According to climate change scenarios, this vulnerability would increase, with higher medium and extreme temperatures (Montero Martínez et al., 2010). In the lower Yaqui River basin, a group of climatologic stations is located with long and virtually complete records. Among them, the Alvaro Obregon Dam station (Code 26068; located in 28°49′23″N; 109°53′9″E) was selected with recording data for the last 63 years.

Mexicali City, on the other hand, is located at Baja California, bordering with the United States. It has 936,826 inhabitants. For this location, the 2033 "Río Nuevo" climatologic station (Lat. 32°39′48″N, Long. 115°28′4″E) of the National Weather Service was used for this study. Mexicali City is one of the hottest cities in Mexico and according with the National Institute of Ecology

Please cite this article in press as: Martínez-Austria, P.F., et al. Temperature and heat wave trends in northwest Mexico. J. Phys. Chem. Earth (2015), http://dx.doi.org/10.1016/j.pce.2015.07.005