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# Regional analysis of climate variability at three time scales and its effect on rainfed maize production in the Upper Lerma River Basin, Mexico

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ABSTRACT

This study explored climate variability in the Upper Lerma River Basin, State of Mexico, Mexico, at three timescales: annual (1960–2010), monthly (1980–2010) and seasonal (1980–2010). The effects of monthly and seasonal (2003–2010) variability on rainfed maize crops were also evaluated. The variables of rainfall, maximum temperature, minimum temperature and number of hailstorms were interpolated to generate monthly spatial-temporal series. Over a period of 51 years, the climate of the region shows an accumulative annual increase of 131 mm in rainfall and an increase of 0.8 and 0.74 °C in maximum and minimum temperature, respectively. In conclusion, significant changes in the climate variables were found at the three analyzed timescales. Seasonal climate changes were found to coincide with the most vulnerable stage or flowering period of maize; particularly, a shift in the rainfall pattern generates a water deficit that impacts production yield. Hailstorms have increased in frequency, yet their phase shift results in a lesser impact to maize during its most critical stage of development.

## 1. Introduction

Agriculture is an important economic, social, and cultural activity, and it is also one of the most determinant factors influencing land uses and transformations across the surface of the Earth. Furthermore, agriculture has contributed towards global warming due to the use of agrochemicals (O'Neill et al., 2005) and the resulting effects of extensive land use changes that lead to modifications of the surface energy and water balance (Foley et al., 2005). The scale and impact of agriculture is evident, where in 2013, farm land for cultivating permanent crops represented 3400 million hectares or 23% of the world's surface area (FAOstat, 2013).

Although agricultural activity has contributed to climate change, it is in turn affected by changes in rainfall patterns and temperatures, which are key influential factors in agricultural production. In particular, extreme rainfall and temperature events have a negative effect on crop yield (Skoufias and Vinha, 2013), and these may be experienced as more frequent or intense hurricanes, flooding, hailstorms, drought or frosts (Loaiciga et al., 1996; Reyer et al., 2013). Since climate variability affects crop yield in addition to the socio-economic processes involved in the distribution and accessibility of food supplies, the stability of local food systems may be compromised (Ericksen et al., 2009). However, not all of the effects of climate change are easily predictable, quantifiable or able to be absolutely characterized as negative. For example, increasing concentrations of carbon dioxide in the atmosphere could stimulate photosynthesis (Cao and Woodward, 1998), have a fertilizing effect (Florides and Christodoulides, 2009) or improve efficiency of water usage (Keenan et al., 2013), depending on the crop.

While scenarios of climate change may alert to possible social instabilities, within rural communities dominated by traditional means of agriculture, many peasants appear to react satisfactorily to fluctuations in climate (Eakin, 2005; Mortimore and Adams, 2001). Peasants have a varying ability, depending upon their experience, to adapt and respond to climate change. Losses in productivity may be minimized by the use of local, water deficit-tolerant varieties or management systems that employ polycultures, opportune weeding or agroforestry, among other techniques (Altieri and Nicholls, 2009). In fact, peasants have developed agricultural systems over many years to be specifically adapted to

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local climate conditions, as many are dependent upon subsistence farming and must achieve necessary production levels to satisfy their needs in spite of other disadvantages, such as marginal land holdings, unfavourable topography or climate variability (Andrews and Tommerup, 1995).

At the international level, maize (*Zea mays*) is the third most cultivated crop, after wheat and rice (Asturias, 2004). Maize cultivation originates approximately 7000 years ago in Mexico and Central America (FAO, 1993). Due to the resistance of maize to variable climate conditions, it was traditionally grown alongside beans and squashes, leading to the emergence of a longstanding agricultural practice that has formed the basis of the Mexican diet. Currently, adaptations to regional climates over the course of thousands of years have resulted in more than 62 documented races of maize in Mexico, including 350 particular varieties that have been conserved on small parcels of land in indigenous and rural communities. Along with its cultural, ritualistic, symbolic, culinary and nutritional uses, maize continues to form the basis of food diet for the majority of the Mexican population (Kato, 2009).

In 2013, according to the Agroalimentary and Fisheries Information Service (SIAP, for its initials in Spanish) of Mexico (SIAP, 2014), 16 million hectares were occupied by rainfed maize crops at the national level, representing 74% of the total area dedicated to maize production. For the same year in the State of Mexico (located in the central portion of the country), 700,000 ha of rainfed maize were planted, encompassing 84% of state's total maize crops.

In Mexico, extreme climate phenomena regularly affect the agricultural sector. For example (Monterroso et al., 2014) found that from 1980 to 2000 more than 3000 floods, 450 landslides and 750 frosts or hailstorms were reported. Hailstorms are extreme events that have a wide geographical reach and affect five out of every 10 Mexicans, mainly in the northern and central regions of Mexico (Monterroso and Conde, 2015). In this regard, it has been observed that temporal fluctuations in minimum temperature and rainfall coincide with hailstorms, although (Requejo et al., 2012) conclude that regional analyses are important due to the diverse topography and climatology of distinct geographical regions.

Several authors have recognized that in Mexico, rainfed maize crops experience a greater vulnerability to variations in climate (Conde et al., 2006; Eakin, 2005). Variations in temperature, rainfall and hailstorms affect crops differentially, depending on the intensity of the event and their time of occurrence with respect to the phenological stages of the crop. In general, it has been observed that the stages of plant growth and flowering are the most vulnerable to climate events, which may lead to decreases in yield. Thus, the objective of this study was to analyze climate variability and seasonal changes in order to detect spatial-temporal trends in rainfall ($P$), maximum temperature ($T_{max}$), minimum temperature ($T_{min}$) and number of hailstorms ($G$) at different time scales and potential effects on the yield of the rainfed maize crops farmed by small-scale peasants in the Upper Lerma River Basin (ULRB) in the State of Mexico. Finally, these analyses are performed with the goal of generating useful information that could aid peasant farmers

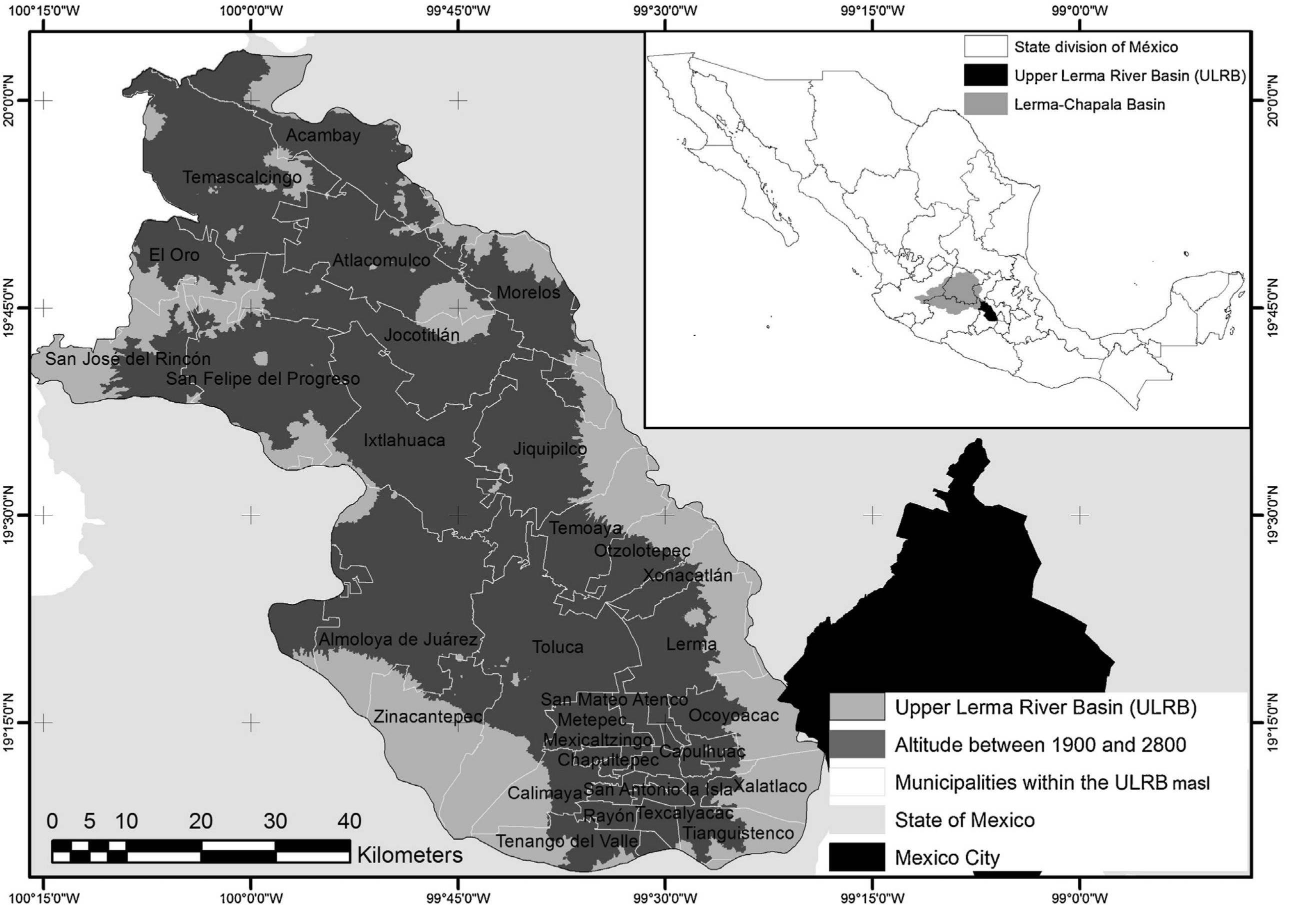

**Fig. 1.** Location of the Upper Lerma River Basin (ULRB) and the 32 municipalities that compose more than 80 per cent of the study area (1900–2800 masl).