Climate Change as Migration Driver:

Evidence from Rural and Urban Areas in Mexico

By

Raphael J. Nawrotzki and Lori M. Hunter

University of Colorado at Boulder

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Abstract

While most prior studies on the climate-migration association have used relatively coarse measures of rainfall and drought, this study employs 17 climate change indices, developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) to capture nuanced changes in climatic extremes. Cokriging as a method of spatial interpolation was employed to obtain climate change index values for 111 Mexican municipalities, for which detailed migration histories are available from the Mexican Migration Project. Multi-level event history models are employed to estimate the impact of climate change on international migration patterns. Households are followed across a 14-year study period from 1986 to 1999. The results show that climate change stronger impacts international migration from rural compared to urban areas. Generally, an increase in temperature (warming) and a reduction in precipitation increase the probability of an international move, providing evidence that climate change will likely drive out-migration during the 21st century.

Key words

Climate change, climate change index, international migration, Mexico, Mexican Migration Project, Multi-level models

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Climate change has become a publically recognized problem of global magnitude. The award winning work of the International Panel on Climate Change (IPCC) first brought public-wide attention to the impact of industrialization and anthropogenic Greenhouse Gas (GHG) emission on changes on the climatic system (IPCC, 20013). Furthermore, a general consensus exists that particularly poor, less developed countries (LDCs) will suffer the most from the impacts of climate change (Adamo and de Sherbinin, 2011; Huq et al., 2003; Roberts and Park, 2006; UNHR, 2007).

The differential impact on LDCs is a result of relatively higher dependence on agriculture and natural resources, as well as a lack of financial capital to employ technological barriers as protection against adverse climatic shocks (Gutmann and Field, 2010). In the face of adverse weather effects, rural populations frequently employ *in situ* (in place) adaptation strategies as a first response towards livelihood insecurities (Bardsley and Hugo, 2010; Davis and Lopez-Carr, 2010). As an example, *in situ* adaptation strategies may include sales of assets, intensifying livelihood activities (e.g., using agricultural inputs) or adopting new ones, use of formal and informal credit, reducing nonessential expenditures, and drawing on social networks and public programs for assistance (Gray and Mueller, 2011). If those strategies prove to be insufficient or infeasible, a household might decide to send a member elsewhere, or as an option of last resort, the entire household might decide to relocate (Warner et al., 2010). A number of studies have investigate the impact of droughts and a decline in rainfall on migration (e.g., Henry, Schoumaker, Beauchemin, 2004; Hunter, Murray, and Riosmena, 2013) but studies employing direct measures of climate change are rare. Moreover, it can be assumed that people employ some types of migration more than others (e.g., international vs. domestic) and this preference is likely to be location specific. This study is an attempt to shed more light on the climate change migration relationship by investigating the impact of long term changes in climate patterns and their differential impact on distinct migration flows.

The Study Region: Mexico

Research from all major continents shows that climatic variability and weather extremes are associated with outmigration (e.g., Dun, 2011; Findley, 1994; Gray and Mueller, 2011, 2012; Henry, Schoumaker, and Beauchemin, 2004; Juelich, 2011; Warner, 2011). However, only four published studies have explored the impact of climatic variability on migration from Mexico to the U.S. Using rainfall in the origin community as an instrument for the size of the network at the U.S. destination, Munshi (2003) found that rainfall deficits are connected to international outmigration from Mexico. This association was confirmed at the state-level by Feng, Krueger, and Oppenheimer (2010). They observed that climate-driven changes in crop yields were related to a significant increase in emigration during the period of 1995 and 2005 in 16 more rural Mexican states (Feng and Oppenheimer, 2012). More recently, Hunter, Murray and Riosmena (2013) employed a categorical measure for long-term changes in rainfall patterns and found that households subjected to drought conditions were far more likely to send a migrant compared to those subjected to wet conditions, but only in communities with strong migration histories. Another study used a 12-year period to investigate the impact of severe drought conditions on migration (Nawrotzki, Riosmena, and Hunter, 2013) and this study confirmed the general pattern of an increase in out-migration under conditions of rainfall decline, but specified that this impact is strongest for the arid northern states during the crop-growth period of corn. A similar pattern was confirmed for other Latin American countries such as Ecuador (Gray, 2009, 2010) and El Salvador (Halliday, 2006).

Mexico is uniquely positioned for the study of the association between climate change and migration due to Mexico's established history of high levels of migration, and the vulnerability of the agriculture sector with regard to climate change.

Established History of Migration. International migration to the U.S. is a century-long tradition. The first substantial flows of Mexican migration to the U.S. began in the early 1900s mostly from rural areas of western Mexico when labor recruiters sought railroad and agricultural labor (Fussell, 2004). Migration flows continued to grow early in the twentieth century in response to a mix of push and pull factors associated with U.S employer recruitment efforts and the Mexican Revolution (Cardoso, 1980). This initial surge in migration flows abated during the Great Depression (Hoffman, 1974) but regained momentum in 1942 in response to the Bracero Program, a bi-national labor accord aimed at providing Mexican farm labor to the U.S. during World War II (Calavita, 1992). The Bracero Program was discontinued in 1964 as part of broader civil rights and immigration reforms (Calavita, 1992). Despite the lack of official program support, both documented and undocumented migration continued (Cornelius, 1992; Massey et al., 2002). Even under conditions of increased border militarization, the number of Mexicans in the U.S. increased by 450 % between 1980 and 2000 (Massey and Capoferro, 2004). A factor that contributed to this massive increase in migration flows was the establishment of the North American Free Trade Agreement (NAFTA) of 1994 (Sanchez Cohen et al., 2012). NAFTA contributed to a decline in job opportunities in the agriculture sector since small-scale Mexican farmers were unable to compete with U.S. and Canadian agricultural imports and frequently reverted to undocumented migration to find employment in the U.S.

(Fussell, 2004). In contrast, an increase in documented migration resulted from the 1986 Immigration Reform and Control Act (IRCA), which provided a relatively easy path to U.S. citizenship for large numbers of undocumented migrants already residing within the U.S. (LoBreglio, 2004). The Special Agriculture Worker (SAW) and Replenishment Agricultural Workers (RAW) sub-components of IRCA have likely led to a large increase in the number of migrants due to a program design that encouraged fraudulent claims to obtain legal permanent resident status (Martin, 1990). IRCA brought about some other changes in immigration law intended to deter immigration from Mexico, including the penalization of employing undocumented migrants and a substantial increase in the border patrol budget and programs (Orrenius and Zavodny, 2003). Although the largest amount of migrants came traditionally from rural areas, urban areas (especially small cities) have increasingly contributed to the migration flow (Fussell and Massey, 2004). Through this unique century-long history of migration, a dense migrant network has been developed. These networks operate as "migration corridors" (Bardsely and Hugo, 2010, p. 249), which may facilitate the relocation of individuals from Mexico to the U.S. under conditions of declining livelihoods due to factors such as climate change (Adamo and de Sherbinin, 2011).

The Climatic Context. For an informed investigation of the impact of climate change on migration patterns, it is important to understand the climatic context of Mexico and the vulnerability of the agriculture sector with regard to changes in weather patterns. The country of Mexico covers an area of around 2 million square kilometers with varying climatic zones. Overall, two distinct seasons can be identified: A warm rainy season (May to October) and a cold dry seasons (November to April) (Schwartz, 1977; Pearce and Smith, 1990). However, there are large geographical variations in climatic conditions. The northern states, from the U.S. border to north of Mexico City, show a semiarid dry to very dry climate throughout the year. The central-western part of the country experiences a temperate sub humid climate, while the southern coasts and the Yucatan Peninsula are warm and sub humid. Warm humid conditions prevail in the area west of the Yucatan Peninsula to the south central interior (Boyd and Ibarraran, 2009; Marty, 1992). Knowledge of these climatic patterns is important for the present analysis and provides relevant information for the investigation of temporal and spatial variation in the weather-migration association. Figure 1 below shows climatic zones derived from a Koeppen classification for Mexico.

(Figure 1 about here)

Climate Change and Agriculture. Although most households do not rely entirely on agriculture, income from farming activities contributes in important ways to sustenance and livelihood portfolios particularly in rural Mexico (Wiggins et al., 2002; Winters et al., 2002; Conde et al., 2006). For rural Mexicans, agriculture contributes between 23% and 67% to the household income depending on the size of land holdings (de Janvry and Sadoulet, 2001). This reliance on agriculture makes rural Mexicans vulnerable to climatic shifts and any resulting adverse impacts on crop production (Eakin, 2000, 2005; Eakin and Appendini, 2008; Endfield, 2007; Schroth et al., 2009; Vasquez-Leon et al., 2003). The sensitivity of the agriculture sector to climate variability can be partially attributed to lower levels of infrastructure designed to mitigate the impacts of environmental stresses (Endfield, 2007). For example, only 23.15% of the arable and permanently-cropped land was irrigated in 2001 (Carr, Lopez, and Bilsborrow, 2009). Given this sensitivity of the agricultural sector, some climate change scenarios predict massive losses in Mexico's crop productions for the coming decades (Boyd and Ibarraran, 2009; Flores et al., 2003).

In addition to the direct impact on the agricultural sector, a sustained lack of water may reduce economic outputs, worsen the trade balance, increase government debt, increase poverty, and slow down economic development (Rasmussen, 2004). Using general equilibrium models, Boyd and Ibarraran (2009: 388) confirm this ripple effect on the non-agriculture production sectors. Their models show for drought conditions that as food and electricity prices rise, productivity slows in the manufacturing, chemicals, and refining sectors. In addition, the service sector such as tourism may be adversely impacted by climate change (Amelung, Nicholls, and Viner, 2007; Lise and Tol, 2002). As such, the adverse impact of climate change will likely be felt in urban areas as well.

Data

For this study, we combined socio-demographic data from the Mexican Migration Project (MMP)[1] with climate information obtained from the Global Historical Climatology Network (GHCN) Daily data set (Menne et al., 2012) and a few other publically available data sources (e.g., INEGI, IPUMS-I)

Demographic Data. The Mexican Migration Project (MMP) constitutes the first ethnosurvey and began data collection in 1982 (Massey and Capoferro, 2004). Every year, the MMP selects between 4 and 6 Mexican communities and interviews a simple random sample of approximately 200 households in each community. To date, MMP has surveyed 143 Mexican

[1] The Mexican Migration Project (MMP) is a collaborative research project based at Princeton University and the University of Guadalajara. The MMP provides high quality public data at http://mmp.opr.princeton.edu.

communities located in 24 states. It is important to stress that the MMP does not yield a probability sample of Mexico because communities are not randomly selected. However, Massey and Zenteno (2000) and Massey and Capoferro (2004) used data from Mexico's National Survey of Population Dynamics (ENADID by its Spanish acronym) to validate the accuracy of the MMP and found that the MMP very accurately captured the characteristics (e.g., gender, age, marital status, education) and behavior (e.g., trip duration) of international migrants.

Climate Data. Climate data were selected from a dataset known as Global Historical Climatology Network (GHCN) Daily (version number: 2.93-upd-2012082407), compiled and made publically available by the National Oceanic and Atmospheric Administration (NOAA). The data are provided pre-compiled at a daily time resolution, which allows the assessment of climatic change associated phenomena such as the frequency of heavy rainfall or heat wave durations based on measures of maximum and minimum daily temperature and total daily precipitation (Menne et al., 2012). Rigorous multi-tiered quality assurance checks are routinely applied to the full dataset to guarantee the highest possible levels of data integrity (see Menne et al., 2012 for a detailed description). GHCN-Daily has been used in prior published work for climate monitoring and change assessments (e.g., Alexander et al., 2006; Caesar et al., 2006).

Unit of Analysis

Although migration ultimately occurs at the individual or person level, the decision to stay or go is typically reached within some larger family or household unit (Massey et al., 1993; Taylor, 1999). The household is the fundamental unit through which Mexicans create a sense of identity and belonging within their communities and through which they obtain status and prestige (Cohen, 2004). Based on these considerations, we conducted the analysis at the household level in line with prior studies of Mexican migration (Hunter, Murray, and Riosmena, 2013; Kanaiaupuni, 2000; Nawrotzki, Riosmena, and Hunter, 2013).

Time Frame

The time period under investigation span the years 1986 to 1999. This time frame was chosen for the following methodological and theoretical reasons: (1) As outlined above, the 1986 Immigration Reform and Control Act (IRCA) had major impacts on the policy context of migration, and thus only the post-IRCA period will be investigated. (2) In addition, the number of weather stations available in the GHCN-D data set drops from an average of n=182 for the years 1961 to 1998 to n=15 after 1998, rendering interpolation methods (see details below) unreliable. Because all predictor variables are lagged by one year climatic data of 1998 as the last available year can be used to predict migration in 1999. (3) A change in macro-level factors has substantially altered the milieu of migration since the early 2000s. Several factors taken together, such as a growing anti-immigrant sentiment (Varsanyi, 2011), increasingly strict federal, state, and local immigration enforcement policies (Hanson, 2009), a much more robust border enforcement effort (Orrenius, 2004), and the worsening U.S. economic climate (Papademetrious and Terrazas, 2009) have substantially changed the nature of Mexico-U.S. migration dynamics. Since the main focus of this study is the investigation of nuances in climate factors as drivers for different migration streams, the value of this contribution is not diminished by the use of a historical time frame.

Variable Construction

Outcome Variables. The Mexican Migration Project (MMP) defines migration as a move that involved a change in usual residence, excluding short visits for vacation, shopping, visits, and commuting (Fussell, 2004). This research investigates the first international move from rural and urban areas. The outcome variable was coded either 0 if no move occurred or 1 if the household experienced a move. To reduce the number of records in the household-period file to a computationally manageable size, we employ a common practice and extended the observation intervals from one-year to two-year periods (c.f., Allison, 1984; Steele, 2005). Table 1 shows the households at risk of migration (rt) and the number of observed moves (migt) that occurred during the particular time interval for both rural and urban municipalities. From these numbers, we computed the hazard rate ($h_t = \frac{mig_t}{r_t}$) and the survival rate ($s_t = \prod_{j=1}^{t-1}(1-h_j)$) (Steele, 2005).

(Table 1 about here)

Primary Predictor Variables

The primary predictors in this research project are a set of 27 climate change indices, developed by The Expert Team on Climate Change Detection and Indices (ETCCDI)[2] (Alexander et al., 2006; Peterson, 2005). These indices were originally developed for the International Panel on Climate Change (IPCC) Third Assessment Report (TAR) and focus primarily on climate extremes (Peterson et al., 2001). The indices have been widely used in the climatological research community (including the recent IPCC report) to investigate long term climatic trends (e.g., Alexander et al., 2006; Bindoff et al., 2013; Frich et al., 2002; Klein Tank et

[2] The Expert Team is part of the Climate Variability and Predictability (CLIVAR) project, which is jointly sponsored by the World Meteorological Organization's Commission for Climatology (CCl) and the World Climate Research Programme (WCRP).

al., 2006,), but have not been used for demographic studies of migration behavior. The climate change indices can be grouped into measures of high and low temperature extremes (Table 2) and measures of high and low precipitation extremes (Table 3).

(Table 2 about here)

(Table 3 about here)

Constructing the climate change measures was a four step approach involving missing data imputation, climate change index computation, spatial interpolation, and computation of relative change measures.

Missing Data Imputation. Unfortunately, the 38-year time series (1961-1998) of daily temperature and precipitation readings for the 200+ Mexican weather stations were not complete and about 20.6% of the records were missing. To maximize the use of the available climate information, missing data was imputed using Multiple Imputation (MI) (Rubin, 1987).

Climate Change Index Computation. We used the R package *climdex.pcic*, managed and releases by the Pacific Climate Impacts Consortium (Bronaugh, 2014) to compute the climate change indices. The climate change indices are computed from daily observations but reflect specific climatic condition in a given year for a given weather station.

(Figure 2 about here)

Spatial Interpolation. The climate change indices are computed for the 200+ weather stations that are not necessary situated at the particular location of a MMP municipality (see

Figure 2). As such, we used Cokriging to interpolate values of the climate change indices for the 111 MMP municipalities. To improve the interpolation, a measure of altitude (digital elevation model, DEM) was included as a covariate in the Cokriging model. The DEM is based on remote sensed images from the Shuttle Radar Topography Mission (SRTM) with a 1 kilometer (30 arc-seconds) grid cell resolution, created and released by the U.S. Geological Survey (USGS) and the National Geospatial-Intelligence Agency (NGA) (Danielson and Gesch, 2011). Other researchers have generated data products at a more coarse resolution, using similar interpolation techniques to generate gridded surfaces of the ETCCDI climate change indices (Donat et al., 2013).

Computation of Relative Change Measures. We express all climate change measures as standardized variables (sometimes called a z-score or a standard score) by subtracting the mean of the baseline period (1961-1990) from the value for each case, and then dividing the resulting difference score by the standard deviation of the original variable. To guard against the impact of short term fluctuations, each index value was computed as three-year average, prior to the standardization (see Hunter, Murray, and Riosmena, 2013). Because it is the goal of this study to compare substantively different types of climate change, too highly correlated variables were dropped, resulting in 17 indices used in the analysis.[3] Within the reduced sub-groups, all correlations among variables remain below $r = 0.70$.

Secondary Predictors (Controls)

[3] Among high temperature indices, wsdi is highly correlated with tx90p (r = 0.91) and we chose wsdi. Among low temperature indices, txn and tnn are highly correlated (r = 0.73) and we selected txn. Among high precipitation variables, indices come frequently in pairs that differ only in the threshold and are usually highly correlated. Among these pairs, we selected the index that captures the most extreme climatic conditions. Among r10mm and r20mm are only moderately correlated (r = 0.51) and we keep both in the analysis. The indices rx1day and rx5day are highly correlated (r = 0.88) so we selected rx5day. However, rx5day is also highly correlated with sdii (r = 0.83) and we selected rx5day since it appears better capture of a climatic extreme.

Informed by the SL framework (Carney et al., 1999), variables representing the economic environment and livelihood capitals (e.g., financial, physical, human, social, and natural) were included as controls. These variables operate at the household and at the community-level and were constructed as time-varying and time-invariant predictors. Table 4 presents summary statistics for all secondary predictors.

(Table 4 about here)

Household Social Capital. To account for the gendered nature of migration in Mexico (e.g., Cerrutti and Massey, 2001), we included a dummy variable for the gender of the household head (coded 1=male and 0=female) in all models. In addition, the marital status (1=married, 0=not married) of the household head was included as a time-varying predictor and may reflect access to social capital through an extension of the kinship network as well as through the ability to share responsibilities and resources among the partners (Sanders and Nee, 1996; Riosmena, 2009).

Household Human Capital. The presence of young children ties human capital in terms of labor capacity to nurturing and household tasks and usually deters migration in Mexico (Nawrotzki, Riosmena, and Hunter, 2013; Riosmena, 2009; Massey and Riosmena, 2010). To capture this effect, we constructed a time-varying predictor, indicating the number of young children (age < 5 years) within the household during each observation year. To capture the effect of other forms of human capital, we constructed time-varying predictors for the number of years of schooling (Fussell, 2004; Massey and Riosmena, 2010), as well as cumulative work experience in years (Riosmena, 2009) of the household head. Moreover, a set of time-varying dummy variables captures the occupational status of the household head (unemployed/not in labor force, blue-collar, white-collar) (Massey and Riosmena, 2010).

Household Physical Capital. A time-varying measure of whether the household owns a house or lot (1=property owner, 0=not property owner) was included to account for the fact that migration is frequently used to finance the acquisition of a home (Massey and Riosmena, 2010). Also, to obtain the necessary capital for business formation, a household might employ migration as a tool to access funds through remittances (Woodruff and Zenteno, 2007), and we attempt to capture this effect using a time-varying measure reflects the ownership of a business (1=business owner, 0=not business owner).

Municipality Social Capital. A time varying predictor of international and domestic migrant prevalence were used as a proxy for the access to migrant networks at the community level (Nawrotzki, Riosmena, and Hunter, 2013). While the respective variable for international migrant prevalence came from the COMMUN supplementary data file of the MMP, a variable for domestic migrant prevalence was constructed using data from the Mexican census, obtained via IPUMS-I (Ruggles et al., 2003; MPC, 2013). Migrant information is usually available in decadal time steps and we employ linear interpolation to construct a time varying predictor.

Municipality Physical Capital. To capture the effect of access to roads (e.g., Barbieri and Carr, 2005; Gray, 2009, 2010), we constructed a time invariant measure of road network density (km/10square kilometers) for each municipality based on data provided by the Global Roads Open Access Data Set (gROADS) (CIESIN and ITOS, 2013). In addition, we computed the average Euclidean distance (in 100 kilometers) from each municipality to the U.S.-Mexico border as well as to the closest urban center as time invariant measures, employing polygon and polypoint layers from ESRI's spatial data library (ESRI, 2012). Finally, a time-invariant measure of the urbanization status of each community (rural=1; urban=0) helps to account for differences in access to infrastructure, services, and amenities more generally. This variable comes from the COMMUN supplement of the MMP. Communities located in a “metropolitan area” (a state’s capital city or some other large city) or a “smaller urban area” (10,000 – 100,000 inhabitants) were considered to be urban while communities located in a “town” (2,500 – 10,000 inhabitants) or a “rancho” (< 2,500 inhabitants) were considered to be rural.

Municipality Financial Capital. To account for region specific overall differences in wealth status, we constructed a standardized wealth index using data from the Mexican Census for the years 1990 and 2000 (Ruggles et al., 2003; MPC, 2013). The time-varying municipality level wealth index is composed of 11 variables measuring the quality of the housing units (7 variables: building materials used for wall, floor, roof, the number of rooms and bedrooms, type of kitchen, type of toilet), and the quality of services (4 variables: electricity, water supply, sewage collection, fuel source) and demonstrates a high level of reliability (Cronbach’s alpha: 0.8476).

Municipality Natural Capital. We constructed a measure of agricultural dependence by computing the proportion of the surface area planted in each municipality during the years 2003-2006 (INEGI, 2012). However, households will be more resilient to climate shocks if technology (e.g., irrigation systems) makes the agricultural production largely independent of weather irregularities (Eakin, 2005). To capture community differences, we computed a time-invariant measure of the proportion of irrigated farmland for the year 2003 (INEGI, 2012). Finally, we account for differences in the general climatic conditions by including a variable for the average daily temperature (°C) and the average daily precipitation (mm) during the 30 years baseline period (1961 to 1990) as time-invariant controls in the models.

Municipality Economic Environment. To approximate job availability in climate sensitive sectors, we constructed a time-varying measure for the proportion male labor force employed in the agricultural sector, derived from the COMMUN supplement of the MMP data set.

Estimation Strategy

To investigate the climate change migration association, we employed a discrete-time event history analysis. The analysis used each year in which the household head was 15 years or older, beginning in 1986 (post-IRCA area), up until the time of the first U.S. trip, or the end of the study period (1999) if the household never sent a migrant. The logistic event history models take the general form suggested in Equation 2 (Allison, 1984; Goldstein, 2011; Singer and Willett, 2003; Steele, 2005). In order to reduce the possibility of endogeneity, the odds of a migratory trip in a given year will be predicted by climate change indices, as well as individual and community-level characteristics in the prior year (Gray, 2009).

Equation 2:

$$\alpha = \alpha_{1986\text{-}87} D_{1986\text{-}87j} + \alpha_{1988\text{-}89} D_{1988\text{-}89j} + \ldots + \alpha_{1998\text{-}99} D_{i1998\text{-}99j}$$

$$\text{logit}\,(h_{ij}) = \log\left(\frac{P_{ij}}{1-P_{ij}}\right) = \alpha$$

The discrete-time hazard h_{ij} for interval i is the probability P that a household j experiences a migration event during the particular interval, given that no migration event has occurred in a previous interval. The parameter α represents the baseline hazard of migration and was included as a set of dummy variables D, one dummy variable for each period, to invoke the most flexible representation for time (Allison, 1984; Singer and Willett, 2003).

The odds of a household to send a migrant are affected by household-level characteristics but also by municipality-level factors. To appropriately account for the nested data structure, we follow Courgeau (2007) and Goldstein (2011) and use a multilevel version of the event history model (Equation 3). The models use a two-level structure in which households and time (level-1) are nested within municipalities (level-2).

Equation 3:

$$\operatorname{logit}(h_{ijk}) = \alpha + u_{0k}$$

The odds of migration are predicted for a given period i for a household j located in municipality k. The variance component u_{0k} indicates that the odds of migration are allowed to differ across municipalities (level-2). To this basic model, a number of control variables are added (Equation 4).

Equation 4:

$$\operatorname{logit}(h_{ijk}) = \alpha + \sum_{n=1}^{y} \beta_n (x_{nz}) + u_{0k}$$

The coefficients β_n, represent the effects of various secondary predictors (x_{nz}). These predictors may operate at different levels as indicated by the generic subscript *z*, which can take the form *ijk* (all time-varying predictors and time-invariant household-level variables), or k

(time-invariant municipality-level predictors). In the next step of the modeling exercise, one climate change index at a time is entered into the model.

Equation 5:

$$\text{logit}(h_{ijk}) = \alpha + \beta_1(ci_{ijk}) + \sum_{n=2}^{y} \beta_n(x_{nz}) + u_{0k}$$

In equation 5, the coefficient β_1 shows the effect of a particular climate change index (ci_{ijk}) on the odds of outmigration. Although the climate change indices are community-level variables, they vary across time and therefore operate at level-1 as indicated by the ijk subscript. The models were fit using the multilevel package *lme4* (Bates, 2010; Bates et al., 2014) within the "R" statistical environment version 3.1 (R Core Team, 2014).

Hypotheses

Climate Change Effects. Climate change is a multi-facetted phenomenon and not all forms of climate change may have the same effect on the agricultural sector, and by extension migration. As such, we hypothesize different effects for four groups of climate change indices: (1) high temperature, (2) low temperature, (3) high precipitation, (4) low precipitation. Research shows that increases in temperature extremes as well as increases in mean temperature have similar adverse effects on crop yields (Challinor et al., 2007) and may in turn lead to increased levels of outmigration. Changes in mean temperature impact the evaporative and transpirative demand of plants (Priestley and Taylor, 1972; Stone, 2000) and can change the crop-growth and maturity duration (e.g., Roberts and Summerfield, 1987). Increased temperature shortens the length of the growing cycle, decreasing opportunity to capture more radiation and reducing total

CO_2 assimilation, reducing total biomass and grain yield (Bassu et al., 2014). In addition, episodes of high temperature at critical states of crop development can impact yield independently of any substantial changes in mean temperature (e.g., Wheeler et al., 2000; McKeown et al., 2005). In contrast, a cooling or transition to more moderate temperatures could be considered beneficial in a warm, arid country such as in Mexico where temperatures frequently surpass the optimal growing temperatures (c.f., Bassu et al., 2014). As such we hypothesize that a*n increase in high temperature extremes (warming) increases international (U.S.) out-migration from Mexico* (H1) and that *an increase in low temperature extremes (cooling) decreases international (U.S.) out-migration from Mexico* (H2).

Most studies in Mexico have found that a decline in the average level of precipitation increases outmigration (Hunter, Murray, and Riosmena, 2013; Nawrotzki, Riosmena, and Hunter; 2013). Based on these studies, it can be anticipated that an increase in dry spells have a negative effect on the agricultural sector resulting in higher levels of migration. In contrast, increases in precipitation likely improve overall growing conditions. Since precipitation extremes often capture a general trend of an increase in average precipitation, it can be assumed that such changes improve agricultural production, leading to a decline in outmigration. However, the effect of precipitation is likely bound to thresholds, and too much rainfall may lead to flooding, damage plants and indirectly cause an increase in outmigration. As such, we hypothesize that *an increase in high precipitation extremes (more wet) decreases international (U.S.) out-migration from Mexico* (H3) and that *an increase in low precipitation extremes (more dry) increases international (U.S.) out-migration from Mexico* (H4).

Rural vs. Urban. Although historically the largest fraction of migrants came from rural areas, a growing number of Mexican migrants originates from urban areas (Durand, Massey and

Zenteno, 2001; Marcelli and Cornelius, 2001; Riosmena and Massey, 2012). It is unclear if migration from urban areas is similar responsive to changes in the climatic system. A general assumption is that climate change drives migration through its impacts on the agricultural sector. As such it seems to be a logical conclusion that rural populations are more sensitive towards climate change than urban populations due to their dependence on farming and the agricultural sector (Conde et al., 2006). For that reason studies of the migration – environment association in Mexico have been frequently limited to rural areas (Hunter, Murray, and Riosmena, 2013; Nawrotzki, Riosmena, and Hunter, 2013). However, climate change may impact various non-agricultural sectors of the economy including forestry, hydropower generation, and tourism (Black et al., 2011; Boyd and Ibarraran, 2009; Lise and Tol, 2002) and may therefore induce migration from urban areas as well. Other sectors such as production and manufacturing are dependent on the agricultural sector and climate change may have indirect impacts. For example, a worker employed in an urban coffee mill may lose his/her job if the coffee production is adversely impacted by climate change. Nevertheless, a direct effect should be stronger than an indirect effect and therefore, we hypothesize that *there is stronger evidence that climate change impacts international (U.S.) out-migration from rural compare to urban areas in Mexico* (H5).

Hypothesis Testing Conventions

Because each hypothesis relates to a group of climate change indices, it is necessary to define evaluative criteria that allow for the confirmation or rejection of a particular hypothesis based on multiple variables. These criteria will be used in all three results chapters. Drawing on the climate change literature, we adopt a modified version of an evidence evaluation scheme developed for the IPCC Fifth Assessment Report (Mastrandrea et al., 2010), presented in Figure 3 below.

(Figure 3 about here)

Using this evaluation scheme, the evidence for a particular climate change effect is first evaluated. When for example, 50% of the variables in a certain climate change category (e.g., high temperature extremes) are significant, there is medium evidence for the presence of a climate change effect. In the next step the directionality is evaluated. When of the 50% significant coefficients, the sign of 75% of the coefficients point in the hypothesized direction, then there is high agreement. Percentage points are rounded to the closest integer. A cell with high agreement and medium evidence is assigned a high level of confidence (C4). This "confidence" should not be interpreted probabilistically, and it is distinct from "statistical confidence." A hypothesis is confirmed when there is high (C4), or very high (C5) confidence, and rejected when there is low (C2), or very low (C1) confidence. For medium evidence (C3), the hypothesis is neither confirmed nor rejected due to ambiguous evidence. For hypotheses that compare the strength of an overall climate change effect, we only employ the evidence classification (e.g., significance of a coefficient) for the following reason: When a coefficient is significant, it indicates that a climate change effect exists, even if the direction is at odds to what was hypothesized.

Results and Discussion

Model Building

As the first step in the investigation of the effects of climate change on migration, we first develop a reliable multivariate base model to predict international (U.S.) out-migration from Mexico. Table 5 shows the model building for the complete sample (rural and urban), including the intercept terms for the baseline hazard (Model 1), then adding household covariates (Model 2), and ultimately adding community covariates (Model 3).

(Table 5 about here)

The effects of various predictor variables in Table 5 are largely in the anticipated direction, lending credibility to the base model. The results confirm that migration in Mexico is a gendered phenomenon with lower odds of migration when the household head is female (Lindstrom and Lauster, 2001). The presence of young (age < 5 years) children also reduces the odds of sending a migrant to an international destination. A young child requires much attention and care so that less human capital is available for external ventures such as an international move (Nawrotzki, Riosmena, and Hunter, 2013; Massey and Riosmena, 2010). An increase in working experience has a tendency to reduce migration. In addition, blue collar workers are much more likely to migrate internationally compared to white collar workers. Prior research has demonstrated that Mexican migrants coming to the U.S. are mostly young, uneducated males (Massey et al., 1987; Fussell, 2004) and the observed effects confirm this tendency. Households that own a business are less likely to send a migrant internationally. Operating a business requires human capital, which is then unavailable for other livelihood strategies such as an international move. In addition, international migration frequently serves the purpose of obtaining the necessary capital to start a business (Woodruff and Zenteno, 2007) and once this goal has been achieved a further move becomes unnecessary. Among the municipality predictors, the presence of adults with migration experience has a strong, positive impact on the odds of international outmigration. This finding is in line with prior research, demonstrating the importance of migrant networks for an international move (Fussell and Massey, 2004). Finally, the percentage of males in the labor force employed in the agricultural sector is positively associated with the odds of an international move. This suggests that most international migrants come from agriculture dependent areas, perhaps due to this sector's sensitivity to climatic stressors (Eakin, 2005). However, the determinants of an international move may differ for rural versus urban populations. Table 6 shows the full model (all predictors included) when restricting the sample to rural and urban regions.

(Table 6 about here)

Estimating separate models for rural and urban areas reveal mostly similar drivers of a first international move. The few differences include education, business ownership, road network density, and baseline temperature. Education impacts the odds of an international move only in urban areas. In these areas, households with a higher educated household head are less likely to send a migrant to the U.S (Fussell, 2004). In addition, road networks matter only in urban but not in rural areas. The denser the road network, the lower the probability that the household will sent a migrant. Road networks may facilitate access to local employment opportunities or may capture different levels of industrialization within urban areas (c.f., Gray, 2009; Barbieri and Carr, 2005). In contrast, business ownership is only significant in rural areas, suggesting that moving abroad to remit funds to start a business is largely a rural phenomenon. In addition, the effect of the baseline temperature on an international move is significant in rural areas only. This indicates a stronger association between weather conditions and migration patterns in rural compared to urban areas.

In the next step of the analysis, we added the climate change indices to the full model. To investigate the individual effect of each climate change measure, we included one index at a time, estimated the full model (including all control variables), and then reported the coefficient and significance level in the below table (Table 7).

(Table 7 about here)

Climate Change Effects

High Temperature. Table 5.3 shows that three of the five coefficients (60%) in the high temperature group are significant, indicating medium evidence according to the confidence matrix. Of these three significant coefficients, two (67%) demonstrate a positive effect of high temperatures on international out-migration, which leads to the assignment of a high agreement in the confidence matrix. Medium evidence and high agreement result in a confidence class C4 (high confidence). Therefore, the results allow to confirm hypothesis H1 because there is high confidence that a*n increase in high temperature extremes (warming) increases international (U.S.) out-migration from Mexico*. A similar relationship has been observed for the U.S. where higher temperatures were associated with an increase in state-level outmigration (Poston et al., 2009).

With regard to specific climate change indices, an increase in the warm spell duration as well as an increase in the percent of warm nights, relative to the 30-years (1961-1990) baseline period, increase international out-migration. Particularly warm spells may serve as indicators of droughts and have likely negative impacts on the crop yield and the agricultural sector (Turner et al., 2011). Under identical precipitation, higher temperatures lead to the drying of the soil because of an increase in evapotranspiration (Mendelsohn, 2007). However, when sufficient precipitation is available, summer days (days when maximum temperature exceeds 25°C) are not necessary bad for the harvest if such days are evenly spread across the growing season. For example, an increase in summer days may extend the growing season, increase plant metabolism, and facilitate the drying of the crop prior to harvest (Turner et al., 2011; Challinor et al., 2007; Mendelsohn, 2007). However, in agricultural production plant growth and temperature are non-linearly related (Tollenaar, Daynard, and Hunter, 1979). For maize an increase in temperature increases plant growth until the optimal temperature of 31°C is reached (Sanchez et al., 2014). Higher temperatures lead to a decline in plant growth and the maximum growth temperature is reached at 42°C after which the plant dies (Sanchez et al., 2014). However, crop yield is sensitive to different stages in the plant growth cycle. For example, in maize the period of tassel initiation is important for crop yield because during this stage the number of kernels is defined (Tollenaar and Bruulsema, 1988). In addition, maize is particularly sensitive to high and extreme temperatures in the phase before and during anthesis (flowering). Especially pollination can be seriously affected by high temperatures. Temperatures over 32°C can reduce the percentage of non-germinating pollen by up to 51% (Schoper, Lambert, and Vasilas, 1987). Finally, maize kernel yield is affected by high temperatures, which shorten the kern filling period and can lead to lightweight grain or kernel abortion (Sanchez et al., 2014). This reference to the heat sensitivity of maize might explain why the percentage of warm nights (percentage of days where the daily minimum temperature exceeds the 90^{th} percentile), as a measure of more extreme high temperature events is positively associated with international out-migration. Overall these observations are in line with research that has demonstrated at the global level that a warming temperature trends between 1980 and 2000 negatively impacted crop yield of wheat, maize, and barley (Lobell and Field, 2007). Moreover, a study by the Agricultural Model Intercomparison and Improvement Project (AgMIP) using 23 maize simulation models demonstrated that a climate change induced warming would lead to a yield loss of 4 to 7% per degree temperature increase (Bassu et al., 2014).

Low Temperature. In the low temperature group two of five coefficients (40%, medium evidence) and both indicate the expected directionality (100%, high agreement), leading to the assignment of a confidence class C4 (high confidence). Note that the coding of the two variables leads to opposing signs of the effect, but both coefficients suggest that *an increase in low temperature extremes (cooling) decreases international (U.S.) out-migration from Mexico.* As such, with high confidence the findings of this study confirm H2. Among the significant coefficients, the climate change index for the temperature of the coldest day indicates a strong positive effect on international out-migration. This index measures an increase in the minimum daily maximum temperature relative to the 30-year baseline period. An increase in the coldest daily temperature, meaning an overall warming, has a negative impact on the agricultural production. The inverse effect can be inferred from the relationship. A cooling in the coldest day temperature would result in a significant decline in international migration. The climate change index for the number of frost days suggests the same directionality. An increase in the number of frost days, and thereby an overall cooling, is related to a decline in international out-migration. This effect can be explained in reference to the agricultural sector and optimal crop growing temperatures (Sanchez et al., 2014). When temperatures are above the optimum, a cooling may increase crop yields (c.f., Bassu et al., 2014). An added benefit of cooler temperatures is the drop in dew point, meaning that the amount of precipitable water increases and moisture becomes easier available for plants (Reitan, 1963). Moreover, an increase in the number of frost days in the right season (e.g., winter) may kill pests that would otherwise negatively impact the crop yield (Porter, Parry, and Carter, 1991).

High Precipitation. Of the six measures in the high precipitation group, five (83%, robust evidence) are significant. All of these significant measures (100%, high agreement) indicate the expected directionality, resulting in confidence class C5 (very high confidence). As such, hypothesis H3 can be confirmed due to the very high confidence that *an increase in high precipitation extremes (more wet) decreases international (U.S.) out-migration from Mexico.*

Judging by the size of the coefficients, the effect of the total wet-day precipitation (total amount of rain during wet days, prcptot) is strongest associated with international migration. As precipitation increases, less people tend to migrate to the U.S., a relationship that is well established in the literature (Hunter, Murray, and Riosmena, 2013; Nawrotzki, Riosmena, and Hunter, 2013). For the agricultural sector an increase in precipitation is largely beneficial (Lobell and Field, 2007), especially given that only a small percentage (23.15%) of arable and permanently-cropped land in Mexico is irrigated (Carr, Lopez, and Bilsborrow, 2009). The plant requires water for various metabolic processes such as photosynthesis (Setter, Flannigan, and Melkonian, 2001) leading to a direct relationship between evapotranspiration and crop yield (Payero et al. 2006). Sensitivity to water stress varies by plant species and development stage (Steduto et al., 2012). Taking maize as example, water deficit significantly reduced plant growth, dry matter accumulation, and yield (kernel weight and kernel number per ear) (Cakir, 2004).

Grain yield is particularly sensitive to water deficits during the tasselling and ear formation stages. When the plant experiences prolonged water stress during these sensitive stages grain yield losses of 66-93% can be expected (Cakir, 2004). These negative impacts are the cumulative result of reduced leaf area increase, delayed ear and ovule development, poor pollination, reduction in starch synthesis and accumulation, and kernel abortion (Cakir, 2004; Jama and Ottman, 1993; Setter, Flannigan, and Melkonian, 2001; Zinselmeier, Jeong, and Boyer, 1999). In evaluation of the results, it is important to keep the historical context in mind. The 1990s were exceptionally dry years (Stahle et al., 2009) during which even heavy rainfall extremes may still not have been enough to meet the water demand of the agricultural sector.

Low Precipitation. Only one variable is available in the low precipitation category, measuring the length of the dry spell duration as the maximum number of consecutive days when precipitation was below 1 mm. The coefficient is significant (100%, robust evidence) but the direction is in contrast to what was hypothesized (0%, low agreement), resulting in a confidence class C3 (medium evidence). As such, we are unable to confirm or reject hypothesis H4.

It is well known that water stress has adverse effects on crop yield when it occurs during sensitive stages in the plant growth cycle (e.g., Steduto et al., 2012). However, the annual measure of the dry spell duration does not provide information on timing. To certain times of the year, an increase in the length of dry days might be beneficial. For example, dry and warm weather is the preferred climate during the harvest season. Under rainy conditions, harvest machineries perform poorer, additional costs for manual drying is incurred, and the crop might be damaged by mold (c.f., Abawi, Smith, and Brady, 1995). In addition, an increase in dry periods during the winter season will not negatively impact the crop yield. Moreover, if the impact of climate change leads to an increase in extreme conditions on both ends of the precipitation spectrum, such as a drier winter and at the same time a wetter summer, then an increase in the dry spell duration that is correlated with an increase in the rainfall during the growing season may in fact lead to a decline in migration. To test this assumption, we computed the correlation matrix between the dry spell duration index (cdd) and the measures in the high precipitation group. And indeed, most of the significant measures are positively correlated with cdd (r10mm: r=0.18, r20mm: r=0.32, rx5day: r=0.44, r99ptot: r=0.23, prcptot: r=-0.12).

Rural vs. Urban Areas

In order to compare the impact of climate change on migration from rural vs. urban areas, we employ the evidence scale of the confidence matrix (Figure 5.1). Among the 17 climate change indices in the four relevant groups (high and low temperature, high and low precipitation), 12 (71%, robust evidence) significantly predict international out-migration from rural areas. In contrast, for urban areas only 2 of the 17 (12%, limited evidence) climate change indices are significant predictors of international out-migration. Therefore, the results confirm hypothesis H5, because *there is stronger evidence that climate change impacts international (U.S.) out-migration from rural compare to urban areas in Mexico*.

This finding is in line with the theoretical assumption that climate change impacts migration largely through its impact on the agricultural sector (e.g., Massey et al., 1993), and rural populations stronger depend on subsistence farming and agricultural employment (Eakin and Appendini, 2008). Similarly, Feng and Oppenheimer (2012) observed an effect of crop yield changes on U.S. bound migration only for more rural states in Mexico. However, there is also some limited evidence that climate change drives migration from urban areas, in line with other authors' (Black et al., 2011; Boyd and Ibarraran, 2009) notion that climate change may also impact non-agricultural parts of the economy that are more frequently represented in urban areas. However, this effect is quite weak and only emerges for two climate change indices in the high precipitation group (r99ptot, prcptot).

Conclusions

This study has set out to investigate the climate change migration association using 17 climate change indices to investigate nuanced differences at high temporal and spatial resolution. As key findings, we observed that a temperature increase (warming) and precipitation decline drive international out-migration. The recent fifth assessment report of the Intergovernmental Panel on Climate Change suggests that in Mexico precipitation will decline (Christensen et al., 2013) while temperatures will increase (Collins et al., 2013) over the 21st century. Although conducted for a historical period of 1986-99, this study demonstrates that under certain conditions the projected changes in the climatic system may increase the number of international migrants from Mexico to the U.S. Our findings further demonstrate that the impact of climate change on migration is stronger for rural than for urban areas. We therefore suggest that livelihood based climate change adaptation programs should target rural areas. Adaptation assistance may draw on recent developments in biotechnology and genetic engineering and involve the distribution of seeds of drought resistant crop varieties at reduced prices (Eisenstein, 2013). In addition, adaptation may be assisted through the supply of advanced technologies such as solar powered drip-irrigation systems (Bourzac, 2013). Institutional reforms are needed to improve access to financial and insurance markets to reduce climate change vulnerability (Juelich, 2011). In this regard, fostering the development of index-based microinsurance schemas might provide a way of community based protection against climatic shocks that are affordable to poor subsistence farmers (Hochrainer, Mechler, and Pflug, 2008). Furthermore, an increase in the access to education as well as an improvement in employment opportunities (e.g., manufacturing and service employment) within Mexico might allow livelihood diversification without the need to migrate (Fussell, 2004).

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Table 1: Life table describing the event of first international migration during the period 1986-1999 for households of all MMP communities (rural & urban)

Years	rt	migt	ht	st
Migration by Household-Period				
1986-87	14889	413	0.028	1
1988-89	15077	443	0.029	0.972
1990-91	14452	420	0.029	0.944
1992-93	13777	279	0.02	0.916
1994-95	12660	300	0.024	0.898
1996-97	11715	276	0.024	0.876
1998-99	10616	290	0.027	0.856
Total	93186	2421		
Migration by Households				
1986-99	17001	2421		
%	100	14.24		

Note: rt = households at risk during interval; migt = number of migrations during interval; ht = hazard of migration during interval; st = probability of survival up to the start of the interval

Table 2: List of ETCCDI climate change indices measuring temperature extremes

Indicator Name	ID	Indicator definition	Unit
Temperature (high)			
No. summer days	su	Annual count when daily max temperature > 25°C	days
Tropical nights	tr	Annual count when daily min temperature > 20°C	days
Warm spell duration	wsdi	Annual count when at least six consecutive days of max temperature > 90th percentile	days
Warmest day	txx	Annual maximum value of daily max temperature	°C
Warmest night	tnx	Annual maximum value of daily min temperature	°C
% warm nights	tn90p	Percentage of days per year when daily min temperature > 90th percentile	%
% warm days	tx90p	Percentage of days per year when daily max temperature > 90th percentile	%
Temperature (low)			
No. frost days	fd	Annual count when daily minimum temperature < 0°C	days
Ice days	id	Annual count when daily maximum temperature < 0°C	days
Cold spell duration	csdi	Annual count when at least six consecutive days of min temperature < 10th percentile	days
Coldest day	txn	Annual minimum value of daily max temperature	°C
Coldest night	tnn	Annual minimum value of daily min temperature	°C
% cool nights	tn10p	Percentage of days per year when daily min temperature < 10th percentile	%
% cool days	tx10p	Percentage of days per year when daily max temperature < 10th percentile	%

Note: Table adjusted based on Donat et al. (2013).

Table 3: List of ETCCDI climate change indices measuring precipitation extremes

Indicator Name	ID	Indicator definition	Unit
Precipitation (high)			
No. days heavy precip	r10mm	Annual count of days when precip > 10mm	days
No. days very heavy precip	r20mm	Annual count of days when precip > 20mm	days
Wet spell duration	cwd	Maximum number of consecutive days with precip > 1mm	days
Max 1-day precip	rx1day	Annual maximum 1-day precip amount	mm
Max 5-day precip	rx5day	Annual maximum consecutive 5-day precip amount	mm
Precip very wet days	r95ptot	Annual total precip from days when precip > 95th percentile	mm
Precip extremely wet days	r99ptot	Annual total precip from days when precip > 99th percentile	mm
Total wet-day precip	prcptot	Annual total precip from days when precip > 1 mm	mm
Precip intensity index	sdii	The ratio of annual total precip to the number of wet-days (precip > 1mm)	mm/day
Precipitation (low)			
Dry spell duration	cdd	Maximum number of consecutive days when precip < 1mm	days
Temperature & Precipitation (other)			
Average precip	aprec	Average daily precipitation	mm/day
Average temperature	atemp	Average daily temperature	°C
Temperature range	dtr	Annual mean difference between daily max and min temperature	°C
Growing season length	gsl	Count between six day periods with daily mean temperature > 5°C and < 5°C	days

Note: The 27 ETCCDI climate change indices contain a precipitation index that is constructed similarly to r10mm and r20mm but lets the user define the precipitation threshold. This measure was not employed and only the remaining 26 indices were considered for the present analysis. Table adjusted based on Donat et al. (2013).

Table 4: Secondary predictors (controls) for the analysis of the impact of climate change on migration in Mexico during the years 1986 to 1999

Variable	Mean	SD	Min	Max	1986-87	1992-93	1998-99
Household level							
Social capital							
Female (yes=1)	0.14	0.35	0	1	0.14	0.14	0.14
Married (yes=1)	0.68	0.46	0	1	0.65	0.68	0.7
Human capital							
No. of children (< 5 yrs)	0.61	0.9	0	8.5	0.71	0.6	0.48
Education	6.11	4.5	0	25	5.69	6.2	6.57
Working experience	24.83	15.74	0	87.5	22.24	25.18	27.68
Occupation: NLF	0.14	0.35	0	1	0.15	0.14	0.14
Occupation: Blue collar	0.77	0.42	0	1	0.78	0.77	0.76
Occupation: White collar	0.09	0.28	0	1	0.07	0.09	0.1
Physical capital							
Owns property (yes=1)	0.6	0.48	0	1	0.52	0.6	0.71
Owns business (yes=1)	0.16	0.36	0	1	0.13	0.16	0.19
Municipality level							
Social capital							
International migrants (%)	15.1	13.83	0	85.82	14.9	15.22	14.69
Domestic migrants (%)	6.52	7.15	0	50	5.56	6.44	8.23
Physical capital							
Road network (km/10sqkm)	1.06	0.53	0	3.31	1.04	1.06	1.11
Distance border (100km)	7.03	2.14	0.2	10.32	7.06	7.06	6.89
Distance city (100km)	0.65	0.49	0.05	3.29	0.66	0.65	0.65
Rural (yes=1)	0.59	0.49	0	1	0.58	0.58	0.61
Financial capital							
Wealth index	-0.48	0.52	-2.02	0.41	-0.59	-0.46	-0.36
Natural capital							
Land area planted (prop)	0.25	0.21	0	0.97	0.26	0.25	0.25
Farmland irrigated (prop)	0.26	0.27	0	1	0.26	0.25	0.26
Base period precip (mm/day)	2.66	1.28	0.66	7.5	2.61	2.65	2.75
Base period temp (°C)	20.76	2.95	15.26	26.84	20.72	20.81	20.68
Economic environment							
Male labor in Ag. (%)	45.66	24.41	0.74	98.72	50.81	44.41	40.77

Note: precip = precipitation; temp = temperature; km = kilometer; prop = proportion; Household-level n= 124,478; Municipality-level n=714; Mean, SD, Min, Max were computed across periods.

Table 5: Building of a multilevel event history models to predict the odds of a first international move from households in Mexico during 1986-99

	Model 1		Model 2		Model 3	
	b	sig.	b	sig.	b	sig.
Variables						
Period 1	0.03	***	0.06	***	0.07	***
Period 2	0.03	***	0.07	***	0.08	***
Period 3	0.03	***	0.08	***	0.08	***
Period 4	0.02	***	0.06	***	0.06	***
Period 5	0.03	***	0.08	***	0.09	***
Period 6	0.03	***	0.09	***	0.09	***
Period 7	0.03	***	0.12	***	0.12	***
Female			0.55	***	0.55	***
Married			0.94		0.94	
No. of children			0.86	***	0.86	***
Education			0.97		0.97	
Working experience			0.72	***	0.71	***
Occupation: NLF			0.96		0.96	
Occupation: White collar			0.36	***	0.36	***
Owns property			0.94		0.94	
Owns business			0.81	**	0.81	**
International migrants					1.36	***
Domestic migrants					0.93	
Road network					0.87	
Distance city					1.09	
Wealth index					1.26	
Land area planted					1.03	
Farmland irrigated					1.17	
Base precip					0.97	
Base temp					0.97	
Male labor in Ag.					1.08	*
Rural					1.17	
Model statistics						
Var. Intercept (Mun)	0.653		0.857		0.384	
BIC	21606		20888		20918	
N (HH-period)	93186		93186		93186	
N (Mun)	111		111		111	

Note: Coefficients reflect odd ratios; The baseline hazard is captured by the following period dummies: Period 1 (1986-87), Period 2 (1988-89), Period 3 (1990-91), Period 4 (1992-93), Period 5 (1994-95), Period 6 (1996-97), Period 7 (1998-99); Occupation: Blue collar used as reference category; To guard against endogeneity and allow for causal interpretation of the effects, all predictors were lagged by 1 year; * p<0.05; ** p<0.01; *** p<0.001.

Table 6: Multilevel event history models by region type, comparing the determinants of an international move from rural versus urban areas in Mexico during the years 1986-99

	All		Rural		Urban	
	b	sig.	b	sig.	b	sig.
Variables						
Period 1	0.07	***	0.13	**	0.05	***
Period 2	0.08	***	0.16	*	0.05	***
Period 3	0.08	***	0.15	*	0.06	***
Period 4	0.06	***	0.12	**	0.05	***
Period 5	0.09	***	0.17	*	0.06	***
Period 6	0.09	***	0.17	*	0.07	***
Period 7	0.12	***	0.24		0.08	**
Female	0.55	***	0.48	***	0.63	***
Married	0.94		0.9		0.99	
No. of children	0.86	***	0.89	***	0.81	***
Education	0.97		1.13		0.81	*
Working experience	0.71	***	0.72	***	0.7	***
Occupation: NLF	0.96		0.83		1.09	
Occupation: White collar	0.36	***	0.31	***	0.43	***
Owns property	0.94		0.94		0.94	
Owns business	0.81	**	0.78	*	0.84	
International migrants	1.36	***	1.61	***	1.22	***
Domestic migrants	0.93		1		0.83	
Road network	0.87		1.14		0.5	***
Distance city	1.09		1.01		0.84	
Wealth index	1.26		1.2		1.27	
Land area planted	1.03		0.61		1.85	
Farmland irrigated	1.17		1.09		1.86	
Base precip	0.97		1.07		0.99	
Base temp	0.97		0.91	*	1.03	
Male labor in Ag.	1.08	*	1.08		1.06	
Rural	1.17					
Model statistics						
Var. Intercept (Mun)	0.384		0.383		0.198	
BIC	20918		11559		9542	
N (HH-period)	93186		47262		45924	
N (Mun)	111		68		49	

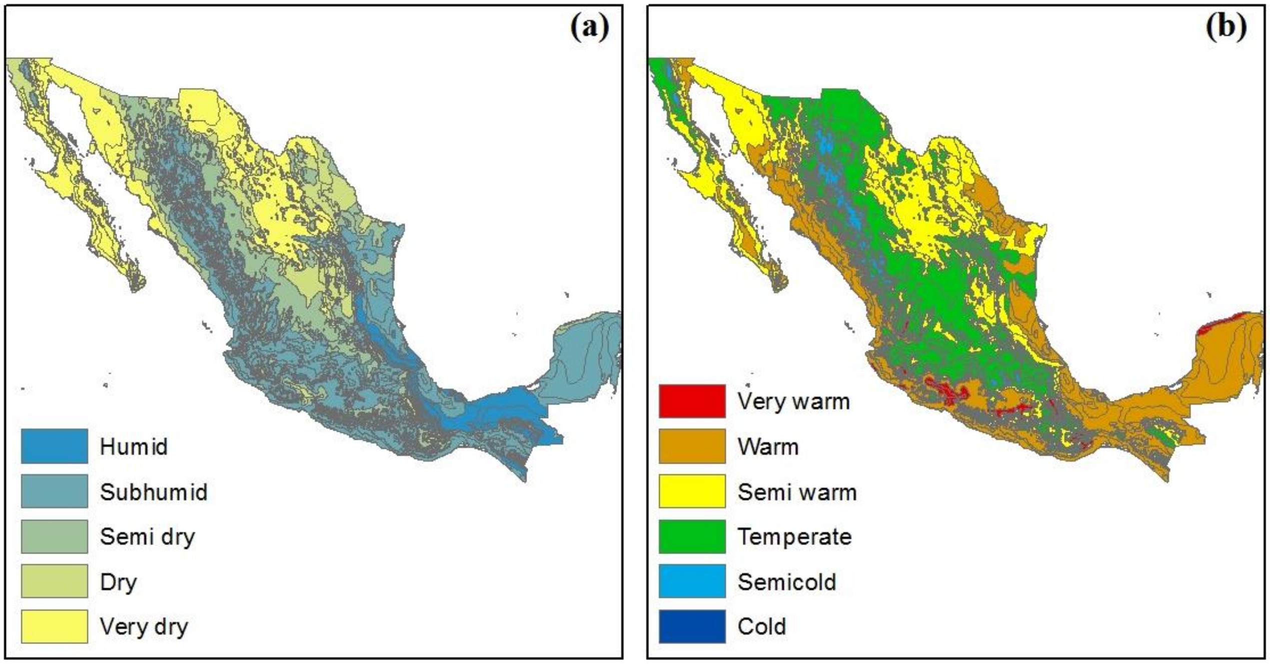
Note: Coefficients reflect odd ratios; The baseline hazard is captured by the following period dummies: Period 1 (1986-87), Period 2 (1988-89), Period 3 (1990-91), Period 4 (1992-93), Period 5 (1994-95), Period 6 (1996-97), Period 7 (1998-99); Occupation: Blue collar used as reference category; To guard against endogeneity and allow for causal interpretation of the effects, the migrant outcome was lagged by 1 year; All models were checked for multi-collinearity and variance inflation factors (VIF) below a value of 3.0 for all substantive predictors, suggesting that multi-collinearity is of no concern in the present model setup * p<0.05; ** p<0.01; *** p<0.001.

Table 7: Estimates of the effect of climate change on the first international move from rural and urban areas in Mexico during 1986-99

		All		Rural		Urban	
Indicator Name	ID	b	sig.	b	sig.	b	sig.
Temperature (high)							
No. summer days	su	0.83	**	0.73	***	0.99	
Warm spell duration	wsdi	1.14	**	1.13	*	1.12	
Warmest day	txx	1.08		1.07		1.13	
Warmest night	tnx	0.88		1.03		0.78	
% warm nights	tn90p	1.15	***	1.19	***	1.11	
Temperature (low)							
No. frost days	fd	0.81	*	0.65	**	0.89	
Cold spell duration	csdi	0.97		0.92		1.01	
Coldest day	txn	1.44	***	1.88	***	1.01	
% cool nights	tn10p	0.94		0.91		0.91	
% cool days	tx10p	0.97		0.89	*	1.03	
Precipitation (high)							
No. days heavy precip	r10mm	0.86	*	0.83	*	0.91	
No. days very heavy precip	r20mm	0.75	***	0.74	**	0.78	
Wet spell duration	cwd	1.02		1.02		0.98	
Max 5-day precip	rx5day	0.82	***	0.8	**	0.84	
Precip extremely wet days	r99ptot	0.84	***	0.82	***	0.83	*
Total wet-day precip	prcptot	0.58	***	0.61	**	0.45	**
Precipitation (low)							
Dry spell duration	cdd	0.84	**	0.67	***	1.1	
Temperature & Precipitation (other)							
Average precip	aprec	0.69	**	0.78		0.47	**
Average temperature	atemp	0.68		0.63		0.83	
Temperature range	dtr	0.99		0.99		0.8	

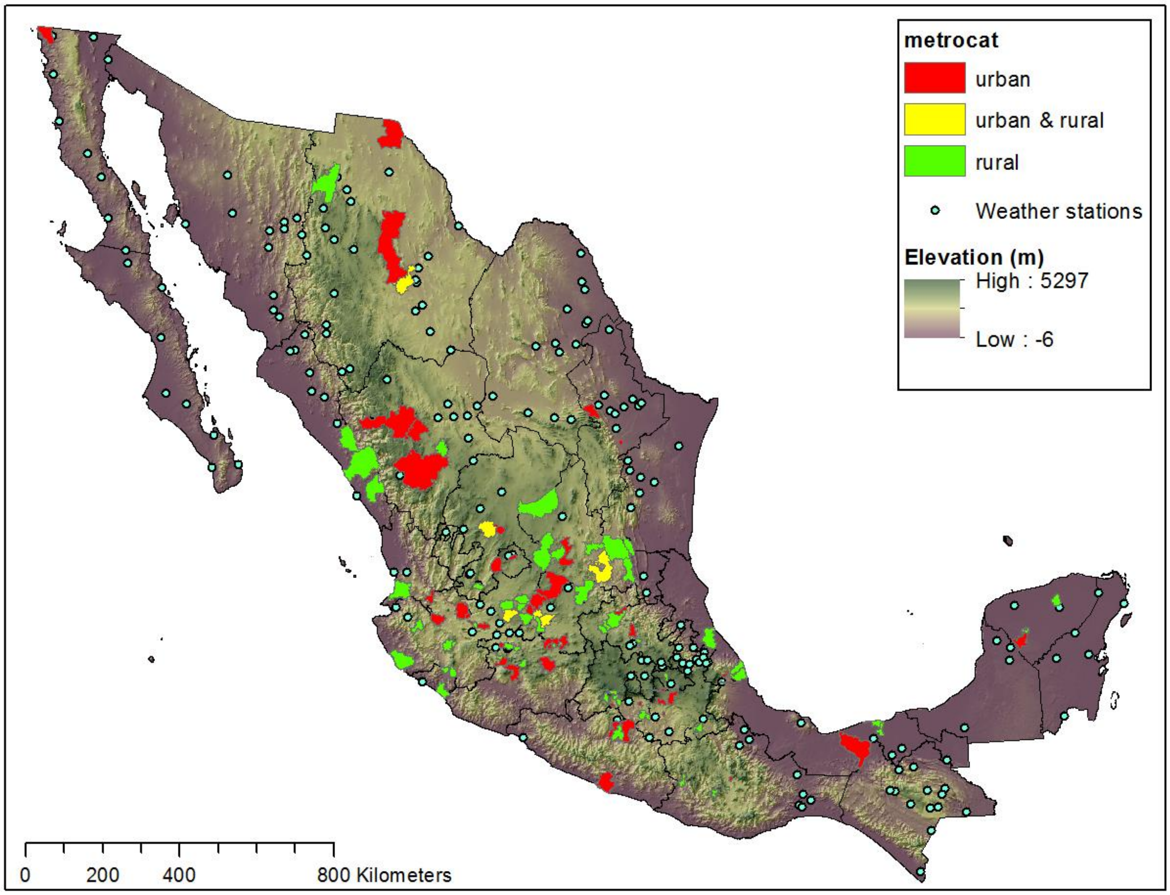
Note: The coefficients are reported in odd ratios; “All” = models use all available cases from rural and urban areas. Each coefficient was estimated using the complete set of household and municipality control variables; A jack-knife type procedure, removing one municipality during each permutation, demonstrated a high level of robustness of the results towards the sample composition * p<0.05; ** p<0.01; *** p<0.001.

Figure 1: Climatic zones across Mexico derived from a Koeppen classification



Note: Panel (a) displays humidity classification while panel (b) shows temperature classifications. Source: INEGI (2000).

Figure 2: Geographical location of MMP municipalities and spatial distribution of weather stations across Mexico



Note: Totol municipalities: n=111; rural municipalities: n=62; urban municipalities: n=43; municipalities containing both rural and urban municipalities n=6

Figure 3: Confidence matrix used to evaluate the hypothesized effect of climate change on migration based on agreement and evidence

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Evidence:
% coefficients significant

↑ **Agreement: % coefficients in anticipated direction**

	0-33%	34-66%	67-100%
67-100%	C3 High agreement Limited evidence	C4 High agreement Medium evidence	C5 High agreement Robust evidence
34-66%	C2 Medium agreement Limited evidence	C3 Medium agreement Medium evidence	C4 Medium agreement Robust evidence
0-33%	C1 Low agreement Limited evidence	C2 Low agreement Medium evidence	C3 Low agreement Robust evidence

Note: Shades of grey as well as class IDs C1 to C5 reflect the confidence in a particular finding. The five qualifiers are: C1=very low; C2=low; C3=medium; C4=high; C5=very high. Source: Adjusted from Mastrandrea et al. (2010).