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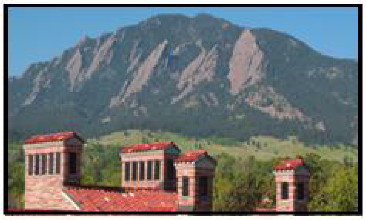

WORKING PAPER

Rainfall Trends, Variability and U.S. Migration from Rural Mexico: Evidence from the 2010 Mexican Census

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ABSTRACT

BACKGROUND: Prior studies showing that drought is (positively) associated with Mexico–U.S. migration looked at periods with historically low rainfall. Though this research informs on the long term potential effects of climate change, it may exaggerate its immediate and medium run effects.

OBJECTIVE: We examine the association between rainfall variability, precipitation tends, and U.S. migration from rural Mexico during 2005–2009, a period with above-average precipitation, a more rigorous test of the climate-migration nexus.

METHODS: We use multilevel models on microdata and municipal-level characteristics from the 2010 Mexican census and state-level precipitation.

RESULTS: In contrast to previous research we find that, in states experiencing relative precipitation declines, these rainfall deficits are associated with *lower* migration. Yet, we find two instances in which lower rainfall is indeed associated with higher migration in these same states. First, low relative precipitation during the secondary maize growing season implied higher emigration levels. Second, rainfall deficits were associated with U.S.-bound migration out of municipalities with stronger migratory traditions.

CONCLUSIONS: We argue that international migration is thus a more common adaptation strategy to climate variability only in times of particularly dire or extended droughts, or out of places with well-established migrant networks.

COMMENTS: Our results question the notion that climate change will displace a large number of rural Mexicans: only more extreme climatic variability may displace individuals, though future research should look into whether this kind of migration is temporary. Finally, climate migration projections should also consider the evolution of migrant networks.

Keywords: international migration; environmental demography; climate change; environment; drought; rainfall; Latin America; Mexico; United States.

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Rainfall trends, variability and U.S. migration from rural Mexico: Evidence from the 2010 Mexican census*

Climate change, mostly driven by an increase of atmospheric greenhouse gases, has raised average temperatures across the globe and lowered rainfall and soil moisture particularly in drier regions (IPCC 2007). In addition to impacting long-term trends, climate change will increase variability, thus intensifying the severity and frequency of adverse weather events, such as droughts (Hoerling and Kumar 2003; IPCC 2007; McGranahan, Balk, and Anderson 2007). Given the dependence of many rural households on natural resources for commercial and subsistence farming and ranching or foraging for foods and fuel, environmental shifts associated with climate change represent major livelihood challenges.

In this context, migration may be used as an adaptation strategy (McLeman and Hunter 2010). Although migration in response to environmental change is often temporary and short-distance (Findley 1994; Henry, Schoumaker, and Beauchemin 2004; Massey, Axinn, and Ghimire 2010), recent evidence from Mexico has contested, or at least qualified, this notion. On the one hand, international migration—both undocumented and legal—tends to be costly, and thus may be postponed in times of economic and environmental stress. On the other hand, given the long history and relevance of U.S.-bound migration in many rural areas of the country (e.g., Durand, Massey, and Zenteno 2001), international movement could be a logical livelihood adaptation for households with strong transnational links (see similar logic applied to economic migration more broadly in Lindstrom and Lauster 2001).

Indeed, prior studies found an association between lower rainfall and international migration (Hunter, Murray, and Riosmena forthcoming; Nawrotzki, Riosmena, and Hunter 2013). However, these studies examined migration during the late 1990s and early 2000s, a period characterized by both historically low rainfall (Stahle et al. 2009) and historically high

U.S.-bound migration (Passel, Cohn, and Gonzalez-Barrera 2012). Even during times of environmental scarcity, these studies found association between rainfall deficits and U.S. migration only in places with particularly dry conditions (Nawrotzki, Riosmena, and Hunter 2013) or in communities in the historical heartland of Mexico-U.S. migration, and thus with well-established migrant networks (Hunter, Murray, and Riosmena forthcoming). As such, the findings from these earlier studies could illustrate the extreme case of particularly low rainfall on times and places with highly dynamic migration conditions. Moreover, these prior studies have examined the association between migration and measures of rainfall change relative to long-term (Hunter, Murray, and Riosmena forthcoming) and short-term (Nawrotzki, Riosmena, and Hunter 2013) averages, therefore examining rainfall variability as opposed to long-term climate *trends*, also relevant when considering climate change.

In this paper, we examine the association between these two standard measures of climate change —relative rainfall variability and precipitation trends—and U.S.-bound migration during 2005–2009, a period with above-average precipitation and decreasing emigration (for an example of rainfall trends see Miranda-Aragon et al 2012, Figure 7; for recent migration levels, see Giorguli and Gutierrez 2012; Passel, Cohn, and Gonzalez-Barrera 2012). We use multilevel models to analyze household- and municipal-level migration and sociodemographic, economic, and land use data on rural communities from the 2010 Mexican census, combined with state-level rainfall information. Following prior studies, we examine these associations using trend and variability indicators based on rainfall data for specific months in order to assess seasonality (e.g., maize-growing season) in the relationship between migration and precipitation. Finally, given that individuals with higher access to migrant networks and the social capital embedded in them may be more likely to use U.S. migration as an adaptation strategy in times of environmental stress, we analyze if the association between rainfall change and migration varies according to the level of migration of municipalities.

1. PREVIOUS STUDIES

Lower rainfall, lower soil and plant moisture, and more intense weather events affect the livelihoods of families living in rural areas with high natural resource/primary sector dependency (McLeman and Hunter 2010). Direct property damage and displacement can occur due to unsafe conditions under extreme, rapid-onset events, such as storms, floods, and mudslides. Slower-onset events such as droughts, caused by lower rainfall and higher temperatures, can lead to a reduction in crop yields and crop failure (de Sherbinin, Warner, and Ehrhart 2011; Sanchez Cohen et al. 2012). Lower yields brings serious challenges to a household's sustenance and a substantial income reduction, particularly in places without good crop insurance mechanisms, as in most of the developing world (Gine, Townsend, and Vickery 2008; Hertel and Rosch 2010). More generally, reductions of natural capital (in crops or foraged materials), often associated with climatic variability, strain the well-being of natural resource-dependent households.

Households and communities adapt to these events through a variety of *in situ* coping strategies such as switching to drought-resistant crops, reducing dependency on natural capital through forms of local employment less dependent on natural resources, and investment in other sectors (see, e.g., Global Leadership for Climate Action 2009). As *in situ* adaptive capacity is generally limited by various forms of social vulnerability affecting individuals and communities (Adger 2006), households also use *ex situ* adaptation strategies such as migration (McLeman and Hunter 2010), most commonly by sending a member to another (usually more urban) labor market. *Ex ante,* this reallocation of household labor can help spread the risk of potential crop failure (Stark and Bloom 1985). *Ex post*, it can otherwise help alleviates losses associated with lower natural capital (Hunter, Murray, and Riosmena forthcoming; Nawrotzki, Riosmena, and Hunter 2013).

Many scholars reject the idea that climate change will create massive *international* displacement and millions of so-called climate refugees (e.g., Bardsley and Hugo 2010). With few exceptions pertaining to island nations, climate change is unlikely to spawn a large number of international migrants, as cross-border movement is generally costly, and thus unlikely to arise among the most vulnerable displaced households (for overviews see Black et al. 2011, Gemene 2011).

Indeed, much of the research on the effects of past climatic variability on migration, generally focused on droughts using precipitation measures, has found an association between rainfall shifts/variability and *short-distance* circular moves within national borders (e.g., Findley 1994; Gray and Mueller 2011; Henry, Schoumaker, and Beauchemin 2004; Massey, and Ghimire 2010). Further, some of these studies found a *negative* association between climatic variability (e.g., droughts) and longer-distance moves (Massey, Axinn, and Ghimire 2010), including international migration (Henry, Schoumaker, and Beauchemin 2004).

Although international movement may less likely to take place in the context of environmental change in many (if not most) settings,[1] the costs and risks of international

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[1] Cross-border movement is generally a riskier, more costly undertaking. In the case of legal migration, it may involve a lengthy (and expensive) visa application process; in the case of irregular migration, it entails the payment of high fees for being smuggled over dangerous terrain or obtaining false crossing documents. It is thus no surprise that individuals do not tend to move

migration can be reduced substantially by social capital contained in ties to prior migrants (Lindstrom and Lauster 2001). These networks of relations to prior migrants are particularly strong in rural areas (Fussell and Massey 2004). As such, migration could be a response to environmental and climate change in some settings.

Indeed, recent research has found an association between lower rainfall levels and international migration out of rural sending communities in central-western Mexico (Hunter, Murray, and Riosmena forthcoming; Munshi 2003), the historical heartland of U.S.-bound migration (Durand and Massey 2003); and from rural dry lands across the country (Aufhammer and Vincent 2012; Feng, Krueger, and Oppenheimer 2010; Feng and Oppenheimer 2012; Nawrotzki, Riosmena, and Hunter 2013). As these associations are particularly strong among households with U.S. migration experience (Hunter, Murray, and Riosmena forthcoming), social capital contained in migrant networks may indeed help reduce the costs of migration and allow people to move during times when substantial environmental change challenges local livelihoods.

However, as mentioned before, this research examined migration decisions during the 1990s and early 2000s, a period of historically-low precipitation (Stahle et al. 2009). In this study we depart from prior work by examining the association between rainfall and U.S.-bound migration during the most recent decade (2005–2009), a period of above-average precipitation (Miranda-Aragon et al. 2012: Figure 7). To be sure, understanding the impact of environmental change in rather adverse climatic conditions is relevant for evaluating the potential effects of

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across international borders when they are more or less suddenly uprooted by an event that severely affects their income and wealth.

long-term climate change. Yet, looking at times of lower environmental stress sheds light on these associations under the *status quo* and, perhaps, conditions in the medium run. Further, regardless of the implications of this research for climate change, this examination can serve as a more conservative test of the effect of rainfall patterns on emigration more broadly.

Our research also examines a period of decreasing emigration from Mexico (Giorguli-Saucedo and Gutiérez 2012; Passel, Cohn, and Gonzalez-Barrera 2012). While the precise contributions of different factors explaining this decline (and whether it is a temporary blip in Mexico – U.S. migration dynamics) are still under debate, this decline was likely the product of economic crisis fueled by the U.S. Housing Bust and, perhaps, higher levels of U.S. immigration enforcement. Our tests for the association between rainfall deficits and migration are thus conservative on this regard as well as conditions in potential destinations were not very favorable during part of the period.

Our work also departs from prior studies by using two distinct measures of changes in long term rainfall variability and rainfall trends across a period of 36 years, to approximate the effects of climate change on population dynamics. Before we describe these variables and our analytical approach, however, we introduce our data our analytical approach.

2. DATA AND METHODS

We use migration, demographic, and socioeconomic data at the household and municipal levels from the 2010 Mexican Census long form. The data come from a random sample representative at the state-, urban-rural, and national scales, collected by the *Instituto Nacional de Estadística y Geografía* (INEGI by its Spanish acronym) during the 2010 Census fieldwork, when roughly 90% of the population was interviewed with a “basic” form. The remaining 10%, selected using complex sampling design techniques, were interviewed with a more detailed questionnaire.[2] A subsample from this census long form was harmonized by the Integrated Public Use Micro-data (International) Series (IPUMS - International), an initiative of the Minnesota Population Center (MPC 2011; Ruggles et al. 2003). We employed a 1.0% extract as a commonly used density in these kinds of analysis (e.g., Saenz and Morales 2006).

On the assumption that environmental influences affect people most in agriculture-dependent rural areas, we restrict our analysis to localities with fewer than 2,500 individuals, in line with other published work (Hunter, Murray, and Riosmena forthcoming; Nawrotzki, Riosmena, and Hunter 2013; Skoufias and Vinha 2013). This restriction yields an analytic sample of 135,171 households.

The Census long form included a section on international migration, in which respondents were asked whether any regular member of the household had moved abroad between January 2005 and the date of the interview (although this took place between May 31 and June 25 2010, for simplicity we call this period 2005–2009), whether or not they had returned by the time of the interview. Though this measure clearly does not cover the emigration of complete households out of the country, Mexican migration has historically followed a sequential pattern in which a household member (generally the head) moves first for labor purposes and are only followed by other members after a few years in the United States (Cerutti and Massey 2001; Hondagneu-Sotelo 1994). Further, this measure should capture not only the initial movement of specific members out of a household but also that of recurrent or "circular" migrants who returned to the country (a relatively common phenomenon among Mexican

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[2] See http://www.censo2010.org.mx/ for details on sampling methodology and for short and long forms.

migrants, though decreasingly so, see Riosmena 2004). As it is less likely that environmental change is affecting U.S.-bound moves for the purpose of family reunification, which imply the relocation of an entire household from the sending community, we deem the omission of these individuals to be only mildly problematic for our purposes. That is, we expect that most kinds of migration used as adaptation to (slow-onset) environmental change be captured in these measures, though we cannot rule the possibility that our estimates may understate the importance of environmental change on U.S. migration.

While it is not possible to identify an individual's country of destination in the IPUMS public release, the United States is by far the most common international destination of rural Mexicans. According to aggregated tabulations from the 2010 census available from INEGI, where information on country of destination was available for individuals returning from an international destination, between 81% and 94% of individuals ages 12 and over who were living in another country in 2005 and had returned to a rural Mexican locality in 2010 returned from the United States.[3] We therefore use the terms international and U.S.-bound migration interchangeably. Since U.S. migration decisions usually involve the active engagement (whether

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[3] An estimated 384,088 individuals moved from an international location to a rural place in Mexico in 2005–2009, with 311,580 of them coming from the United States. The estimate of the proportion of return migrants coming from the United States varies between 81% and 94% depending on what one is willing to assume about the 46,246 individuals for whom there are no data on the country they returned from; it would be as low as 81% only if we assumed that none of those 46,246 had lived in the U.S. We obtained these figures by doing a query at http://www.inegi.org.mx/lib/olap/consulta/general_ver4/MDXQueryDatos.asp?c=27823, last accessed October 28, 2012.

collaboration or opposition) of other household and family members (Hondagneu-Sotelo 1994; Taylor 1999), we aggregate individual-level data to the household level. This includes both people still in the United States and those who had already returned by the time of the interview. Persons who left the country for vacation, temporary work assignments by their Mexico-based employers, visits to relatives, or another reason that did not entail a change of residence were not considered migrants.

Across the sample about 5.6% of households had at least one member moving to an international destination between 2005 and the time of the interview. This is a nontrivial reduction relative to the 8% of households that sent a member to an international destination in 1995–1999 (Nawrotzki, Riosmena, and Hunter 2013: Table 1). These figures reflect the aforementioned slowdown in the rather dynamic migration regime of the late 1990s and the first five or so years of the 21st Century (Passel, Cohn, and Gonzalez-Barrera 2012). Across the 32 Mexican states the average rates of outmigration (not shown in the table) vary widely, from 0% in Baja California Sur (with a small rural sample of 132 households) to 16% in Guanajuato (with a sizable sample of 2,744 households).

Our analytical focus is the impact of climate change on U.S. migration, using two measures of long-term rainfall shifts. Monthly rainfall time series from weather stations are collected by the Mexican National Water Commission (CONAGUA, by its Spanish acronym) and available at the state level from several INEGI publications. The Mexican Migration Project (MMP), based at Princeton University and the University of Guadalajara, compiled these data into one single data file,[4] which we use here. Table 1 shows average precipitation by state during 1974–2009, a 36-year period chosen to depict long-term changes in rainfall. Reflecting the rather dramatic variation in climatic conditions across Mexico (with a relatively clear north-south divide between dry and wet conditions), rainfall levels range at 184 – 441 mm/year in Baja California Sur, Baja California, Coahuila, Sonora, and Chihuahua in the north to 1,321 – 2,318 mm/year in Puebla, Oaxaca, Veracruz, Chiapas, and Tabasco in the south.

-TABLE 1 ABOUT HERE-

There are at least two ways in which climate change is usually reflected in the literature. The first is to measure weather conditions in relation to the average over a (generally long) reference period. We calculated the percentage change in average annual rainfall for 2004–2009, roughly a one-year lag to the period in which international migration was measured, from the long-term mean precipitation of the preceding 30 years (i.e. 1974–2003); a 30-year reference period is commonly used to measure climate change (e.g., Poston et al. 2009; Jonsson 2010; Hunter, Murray, and Riosmena forthcoming). As the bottom of Table 1 shows, there was an average increase of 5.8% in precipitation in 2004–2009 relative to 1974–2003 across all Mexican states. Twenty-three states exhibited relative increases in rainfall, ranging from 0.4% in Zacatecas to 30.1% in Coahuila (both in the north, like several other states in this group, such as Sonora, Tamaulipas, Baja California Sur, San Luis Potosí, Durango, Nuevo León, Aguascalientes, and Chihuahua, all with low precipitation levels in general; see Figure 1a for a map showing states with relative precipitation increases and declines). Only nine states

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[4] Specifically, we use the "ENVIRONS" file, publicly available at http://mmp.opr.princeton.edu/databases/supplementaldata-en.aspx. Last accessed October 28, 2012.

experienced a decrease, ranging from -1.6 in Puebla to -15.7% in Baja California; this group included a mix of both southern and (to a lesser extent) northern states such as the Federal District (-1.8%), Tabasco (-2.8%), Sinaloa (-4.1%), Oaxaca (-4.9%), México State (-6.8%), Quintana Roo (-9.4%), and Yucatán (-12.5%).

-FIGURES 1a and 1b ABOUT HERE-

A second approach employed to reflect climate change looks at more general trends in climate indicators, especially for weather extremes (Frich et al. 2002) but also average precipitation levels (Peterson et al. 2001; Alexander et al. 2006). For this purpose, we estimated the average annual change in precipitation during the 36-year period 1974–2009. To obtain these trend measures, we estimated robust regressions of annual precipitation. Robust regression specifications were used to reduce the weight of outliers and influential time units on the trend measure.[5] Positive (negative) values indicate an overall increase (decrease) in annual total precipitation during the observation period.

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[5] The robust regression algorithm first runs an OLS regression and obtains Cook's D for each observation. Observations with Cook's distance greater than 1 are dropped. Then an iteration process begins in which weight calculations are based on absolute residuals. The iterating stops when the maximum change in weights from one iteration to the next is below tolerance. Two types of weights are used. In Huber weighting, observations with small residuals get a weight of 1, and the larger the residual, the smaller the weight. With biweighting, all cases with a nonzero residual get down-weighted slightly. The two different kinds of weight are used because Huber weights can have difficulties with severe outliers, and biweights can have difficulties converging or may yield multiple solutions.

Our two precipitation measures reflect different aspects of climate change. The 36-year trend might be considered a reflection of more general long-term climatic changes. On the other hand, examining a recent 5-year period relative to the 30-year longer-term average is more reflective of climate variability. As Table 1 shows 20 states experienced generally modest increases in rainfall during the period, ranging from 0.04 mm/year in Tlaxcala to 15.3 mm/year in Campeche (the only state with an average increase of more than 10 mm/year). The 12 states that experienced a decrease in rainfall are, as in the case of our relative measure, not quite clustered in one single region of the country (see Figure 1b), although they are indeed more concentrated than the states with relative changes (cf. Figure 1a). Rainfall change in these places ranged from -0.52 mm/year in Chihuahua to -6.9 mm/year in Tabasco; states with decreases also include Tamaulipas (-0.9), Jalisco (-2.1), Sonora (-2.3), Durango (-2.6), Baja California (-3.6), Hidalgo (-4.5), San Luis Potosí (-5.3), Yucatán (-6.3), Sinaloa (-6.4), and México State (-6.7). Note that only five states (Baja California and Sinaloa in the north, México State in the central part of the country, and Tabasco and Yucatán in the south) experienced decreases in both the relative change and trend measures.[6]

Given the importance of moisture during a crop's growing season, we expect the association between migration and our rainfall measures to be stronger when looking at precipitation during the months where crops are most commonly grown. Therefore, in addition to including the average relative change in rainfall and absolute trend measures based on year-round precipitation information, we also perform sensitivity tests to examine whether the association between precipitation change and migration is responsive to rainfall measures using

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[6] While the two measures of rainfall change employed here are indeed positively correlated, this association is not overly high (for aggregate-level data) at r = 0.421.

only information for specific seasons associated with the growth of maize (*Zea mays*), the most important staple/crop in Mexico (Eakin 2000). Although the main growing season for maize is June, July, and August (Smeal and Zhang 1994), maize is grown during a second growing season roughly spanning November to January. This second season primarily takes place in the Northwest as well as parts of the South and East (see Table 5; Baez-Gonzales et al. 2002). We estimated both the relative change and absolute trend measures for these particular seasons and call the months in between "off seasons."

In addition to our rainfall measures, we include a variety of controls, shown in Table 2. Several sociodemographic characteristics such as wealth, education, and social networks have been found to be associated with international migration (Brown and Bean 2006; Massey and Espinosa 1997). Acknowledging that the various drivers of outmigration operate at distinct scales, we include covariates at the household, municipality, and state levels, summarized next.

-TABLE 2 ABOUT HERE-

2.1. Household-level controls

We use two measures of household life-cycle stage. First, age of the household head is used as general proxy for family life-cycle stage (VanWey, D'Antona, and Bondizio 2007). Households require a certain level of human capital to send a member elsewhere. Ideally there is a pool of young adult children who can be deployed to an international destination. Later in the life-cycle, when the household head has aged and adultchildren have formed their own families, the parental household is likely to lack the human capital to afford a move (Juelich 2011). In our sample, the average age of the household head was approximately 49 years.

Second, we use the number of co-resident children of the household head below age 5. At a very early stage in the life-cycle the presence of young children is negatively associated with outmigration, likely because of the increased requirements for care (Riosmena 2009; White and Lindstrom 2006). Approximately 26% of household heads reported having young children.

We measure human capital using the number of years of the household head's formal schooling. While educational attainment is generally positively associated with internal migration (White and Lindstrom 2006), the educational selection of international migrants from Mexico is relatively weak (e.g., Chiquiar and Hanson 2005; Feliciano 2005). Thus it is not surprising that the level of educational attainment of heads in migrant households, 4.7 years, is similar to that of nonmigrant households at 4.9 years, reflecting the lower schooling of people in rural areas and in the older cohorts to which the average household head in our sample belongs. Weak educational selectivity makes sense in the case of international migration, given the lower returns on schooling in U.S. destinations (Taylor et al. 1996), particularly among undocumented migrants.

We also include other measures of the household's socioeconomic standing. One of the main motivations for sending a migrant abroad is to increase the financial well-being of the household by escaping liquidity constraints (often in response to both poor labor market opportunities and capital and insurance market failures) (Massey et al. 1993). We attempt to capture this general motivation by including measures of household income and the percentage of adult household members employed. Those adults employed, comprise roughly a third of the members of an average household. The typical monthly income in these households was 3,665 pesos (286 U.S. dollars at the average exchange rate of 12.82 MXN/USD in 2010). Note that, in the multivariate models presented below, we divided total household income by the square root of household size to standardize income by family size, a common technique (Franzen and Meyer 2010) and then log-transformed it to account for its skewed distribution.

To control for the household's physical capital, we use information on home ownership and dwelling characteristics. Over 87% of all households live in homes owned by one of their members. Using a procedure similar to that of Mberu (2006), we measure dwelling quality and household amenities with a normalized index based on 17 items (Cronbach's alpha = 0.867). The asset index measures the dwelling quality (6 items: separate bathroom, type of toilet facility, number of rooms, floor material, roof material, wall material); the availability of public services and amenities (5 items: electricity, water supply, sewage system, cooking fuel, hot water); and the possession of consumer goods (6 items: car, computer, washing machine, refrigerator, TV, radio).

Finally, we include two measures of both household amenities and communication networks, namely the household's possession of a landline telephone and a cell phone. These technologies may not only facilitate a move but also reduce the social costs of living abroad by allowing the migrant to stay in close contact with family and friends (Panagakos and Horst 2006; Vertovec 2004). Given the lower coverage of landlines in relatively remote rural areas (and the expansion of mobile phone use across Mexico), cell phones are an important means of contacting relatives living abroad (Horst 2006). This may explain why in our sample a larger percentage of households own a cell phone (26%) while fewer report being connected to a land line (15%). Note that land line and cell phone owners are largely different populations: within the 36% of households with either a cell or a landline, only 14% had both.

2.2.Aggregate-level controls

Three variables operate at the municipality level. First, we employ international outmigration rates of the preceding census round (year 2000) to capture the impact of social networks. Several studies have found that well-established migration networks based in Mexican sending areas are strongly associated with U.S. migration (Fussell and Massey 2004; Massey, Axinn, and Ghimire 2010; Massey and Riosmena 2010). These studies suggest that migrants already in destination areas are able to reduce aspiring migrants' costs and risks to embark on a move by sharing information, assisting them in several ways during the crossing and upon arrival to the United States (Flores 2005), including helping them find jobs. For an average municipality, 2.9% of households had sent a member abroad between January 1995 and the 2000 census date. We use this measure of prior migration in order to avoid the endogeneity of using a migrant network measure for the same period as our main dependent variable.

Second, we account for the effect of community-level affluence through a marginalization index based on 2005 population count data (a census-like enumeration carried out by INEGI), estimated and made publicly available by CONAPO (*Consejo Nacional de Poblacion*), the Mexican government institution in charge of demographic analysis. The marginalization index, which has been used in other migration studies (Riosmena et al. 2012; Saldana-Zorrilla and Sandberg 2009), should be overall positively associated with outmigration to the U.S. from rural Mexico. Households in more marginalized areas may have a higher incentive to improve their financial situation or to insure themselves against market failures given poorer or nonexistent local financial and insurance infrastructure (Massey et al. 1993; Stark and Bloom 1985).

Third, we assume that the impact of climatic/weather events on rural people's livelihood is experienced most profoundly in places that lack technological buffers against adverse environmental impacts (Gutmann and Field 2010). Rural Mexican households are particularly vulnerable to changes in precipitation patterns when agriculture is largely rainfed and irrigation is logistically impossible or at least financially prohibitive (Eakin 2005; Vasquez-Leon, West, and Finan 2003). We used data on hectares of irrigated and rainfed planted surface area for the 2004–2009 period (INEGI 2012a) to calculate the percentage of irrigated land for each municipality during these years. Although the average municipality had 19% of its farmed land irrigated, a quarter of all rural municipalities lacked any irrigation. As such, the median value of 5.37% better reflects the extent of irrigation in these communities.

Finally, to avoid confounding the influence of rainfall variability with economic changes not necessarily associated with precipitation change, we measure the change in state-level gross domestic product (GDP) during our observation window. We calculated the inflation-adjusted percentage growth in GDP for each year in reference to the preceding year with data obtained from INEGI (2012a). We then averaged the annual growth rates for the period 2004–2009, the window also used to measure relative rainfall change. Contrary to the Mexican experience in the 1980s and part of the 1990s, in which the national economy contracted in several years (e.g., Lustig 1990), all states experienced positive average growth in GDP across the 6-year period. Increases ranged from 1.2% in Morelos to 10.7% in Tabasco, with a mean of 3.9%, a nontrivial amount despite the large contraction in the Mexican economy during 2009 in the aftermath of the U.S. Housing Bust and the swine flu epidemic scare (INEGI 2012b).

2.3.Estimation strategy

Migration is a social phenomenon that is influenced by factors operating at multiple scales. To account for this multidimensionality we employ a hierarchical modeling approach. We use a three-level structure, which takes into account that households are nested in municipalities, which are in turn nested within states. In addition to adjusting for clustering, multilevel models also take into account differences in sample sizes at different levels and heteroscedastic error terms (Luke 2004).

We predict the odds of an international move for the i^{th} household in the j^{th} municipality located in the k^{th} state (m_{ijk}) using the logit link function $\sigma_{ijk} = log_e(\frac{m_{ijk}}{1-m_{ijk}})$ (Hoffmann 2004). We report results as odds ratios ($\beta_{OR} = \exp(\beta_x)$), also interpreted as a percentage change in the odds of an international move for a one-unit change in the predictor variable (i.e., $\Delta\% = (\beta_{OR}-1)\cdot 100$). In our models we specify random intercepts at level 2 (municipalities, u_{0jk}), and level 3 (states, ν_{0k}), and thus allow for the estimation of a different migration propensity for each unit within an aggregation level. The models can be formally described with the following equation:

$$\sigma_{ijk} = \beta_0 + \sum_{n=1}^{9} \beta_n (X_{nijk}) + \sum_{n=10}^{12} \beta_n (Y_{njk}) + \sum_{n=13}^{14} \beta_n (Z_{nk}) + u_{0jk} + \nu_{0k} \tag{1}$$

In equation 1, the parameter β_0 represents the odds of outmigration from an average household in rural Mexico for the reference category in all categorical covariates and when all metric predictors are set to zero. The coefficients β_1 through β_9 show the effects of the household-level predictors (X_{1ijk}-X_{9ijk}), such as age of household head, home ownership, or asset possession. The effects of municipality-level variables (Y_{10jk}-Y_{12jk}), such as social networks and marginalization, are reflected by parameters $\beta_{10\text{-}12}$. Of primary interest for this study is the effect of the precipitation change measures (Z_{14k}), β_{14}, measured at the state level, with a control for the potentially confounding impact β_{13} of differences in state level GDP growth rates (Z_{13k}).

In addition to the main effects of precipitation change and given our interests in understanding variation in the effects of rainfall according to the extent of local migrant networks, we also investigate the cross-level interaction between a change in rainfall and the municipal U.S. migration rate in 2005–2009:

$$\sigma_{ijk} = \beta_0 + \sum_{n=1}^{9} \beta_n (X_{nijk}) + \sum_{n=10}^{12} \beta_n (Y_{njk})$$
$$+ \sum_{n=13}^{14} \beta_n (Z_{nk}) + \beta_{15}(Y_{10jk} * Z_{14k}) + \nu_{1k}(Y_{10jk}) + u_{0jk} + \nu_{0k} \quad (2)$$

Equation 2 shows the cross-level interaction (Y_{10jk} * Z_{14k}) between the aforementioned municipal-level predictor, social networks (Y_{10jk}), and the rainfall change measure (Z_{14k}). We follow a commonly used approach (e.g., Subramanian et al. 2009; Dedrick et al. 2009) and allow the slopes of the lower-level variables (i.e., the municipal migration rate) to vary across level-3 units (i.e., states). In this case the variance-covariance matrix of the random effects takes the following shape, assuming a joint multivariate normal distribution:

$$\begin{bmatrix} \nu_{0k} \\ \nu_{1k} \end{bmatrix} \sim N(0, \Omega_\nu) : \Omega_\nu = \begin{bmatrix} \sigma^2_{\nu 0} & \\ \sigma^2_{\nu 01} & \sigma^2_{\nu 1} \end{bmatrix} \quad (3)$$

The variance components are presumed to be independent and normally distributed with a mean of zero and variance of σ^2_{u0} and σ^2_{v0} for the random intercepts at the municipal and state levels, respectively; and σ^2_{v1} for the random slope at the state level, specified when examining cross-level interactions between state-level rainfall and the municipal migration rate. For an easier interpretation of the random effects we transform the coefficients into median odds ratios (MOR, Larsen and Merlo 2005). MORs can be interpreted as the average difference in the odds of outmigration comparing two randomly selected clusters.

The models were fitted using reweighted iterative generalized least squares (RIGLS), the method of choice for small numbers of higher-order units (Luke 2004). The transformation to a linear model was performed using a quasi-likelihood estimation procedure (Rasbash et al. 2008). This procedure employs a linearization method based on a Taylor series expansion to transform the discrete response model into a continuous response model. The linearization requires an approximation for which we employ a penalized quasi-likelihood procedure including second-order terms of a Taylor series expansion (PQL2, for further details, see Goldstein 2003).[7] All models were estimated using MLwiN 2.25 software (Rasbash et al. 2009) run in STATA 11 (StataCorp LP, College Station, Texas) by using the macro *runmlwin* (Leckie and Charlton 2011).

3. RESULTS AND DISCUSSION

Table 3 shows the results of random intercept models predicting the likelihood that households send at least one international migrant for (A) all states; (B) states with rainfall decline in our relative change and trend measures (Models I and II respectively); and (C) states with rainfall increase (likewise, in relative change and trend measures in Models I and II).

First, looking at the models including all states in Column A, the socio-demographic control variables perform largely as expected. Households deploy a member to the U.S. early in their life-cycle, when the household head is younger and has no/fewer younger children. Overall, the associations between our different measures of socioeconomic status and migration is mixed, though mostly suggest that lower SES is associated with higher levels of migration. Migration is negatively associated with the schooling levels of the household head and with household income. In addition, a higher proportion of employed household members is associated with lower emigration. However, homeownership status and a higher index of physical capital are associated with higher U.S. migration. As the data do not include variables that can be used to control for the prior U.S. experience of household members preceding the retrospective window under study, this association could be an artifact of past remittance investment in homeownership

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[7] For models with convergence problems, we used a first-order term for the Taylor series expansion.

and housing quality as home investments are a common use of remittances sent and savings brought back by migrants (e.g., Moran-Taylor and Taylor 2010). As such, we posit that the association between SES and migration is mostly negative in these places, an assumption also supported by the positive association between migration and the level of marginalization of the municipality where these households are located.

-TABLE 3 ABOUT HERE-

Despite hailing from households and places with lower SES, households with higher use of communication networks, i.e., having a telephone landline or cell phone, have a higher likelihood of having a household member living abroad. Rural households owning this kind of communication infrastructure (see also Hamilton and Villarreal 2012: Figure 2) may have had higher emigration rates in the past (i.e., prior to the retrospective window we analyze) as communication networks facilitate migration by helping maintain connections between migrants abroad and their sending areas (Panagakos and Horst 2006; Vertovec 2004).[8] In addition, migrant networks also greatly facilitate migration by providing information and assistance to migrants-to-be (Massey, Goldring, and Durand 1994), which is especially in non-metropolitan

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[8] Another interpretation to these results might suggest that places with better communication infrastructure have received a higher level of capital penetration that also tends to disrupt (rural) livelihoods and stimulate migration (Sassen 1988). As such, our household-scale measures of landline and cell phone ownership could be signaling access to these amenities and thus, the quality of the communications infrastructure at broader scales. We deem this to be unlikely as our models control for the level of marginalization of the municipality (which includes measures of the level of infrastructure access/use at that scale) and in light of the fact that this index is positively associated with migration, as shown in Table 3.

areas in Mexico (Fussell and Massey 2004). Consistent with this notion, households located in municipalities with higher emigration rates in the recent past (1995–1999) have a higher likelihood of sending a migrant abroad. While households located in municipalities with a larger percent of irrigated farmland and states with higher growth rates in GDP are less likely to send migrants abroad, these associations are not statistically significant with the exception of state-level GDP in states with rainfall decline (Column B, Model II). [9] In fact, note that, with few exceptions related to the weak effects of state-level GDP and the municipal share of irrigated land, the "effects" of all control variables discussed thus far are similar in order of magnitude in states with (relative and absolute) declining and increasing precipitation levels (compare column A with columns B and C).

Table 3 also shows the results for both the relative and absolute trend in long-term rainfall change, the analytical focus of this study. Although both long-term relative change (Model I) and absolute precipitation trend (Model II) are positively associated with migration, they are not statistically significant (Column A). However, as pointed out before, prior studies have used a specification of rainfall that allows for non-linear effects of rainfall (on the same log-odds scale used in our models, Hunter, Murray, and Riosmena forthcoming; Nawrotzki, Riosmena, and Hunter 2013).

We allow for nonlinear effects of rainfall by examining the effects of rainfall in states with positive and negative change in our two precipitation measures separately. That is, we allow the effect of our relative rainfall measure to vary according to whether states experienced a

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[9] The models were checked for the influence of multicollinearity. The variance inflation factor (VIF) statistic showed values below 2.2, confirming that multicollinearity does not affect the estimates.

rainfall deficit or surplus in 2004–2009 relative to 1974–2003. Likewise, we estimate separate effects of our rainfall trend measure for states that experienced overall precipitation deficits in 1974-2009 in contrast to those experiencing a surplus during the same period.

Columns B and C in Table 3 show results from these specifications for states with rainfall decline and increase respectively. First, note that the association between rainfall and international migration is negative in three of our four rainfall measure/direction combinations, suggesting that the (non-significant and weak but) positive effects of rainfall on U.S. migration in the global model (Column A) may be the result of nonlinearities. However, only one significant, positive effect emerges for the relative rainfall measure: a 10% increase in rainfall (e.g., going from a rainfall decline of 20% to one of 10%) *increases* the odds of outmigration by a factor of 3.44 ($p \leq 0.01$). As such, a rainfall decline decreases the likelihood of outmigration for households located in states experiencing rainfall decline in 2004–2009 relative to 1974–2003. Although this finding is in line with results from studies in Africa (e.g., Henry, Schoumaker, and Beauchemin 2004), it is at odds with prior research from Mexico (e.g., Feng, Krueger, and Oppenheimer 2010; Nawrotzki, Riosmena, and Hunter 2013). This association is, however, not similar when looking at an absolute rainfall trend, where a rainfall decline implies higher migration. Although not statistically significant, this finding is more in line with prior studies. A potential reason for this difference might be that the relative measure is more sensitive towards short-term fluctuations in weather patterns, and strongly impacted by the above average precipitation during the study years, while the trend measure better captures long-term changes.

3.1. Rainfall seasonality, growing seasons, and migration

As mentioned before, we also sought to investigate if the association between precipitation change and migration is particularly strong during the maize growing seasons, the main season being between June and August plus a second one between November and January. Table 4 shows results of models similar to those presented in Table 3 but in which we estimate the percent relative change and absolute trend measures while stratifying states according to whether they experienced a deficit (Panel A) or surplus (Panel B) in each of these seasonal measures themselves. That is, states that experienced an overall decline (increase) in precipitation could have had a relative increase (decrease) in the same measure when only looking at a particular season. For the sake of parsimony, we only report the rainfall coefficients in the Table, although the models include all other covariates reported in Table 3.

-TABLE 4 ABOUT HERE-

The results shown in Panel B in Table 4 confirm the lack of overall statistical significance of our absolute long-term trend measure: in neither seasonal measure is the trend in rainfall between 1974 and 2009 significantly associated with emigration. On the other hand, Panel A in Table 4 shows that the significant and positive association between rainfall and migration in states experiencing a relative rainfall decline is not significant when using rainfall data for specific seasons. Instead, the models imply that a larger relative decline in rainfall is associated with 27% higher odds of migration (OR=1/0.789=1.27, $p \leq 0.05$).

The significant effect during the winter months might be explained in two ways. First, it could signal the relevance of rainfall deficits in warmer, more humid places with a more intensive secondary growing season, or where the main growing season takes place in the winter months. This is particularly the case in the Northwest and, to a lesser extent, the South and East: as shown in Table 5 using data from the 2007 Agricultural Census, the Northwestern states of Sinaloa, Sonora, Nayarit, and Baja California Sur produce 167%, 75% 20%, and 18% of their Spring-Summer corn yields during the Fall-Winter, while the figure is 17% of the Eastern state of Veracruz. Likewise, of the total maize produced during the main growing season, the Southern states of Oaxaca, Morelos, and Tabasco, and the Eastern state of Tamaulipas produce between 8 and 9% of the their growing-season maize yields during the secondary growing season, a somewhat smaller but nontrivial amount, particularly given their relatively low shares of agricultural land that is irrigated.

-TABLE 5 ABOUT HERE-

Although, as shown in Table 5, at least (roughly) half of the agricultural land in each of the three aforementioned Northwestern states is irrigated, water supply from precipitation is, of course, still a relevant factor determining the amount of water stored and available for irrigation during the growing season. As such, the relevance of the rainfall during the second growing season could alternatively (or, at least, additionally) signal the importance of soil moisture storage. If insufficient rain falls during the winter months, the levels of moisture stored in the soil is low and the crop begins to grow under unfavorable conditions, increasing the potential for a crop failure (McLeman et al. 2010).

3.2.Social capital, rainfall deficits, and migration

As mentioned at the outset, Mexican rural households may engage in international migration as a response to precipitation deficits (as these may lead to lower crop yields) more commonly than in other developing countries, where this relationship is negative, because of the existence of well-established migrant networks. If this is the case, it can be expected that a stronger negative association between rainfall and migration in municipalities with a larger percentage of emigrants in 1995–1999. Table 6 shows results of models interacting our municipal migrant network measure and each of our rainfall change indicators in states experiencing negative precipitation deficits in 2004–2009 relative to 1974–2003 (Column A) and in absolute terms (trend) in the 1974–2009 period (Column B). As in the case of Table 4, we only report coefficients of the interaction and main effects involved in the interaction for the sake of parsimony, even though the models include all other covariates reported in Table 3. Note that these cross-level interaction specifications can be considered conservative since they allow the slope of the municipal-level predictors to vary randomly across states.

-TABLE 6 ABOUT HERE-

The interaction terms are significant for both, the relative change measure and the trend measure and suggest that the impact of a rainfall decline on outmigration is conditional on the presence of social networks. As such, our results confirm that stronger decreases in precipitation lead to an increase in out-migration along established migration corridors (Black, Kniveton, and Schmidt-Verkerk 2011; Hunter, Murray, and Riosmena forthcoming). We illustrate each of these interactions respectively in Figures 2 and 3, which show that the association between rainfall and migration is weak and in fact slightly positive (i.e., larger rainfall declines imply lower migration) in places with low to average emigration rates (represented by the 1st and 50th percentiles of the emigration rate distribution) in both rainfall measures. On the other hand, the association between rainfall and U.S. migration is negative (higher rainfall deficits imply higher migration) in places with very high migration rates (i.e., around the 95th percentile of the municipal migration rate distribution).[10]

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[10] To test the robustness of the observed interactions we employed a Jackknife type procedure, omitting one state from the sample and reestimaing the models using either PQL1 or PQL2 (Ruiter and De Graaf 2006). This procedure helps to detect influential higher order cases. However, only few states experienced rainfall decline (relative measure: n=9; slope measure n=12). This poses issues of degrees of freedom given that already three fixed effects and three

-FIGURES 2 and 3 ABOUT HERE-

4. CONCLUSIONS

Several key conclusions arise from our study, some in line with prior research on migration-rainfall in Mexico. Other findings represent extensions to current knowledge resultant of the particular environmental and geographic foci of our analyses. Our results suggest that under a recent period of (slightly) above-average precipitation in Mexico (2005–2009), there was no clear, consistent association across the nation between rainfall and Mexico-U.S. migration. Instead, the directionality of the rainfall-migration association is weak, not statistically significant, and seems to vary by measure (variability versus long-term trend) and across Mexican states with different rainfall regimes.

Unlike prior research on U.S.-bound migration from rural Mexico, which found an association between lower rainfall and migration at least for particular regions of the country (e.g., drylands, Nawrotzki, Riosmena, and Hunter 2013; the Central-Western region, Hunter, Murray, and Riosmena forthcoming; Munshi 2003) as well as an association between lower crop yields likely related to environmental shocks and migration (Feng and Oppenheimer 2012), we find that recent declines in precipitation relative to the long-run mean may *reduce* emigration in

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random effects operate at level-3. Given this problems we chose to exclude the random slope term in this analytical step, which frees up two degrees of freedom. The “Migration rate in 2000 (%) x rainfall decline (slope)” interaction was found to be highly robust. Regardless which state was excluded, the interaction remained significant. However, the same interaction for the relative measure was found to be less stable. Out of the 9 states only 2 (Oaxaca and Puebla) could be omitted from the sample without impacting the significance level. All other 7 states contribute in important ways to the interaction and exclusion results in insignificance.

areas undergoing rainfall deficits. This association mirrors findings from Burkina Faso (Henry, Schoumaker, and Beauchemin 2004) and could suggest that both shorter- and longer-term rainfall declines reduce household capital enabling investment in a long-distance international migration.

Our estimates may be different from those of prior work because, unlike the aforementioned studies and as stated at the outset, we examined a period of higher-than-average rainfall. As such, one might need to interpret those studies as indicative of the association between *severe* drought and migration. However, note that we also studied a period that included one of the worst periods of economic stagnation in the United States. As such, our results could also point out that drought-related U.S.-bound migration (as well as that following other economic motivations) is contingent on economic conditions in potential destinations as well. While our data do not allow us to identify the role of these two processes separately, our results do suggest that the environment-migration relationship can change considerably in the future depending not only on climate scenarios, but also on economic conditions in both Mexico and the United States. As such, scholars and policymakers should remain aware that long-range forecasting of climate-related international migrants from Mexico (e.g., Feng, Krueger, and Oppenheimer 2010) is laden with just as much if not more uncertainty than that associated with forecasting other forms of economic migration (e.g., Mulder 2002).

Related to the situated nature of the association between environmental change and migration, our study confirms that social networks are important mediators of human-environment interactions. Only in places with higher prior emigration rates, thereby with stronger Mexico-U.S. networks, was declining rainfall associated with U.S.-bound migration. Indeed, financial and other costs associated with longer-distance international movement are lower in regions with well-established migrant networks (Hunter, Murray, and Riosmena forthcoming; Lindstrom and Lauster 2001).

Our finding that declining precipitation during the second growing season is indeed associated with higher emigration out of states with relative rainfall deficits is also consistent with prior research from Mexico (Feng, Krueger, and Oppenheimer 2010; Nawrotzki, Riosmena, and Hunter 2013). Perhaps the negative impact of precipitation decline is particularly strong when extends further into the agricultural season – resulting in the necessity of livelihood diversification through emigration. As such, the timing in which rainfall deficits are distributed may be of relevance not only in terms of affecting crop yields in rainfed areas, but also on water availability in places with irrigation systems.

Not surprisingly, migration seems more sensitive to climatic variability than to precipitation trends. These different associations may reflect humans' ability to adapt to slow-onset environmental shifts that occur over many years --- indeed, humans have been adapting to environmental shifts for millennia (McLeman and Hunter 2010). On the other hand, short term fluctuations around a longer-term mean pose more challenge with regard to livelihood adaptation.

On the recent rainfall measure, note that we observe migration during a retrospective window beginning January 1st 2005 and ending with the Census interview in early 2010. As such, our relative rainfall measure relates precipitation during this 6-year period to a 30-year reference period. In this way, it is indeed a measure of climatic variability (the recent 6 years compared to the past 30 years), but a relatively conservative one since the 6-year recent window is unable to capture the timing of any dramatic events within particular year(s).

Although a useful measure of climatic variability, our relative rainfall change measure also represents a potential weakness of our research design. Data reflecting exact migration timing, unavailable in our data, would allow rainfall measures to be more precisely linked to the pre-migration period. As such this study should be replicated with (quasi-)longitudinal data allowing for the use of proportional hazards models and the inclusion of time lags (e.g., Gray and Mueller 2011, Hunter, Murray, and Riosmena forthcoming). In addition, although we employ two measures of climate change, they operate at the state level. This aggregate unit of analysis poses methodological issues since only few level-3 units (state level) were available for the analysis of a decrease in precipitation. Future research should make efforts to downscale the precipitation measure to the municipality level to improve statistical power and enable a more localized investigation of the migration-environment association.

Despite these limitations, our results expand on prior research by suggest that Mexico-U.S. migration flows may be sensitive to climate and environmental change under specific climatic and social conditions, though not always in the fashion anticipated by looking at prior studies. Still, key findings of this work are that more extreme rainfall variability "push" Mexico-U.S. migrants and that social networks matter in facilitating rainfall-related emigration.

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Table 1. Average Annual Rate of Change (Trend) in State-Level Rainfall in 1974-2009 and Percent Change in 2004-2009 Relative to the 1974-2003 Average

State	Average rainfall 1974-2009 (mm/year)	Relative change 2004-2009 vs. 1974-2003 (%)	Rank in relative change	Absolute trend 1974-2009 (mm/year)	Rank in trend
Baja California	218	-15.7	32	-3.6	26
Yucatán	1,056	-12.5	31	-6.3	29
Quintana Roo	1,282	-9.4	30	3.7	11
México (state)	760	-6.8	29	-6.7	31
Oaxaca	1,454	-4.9	28	1.0	14
Sinaloa	721	-4.1	27	-6.4	30
Tabasco	2,318	-2.8	26	-6.9	32
Distrito Federal	775	-1.8	25	1.9	12
Puebla	1,321	-1.6	24	7.5	4
Zacatecas	506	0.4	23	0.6	16
Sonora	423	1.9	22	-2.3	24
Tamaulipas	797	1.9	21	-0.9	22
Chiapas	1,867	2.0	20	7.7	3
Tlaxcala	702	2.1	19	0.0	20
Hidalgo	736	2.4	18	-4.5	27
Michoacán	778	6.4	17	0.1	19
Veracruz	1,506	6.5	16	9.3	2
Jalisco	791	6.9	15	-2.1	23
Baja California Sur	184	7.2	14	0.5	17
Morelos	881	8.0	13	7.3	5
Querétaro	545	8.3	12	0.4	18
Guerrero	1,017	9.4	11	1.0	15
San Luis Potosí	902	10.8	10	-5.3	28
Colima	852	12.5	9	5.2	8
Campeche	1,278	14.1	8	15.3	1
Durango	476	14.5	7	-2.6	25
Guanajuato	640	15.4	6	6.0	7
Nayarit	1,099	17.7	5	7.0	6
Nuevo León	626	20.3	4	1.5	13
Aguascalientes	460	21.0	3	5.0	10
Chihuahua	441	25.8	2	-0.5	21
Coahuila	364	30.1	1	5.1	9
National average	868	5.8		1.2	

Source: Mexican Migration Project "ENVIRONS" supplementary data file, available at http://mmp.opr.princeton.edu/databases/supplementaldata-en.aspx. Last accessed Oct. 28, 2012.

Table 2. Weighted Summary Statistics of Variables Included in the Analysis

	All households		Migrant households		Nonmigrant households	
	Mean	(S.D.)	Mean	(S.D.)	Mean	(S.D.)
Household characteristics:						
Any member(s) moved abroad, 2005-2009 (%)	5.6	(23.0)	100.0	(0.0)	0.0	(0.0)
Age of household head	48.5	(16.8)	46.5	(14.4)	48.7	(17.1)
No. children of household head under age 5	0.3	(0.6)	0.3	(0.6)	0.3	(0.6)
Household members employed (%)	33.6	(26.2)	28.9	(25.4)	33.8	(26.4)
Years of education (household head)	4.9	(4.0)	4.7	(3.5)	4.9	(4.1)
Monthly household income (pesos)	3,665	(10,088)	2,732	(4,594)	3,397	(8,516)
Home is owned by household member (%)	87.1	(33.5)	0.9	(0.3)	0.9	(0.3)
(Normalized) physical capital index[a]	0.14	(0.57)	0.3	(0.5)	0.1	(0.6)
Household has telephone service (%)	16.5	(37.2)	0.3	(0.5)	0.2	(0.4)
Cell phone owned in household (%)	37.6	(48.4)	0.4	(0.5)	0.4	(0.5)
Municipality characteristics:						
Households with 1+ U.S. migrants in 1995-2000 (%)	2.9	(4.3)				
(Normalized) marginalization index, 2005	0.02	(0.98)				
Irrigated farmland, 2010 (%)	19.0	(27.2)				
State-level characteristics:						
Average annual GDP growth rate, 2004-2009 (%)	3.9	(1.9)				
Relative rainfall change 2004-2009 vs. 1974-2003 (%)	5.8	(10.8)				
States experiencing relative decline (n = 9)	-6.6	(5.0)				
States experiencing relative increase (n = 23)	10.7	(8.2)				
Absolute trend in rainfall change in 1974-2009 (mm/year)[b]	1.2	(5.3)				
States with negative trend (n = 12)	-4.0	(2.3)				
States with positive trend (n = 20)	4.3	(4.0)				
N (households)	130,670		7,342		123,328	
N (municipalities)	2,362					
N (states)	32					

[a] The asset index combined variables that measured the possession of consumer goods (6 items: car, computer, washing machine, refrigerator, TV, radio), the availability of services and appliances (5 items: electricity, water supply, sewage system, cooking fuel, hot water), and the quality of the dwelling (6 items: separate bathroom, type of toilet facility, number of rooms, floor material, roof material, wall material).

[b] Trend obtained from state-level fixed effects from robust regressions on the log of annual precipitation between 1974 and 2009. This procedure was motivated by Frich et al. (2002). A positive (negative) slope-trend indicates an annual average increase (decrease) rainfall over the period.

Source: Household and municipal data come from 2010 Mexican Population and Housing Census 1% sample via IPUMS International (Ruggles et al. 2003). Municipal-level migration and marginalization indices come from CONAPO and are based on 2000 and 2010 Census and 2005 Population Enumeration data. Irrigated farmland data and state-level GDP change come from INEGI (2012); state-level rainfall data come from the MMP supplementary data set ENVIRONS.

Table 3. Odds Ratios from Multi-Level Models Predicting Association between International Migration from Rural Mexican Households According to Direction of State-level Rainfall Change

	A. All states		B. States with rainfall decline		C. States with rainfall increase	
	Model I	Model II	Model I	Model II	Model I	Model II
Household-level covariates:						
Age of household head	0.975 ***	0.975 ***	0.974 ***	0.974 ***	0.975 ***	0.975 ***
No. children of household head under age 5	0.742 ***	0.742 ***	0.721 ***	0.752 ***	0.756 ***	0.741 ***
Household members employed (%)	0.996 ***	0.996 ***	0.995 ***	0.998	0.996 ***	0.995 ***
Years of schooling of household head	0.934 ***	0.934 ***	0.923 ***	0.942 ***	0.939 ***	0.931 ***
Monthly household income (pesos)	0.972 ***	0.972 ***	0.979 **	0.960 ***	0.967 ***	0.975 ***
Home is owned by household member	1.400 ***	1.400 ***	1.366 ***	1.565 ***	1.413 ***	1.341 ***
Physical capital index	2.182 ***	2.184 ***	2.086 ***	2.105 ***	2.254 ***	2.210 ***
Household has land telephone service	1.690 ***	1.690 ***	1.681 ***	1.629 ***	1.690 ***	1.713 ***
Cell phone owned in household	1.420 ***	1.421 ***	1.351 ***	1.469 ***	1.443 ***	1.399 ***
Aggregate-level covariates:						
Municipal marginalization index, 2005	1.209 ***	1.209 ***	1.278 ***	1.241 **	1.155 ***	1.193 ***
Municipal U.S. migration rate 1995-2000 (%)	1.071 ***	1.071 ***	1.089 ***	1.086 ***	1.056 ***	1.065 ***
Irrigated farmland, 2010 (%)	0.999	0.999	1.000	1.002	0.999	0.998
State-level GDP growth (%)	0.914	0.926	0.812 *	0.889	0.960	0.969
Relative change in rainfall (10% increments)	1.008		3.441 **		0.760	
Absolute trend in rainfall change (mm/year)		1.022		0.965		0.972
Variance components (mean odds ratios):						
Between states	1.970 ***	1.950 ***	1.491	2.034 *	1.944 **	1.914 **
Between municipalities	2.064 ***	2.065 ***	2.205 ***	1.962 ***	1.964 ***	2.090 ***
N (households)	128,666	128,666	48,836	34,553	79,830	94,113
N (states)	32	32	12	9	20	23

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

See Table 2 for variable descriptions and data sources.

Table 4. Odds ratios on the on the association between international migration from rural Mexico and relative change in rainfall during selected months of the year

	A. Relative rainfall change 2004-2009 vs. 1974-2003 (%)					
	All states		States with rainfall decline		States with rainfall increase	
	1.008	N (states)	O.R.	N (states)	O.R.	N (states)
Growing season 1 (Jun-Aug)	1.062	32	1.112	7	0.821	25
Off season 1 (Sept-Oct)	0.895	32	19.03	5	0.763 *	27
Growing season 2 (Nov-Jan)	0.869 *	32	0.789 *	30	b	2
Off season 2 (Feb-May)	0.962	32	1.053	21	0.771 *	11

	B. Absolute trend in rainfall change 1974-2009 (mm/year)					
	All states		States with rainfall decline		States with rainfall increase	
	1.022	N (states)	O.R.	N (states)	O.R.	N (states)
Growing season 1 (Jun-Aug)	1.032	32	0.859	12	1.057	20
Off season 1 (Sept-Oct)	0.867	32	0.703	26	0.828	6
Growing season 2 (Nov-Jan)	1.110	32	1.199	27	1.034	5
Off season 2 (Feb-May)	1.059	32	0.275	5	0.979	27

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

See Table 2 for variable definition and data sources.

Note: Each coefficient comes from a separate model using the indicated rainfall specification while controlling for all other covariates shown in Table 3.

All models were run using RIGLS and MQL2 with the exception of rainfall increase (slope) for growing season 2 and rainfall decline (relative) for off season 1 which were both fitted using the more robust IGLS and PQL1 estimation procedure.

b N.C. = Not converged; All efforts to lead the model for an increase in rainfall (relative) for growing season 2 to convergence remained unsuccessful due to the low number of state-level units (n=2).

Table 5. Ratio of state's corn yield in the 2006-2007 Fall-Winter relative to 2007 Spring-Summer season, percent of state's 2007 agricultural land area that is irrigated, and percentage of state's annual rainfall by season

State	Ratio Fall-Winter vs. Spring-Summer corn yield (%)	Pct. agricultural land irrigated	Average rainfall 1974-2009 (mm/year)	Pct. annual rainfall during: Growing season 1 (Jun-Aug)	Pct. annual rainfall during: Growing season 2 (Nov-Jan)
Sinaloa	167.4	46.3	721	56.2	10.6
Sonora	75.2	59.4	423	57.7	14.7
Nayarit	20.0	18.4	1,099	64.8	4.9
Baja California Sur	17.8	72.9	184	35.6	18.1
Veracruz	16.9	3.3	1,506	43.8	12.7
Oaxaca	8.9	4.4	1,454	51.4	8.6
Morelos	8.7	27.9	881	59.0	3.3
Tamaulipas	8.4	22.4	797	43.2	8.6
Tabasco	8.3	0.9	2,318	29.1	24.1
Hidalgo	6.4	16.6	736	43.2	9.3
Quintana Roo	6.2	1.2	1,282	34.9	19.0
San Luis Potosí	6.0	9.8	902	45.9	8.2
Guanajuato	5.6	33.2	640	59.6	5.7
Coahuila	5.6	2.1	364	41.0	14.7
Chihuahua	5.3	33.2	441	54.3	6.5
Puebla	3.9	11.8	1,321	45.8	10.1
Guerrero	3.8	5.8	1,017	57.6	3.7
Colima	3.7	27.7	852	57.9	10.6
Michoacán	3.7	21.5	778	61.3	4.8
Querétaro	3.6	28.8	545	55.5	5.5
Chiapas	3.4	33.9	1,867	36.8	11.5
Yucatán	3.3	7.9	1,056	45.0	11.7
Nuevo León	2.6	21.6	626	35.3	9.4
Durango	2.3	19.9	476	57.3	11.2
Campeche	2.3	1.9	1,278	48.3	10.8
México (state)	2.0	15.2	760	57.8	4.7
Distrito Federal	1.8	6.1	775	59.1	3.6
Jalisco	1.7	11.3	791	64.5	5.1
Zacatecas	1.6	11.4	506	60.4	8.5
Tlaxcala	1.0	5.2	702	54.0	4.5
Aguascalientes	0.9	29.6	460	60.9	7.3
Baja California	0.0	69.0	218	3.4	43.8

Sources: Rainfall data come from Mexican Migration Project "ENVIRONS" supplementary data file, available at http://mmp.opr.princeton.edu/databases/supplementaldata-en.aspx. Last accessed Oct. 28, 2012. Corn production and irrigation figures come from 2007 Agricultural Census, available at

Table 6. Odds Ratios from Main Effects and Interaction Between Municipal-Level U.S. Migration Rate and (A) Relative Change and (B) Trend in Rainfall in States Experiencing Rainfall Decline (in Each Measure Respectively)

	A. Relative rainfall change, 2004-2009 vs. 1974-2003 (%)	B. Absolute trend in rainfall change, 1974-2009 (mm/year)
Municipal U.S. migration rate 1995-2000 (%)	1.179 ***	1.138 ***
Relative rainfall change (10% increments)	1.767	
Absolute trend in rainfall (mm/year)^{a}		0.974
x Migration rate in 1995-2000 (%)	0.807 *	0.971 **
N (households)	48,836	34,553
N (states)	12	9

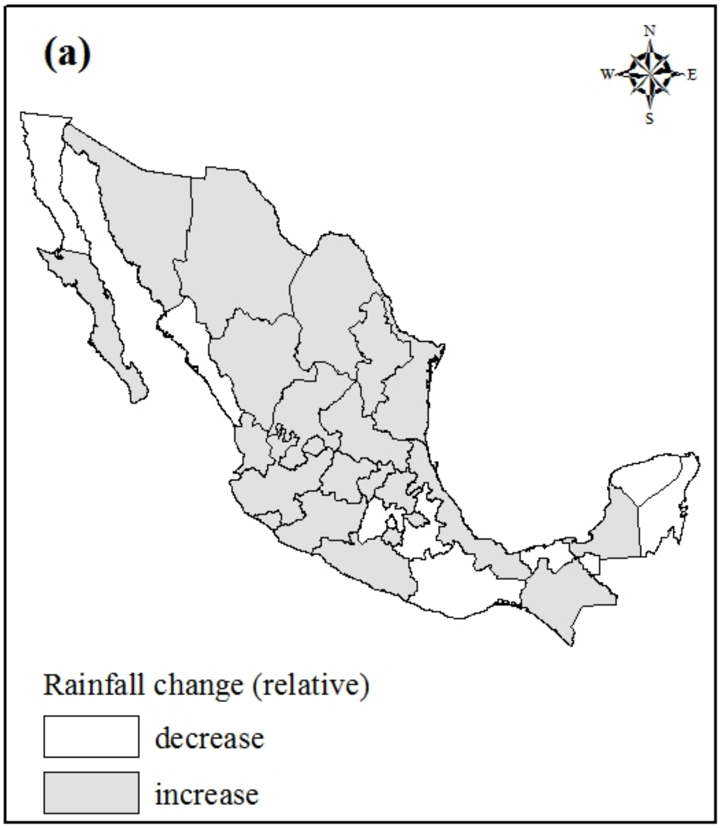
* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

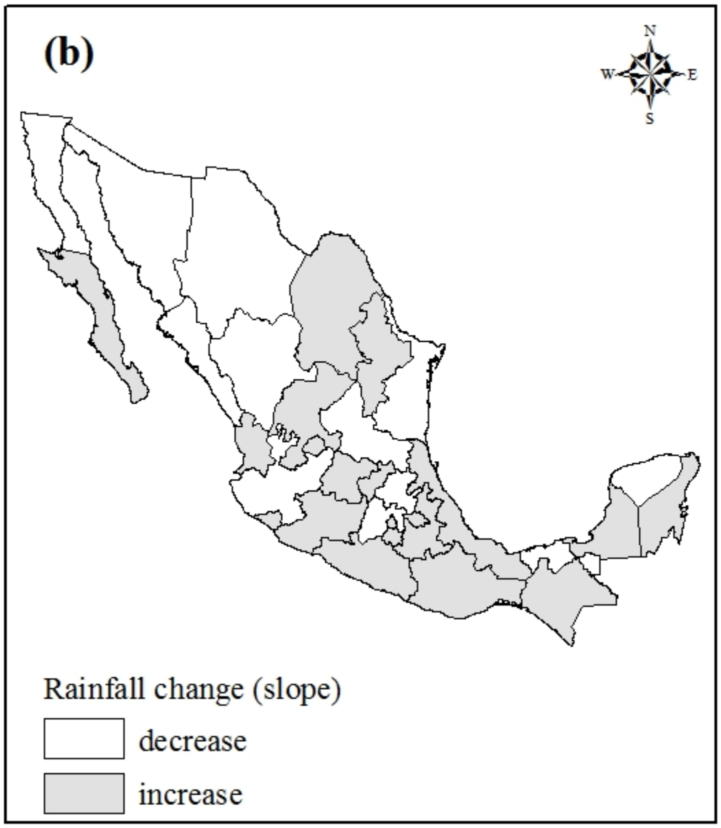
See Table 2 for variable definition and data sources

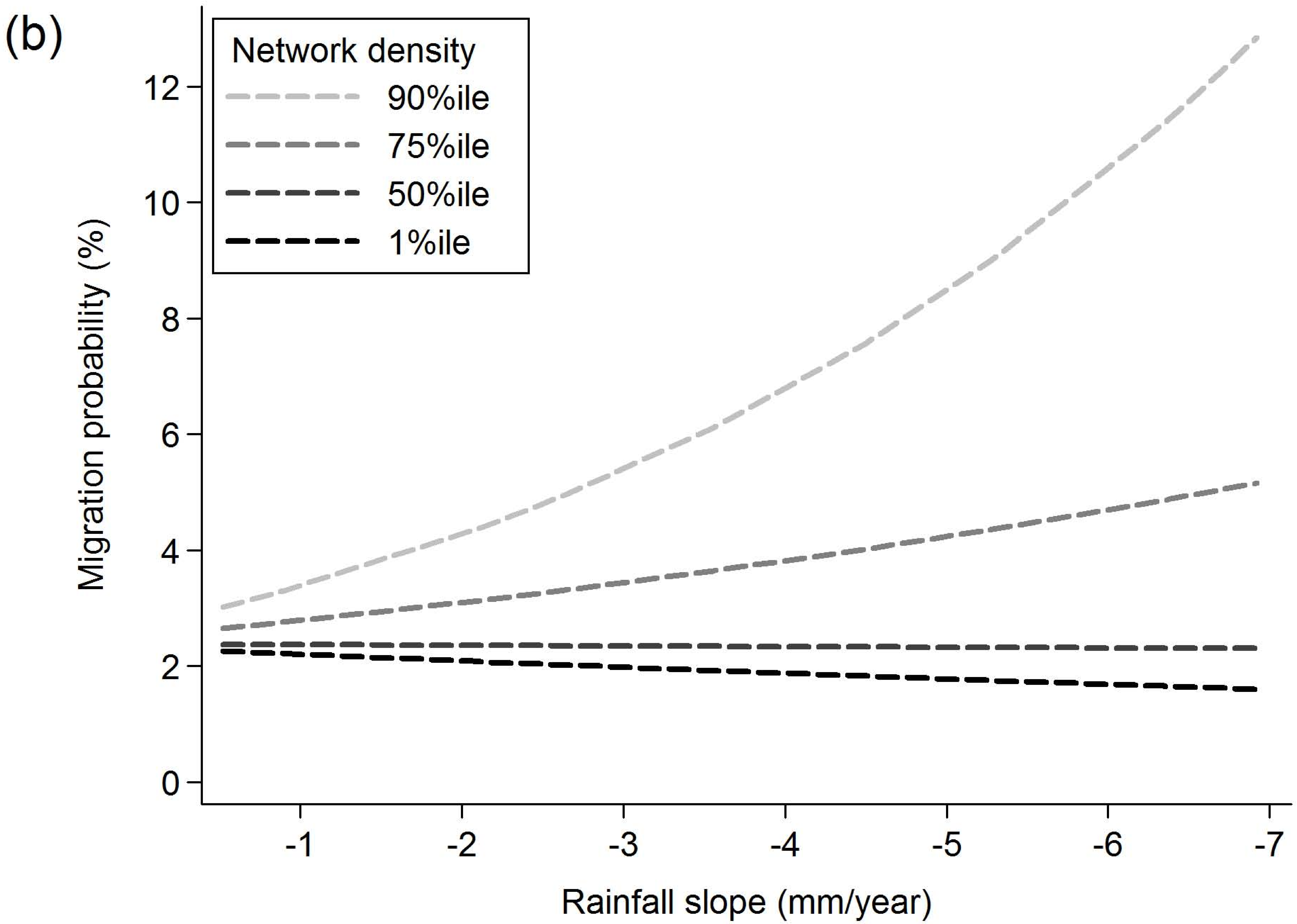
To facilitate the interpretation of the main effects the variables involved in the interactions were centered at their grand mean.

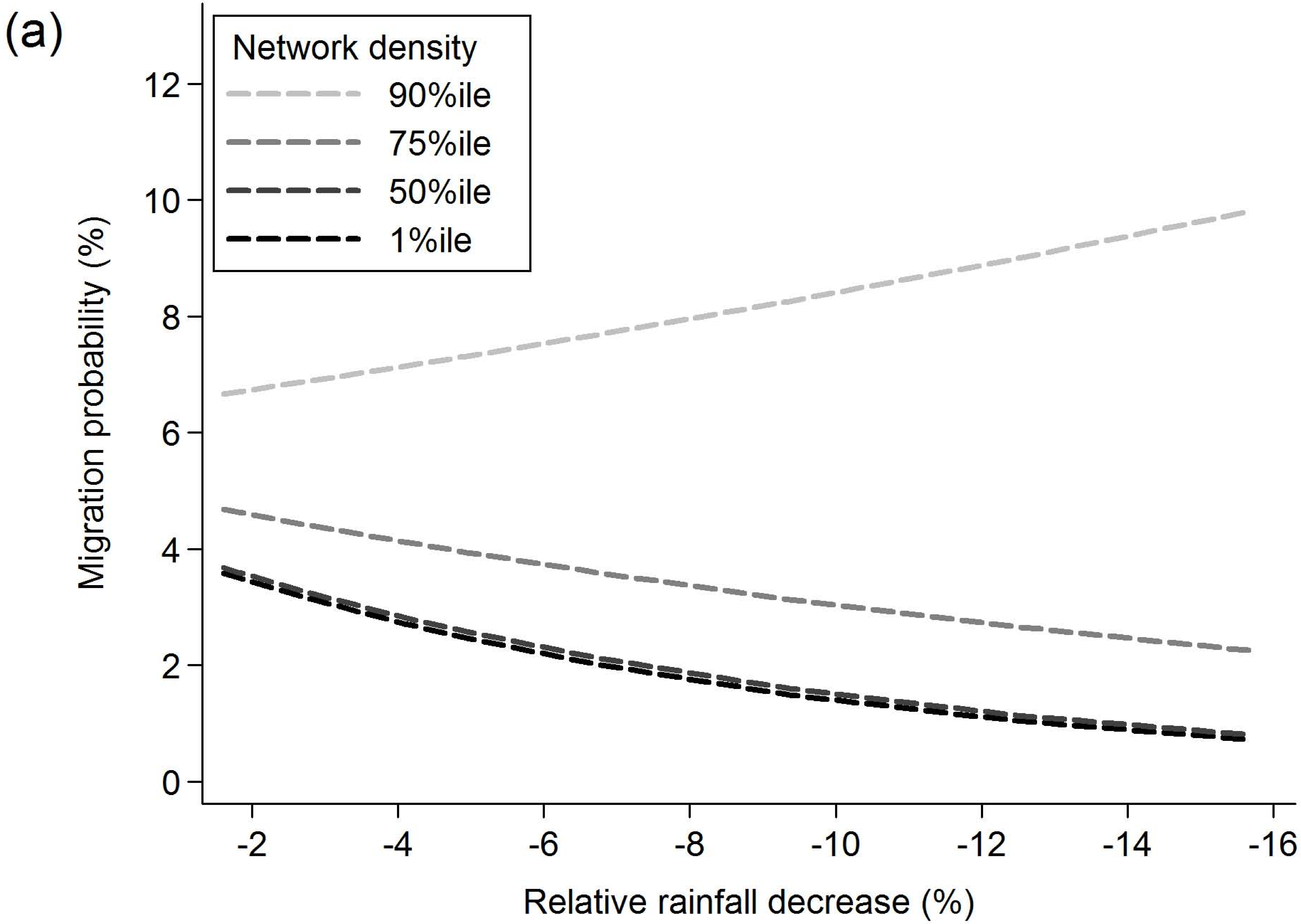
Models estimated using PQL1 to guard against convergence issues.

Models additionally control for all variables listed in Table 3.


(a)
N
W
E
S
Rainfall change (relative)
decrease
increase


(b)
N
W
E
S
Rainfall change (slope)
decrease
increase


(b)
Network density
90%ile
75%ile
50%ile
1%ile
Migration probability (%)
0
2
4
6
8
10
12
-1
-2
-3
-4
-5
-6
-7
Rainfall slope (mm/year)


(a)
Network density
90%ile
75%ile
50%ile
1%ile
Migration probability (%)
0
2
4
6
8
10
12
-2
-4
-6
-8
-10
-12
-14
-16
Relative rainfall decrease (%)