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Modeling Climate-Induced Agricultural Scarcity and Migration in Central America: Evidence from New Machine-Coded Environmental Event Data
Final Report for the Kleinman Center

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Introduction

From Nigeria to Pakistan and Central America to Small Islands States, climate change and corresponding resource scarcity have induced deep social challenge. In many places, climate-induced threats to agriculture have fostered migration and conflict as populations have shifted in response to changing environmental conditions. Our project focuses on how citizens and governments in Central America have adapted to climate change, and the extent to which those adaptations succeed in promoting peace and stability. We define adaptation broadly to include any efforts by individuals, social groups, or governments to address or mitigate the effects of climate change. This includes actions ranging from household migration to inter-group competition over resources to local or national policy changes. Many of these adaptations are modest – i.e. families moving to a neighboring village or an NGO organizing to promote access to community water supply– but precede the large-scale social disruptions that have preoccupied extant work. To date, subnational, high frequency data on these social and political adaptations has been missing. Indeed, perhaps the single largest challenge in understanding climate impacts is the lack of high-resolution, high-frequency data on how people and governments are responding to climate change.

To bridge this knowledge gap, we deploy a novel, AI-driven approach to generate original data on climate adaptation at the individual, social group, and governmental levels. To do so, we developed a series of fine-tuned Large Language Models (LLMs) and applied them to a unique corpus of approximately 25 million articles published by local media in Central American countries from 2012-2024. This allows us to create an unprecedented *monthly, sub-national* dataset on 13 distinct types of environmental adaptations never before measured at such scale. We also use these methods to generate new media-derived data on environmental disasters that improves upon the standard data source in research on climate change. We refer to this as the MLEED (Machine Learning for Environmental Event Detection) dataset.

We combined the MLEED data with climate, agricultural, displacement, and migration data. Together we analyze these data to provide unique insights into the relationship between a) climate and agricultural productivity and b) climate and migration. Our key findings are:

- Our AI-driven approach to generating unique climate adaptation data works. Courtesy of Kleinman funding, we have proof of concept that is fueling additional proposals.
- Our original MLEED data on sudden-onset climate disasters has important advantages over the standard EM-DAT dataset that many researchers in climate research use.
- Climate variability is impacting agriculture across Central America most directly via the cyclical El Niño-La Niña pattern. El Niño periods reduce summer precipitation, intensify mid-summer droughts and increase temperatures, particularly in and around the region's 'Dry Corridor' where it is associated with increasing hunger and displacement. La Niña periods are associated with more precipitation, floods and storms.
- El Niño is associated with reduced agricultural productivity, particularly in the Pacific Coast portions of the region's Dry Corridor. La Niña is associated with increased agricultural productivity.
- Slow-onset disasters, such as drought in the Dry Corridor, is associated with *lower* levels of international migration in subsequent months. Sudden-onset disasters, such as floods, are associated with *higher* international migration in subsequent months.
- Higher prices for key agricultural commodities, associated with Niño-dry periods among others, are associated with *higher* international migration in subsequent months. We interpret this as an income effect whereby higher agricultural incomes are needed to fund expensive migratory trips.
- Climate disasters are sometimes associated with subsequent violence reflecting resource competition. Environmentally-inspired violence is associated with increased international migration in subsequent months.

The MLEED Data

MLEED focuses on providing fine-grained measures of human adaptation to climate change. We conceptualize adaptation as any effort by **individuals, social groups, or governments** to address or mitigate the negative effects of climate change on the wellbeing of their household, constituents, or citizens. These responses can be unambiguously positive, such as the prioritization of vulnerable populations in social safety nets or local efforts to encourage use of more resilient seeds. However, adaptations can also exacerbate societal tensions, such as large-scale migration or escalating conflict over access to scarce resources (Kala et al., 2023). By providing new, more detailed data on adaptations across these three distinct domains (individuals, groups, and governments), we are now able to test hypotheses about the impact and sequencing of climatic changes, disaster events, and different adaptation measures.

Table 1 lists the 13 events that we generate original monthly data on, according to whether they are adaptation measures taken by individuals and households, broader social groups, or governments. To complement our data on these adaptation behaviors, we also measure the salience of three types of environmental disasters—sudden-onset, slow-onset, and man-made disasters. As we show below, this data provides new evidence on the ways in which climate and environmental stressors shape a broad range of individual, group, and governmental adaptation behaviors.

Disasters:

- **Sudden-onset disasters**, such as floods, extreme droughts, heatwaves, cyclones, or crop failures.
- **Slow-onset disasters**, such as sea level rise, long-term droughts
- **Human-induced disaster**, such as oil spills, industrial accidents, or large-scale pollution, focusing on the event's impacts rather than legality or intent

Individual Adaptation event types:

- **Environmental violence**, such as a lethal/non-lethal violent conflict between herders and villagers over firewood or contested land
- **Environmental Displacement**, such as the movement of groups of people away from communities that are affected by climate events
- **Environmental Crime**, Explicit mention of illegal acts such as poaching, illegal fishing, illegal mining, or defiance of environmental regulations by private actors

Social Adaptation event types:

- **Environmental protests**, such as those surrounding extremely bad pollution in cities or the activities of mining companies in local communities
- **Environmental civic activism**, such as the organizing and lobbying done by activists and NGOs around environmental issues or relief efforts by local organizations
- **Environmental corporate initiatives**, such as corporate policy, projects, or decisions that directly affect the environment

Governmental Adaptation event types:

- **Environmental legal change**, such as laws proposed or enacted that directly address environmental stressors or concerns
- **Environmental legal action**, such as legal cases brought against firms that violate regulations
- **Environmental corruption**, such as legal cases brought against corrupt government officials that fail to enforce regulations
- **Environmental arrests**, such as those made of government or corporate officials accused of environmental crimes
- **Environmental security**, such as the use of government security forces to enforce regulations that protect the environment and/or natural resources.
- **Environmental government initiatives,** such as government policy, projects, decisions, or announcements that directly affect the environment
- **Environmental cooperation** such as public/private partnerships, agreements between political actors, joint efforts across local agencies and governments.

To generate the data, we scrape online news stories published in 6 languages by 16 international, 4 regional, and dozens of domestic online newspapers as well as a curated list of 19 country-specific environmental sources. To date, we have scraped *more than 20 million* news articles from 2012 to 2024 for the region. 81% of these articles are from domestic sources, 4% from regional, and 15% from international sources. For each domestic news source, we conducted a detailed desk review of ownership and partisan affiliation. Our corpus, which is constructed through direct scraping and custom parsing, has distinct advantages over other public and proprietary collections of online news, including much more complete coverage of news published by developing country sources, much more accurate metadata, and much greater linguistic diversity (see Wibbels et al. 2024 for specific examples).

To classify individual articles into monthly data, we fine-tuned a ModernBERT large language model using 1868 rows of human-coded data across the event categories described above. We used Optuna-based hyperparameter tuning to find an optimal learning rate, weight decay, batch size, and number of training epochs. This ensured we were using a refined training configuration rather than a default setup or hard grid search.[1] The resulting model performs about as well as human coders--the F1-score (a common metric computed on out-of-sample data) is .77—and the errors occur in the overlap among analytically related event types. For instance, the model sometimes misclassifies 'human-induced disasters' as 'sudden-onset disasters', 'environmental activism' articles as being 'environmental cooperation', or 'environmental corruption' (conducted by government officials) and 'environmental crime' (committed by firms and citizens); these are common sources of disagreement among human coders.

We further validate the data by running a machine learning algorithm to detect surges in media reporting on our environmental event types. This allows us to identify the temporal peaks in coverage that likely correspond to impactful real-world environmental events. We then apply a GPT-based validation pipeline to these surges: for a representative sample of these surges across time and countries, we compile a sample of relevant articles and prompt GPT-4o to generate concise summaries using prompts tailored to the specific environmental category. We use these summaries to assess whether the detected surges reflect real-world events. For example, we manually validated 20 machine-detected surges in the 'environmental displacement' category to assess their accuracy,[2] and found that all summaries were factually grounded in the original articles and real-world events. Only one summary clearly misclassified the nature of the environmental event type. In another case, GPT failed to include a major displacement event affecting over 8,000 people. We have found similarly strong results with other validation efforts.

To add subnational granularity to the data, we developed a new geoparsing protocol using LLMs to identify all geographic locations mentioned in each article. These locations are then mapped to their respective admin0 (Country), admin1 (region/state), and admin2 (district/city) levels. To develop this protocol, we hand-coded the locations and administrative units for a large sample of articles reporting on MLEED events in our corpus. We then tested the accuracy of several LLMs in correctly identifying locations and mapping them to administrative units. Our results indicate accuracy well above 90%, which greatly exceeds standard geoparsing tools used in most geoparsing applications. Applying this highly accurate geoparsing protocol to the full sample of MLEED events will allow us to further investigate the relationship between climate, agriculture, and adaptation at an unprecedented geographic level. Below, we show results from several applications of this subnational data.

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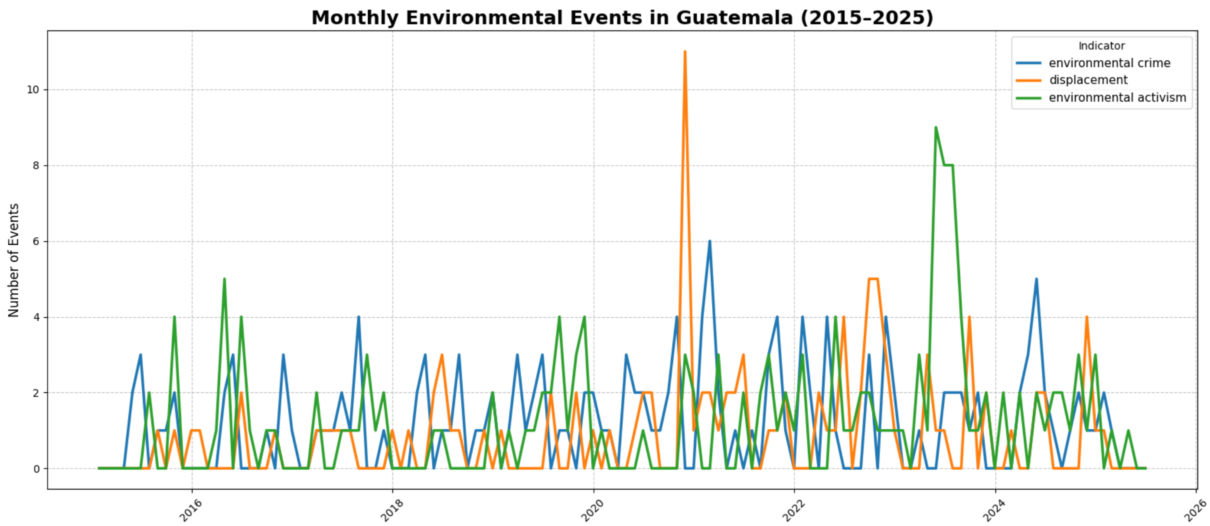
[1] Hyperparameter details available on request.

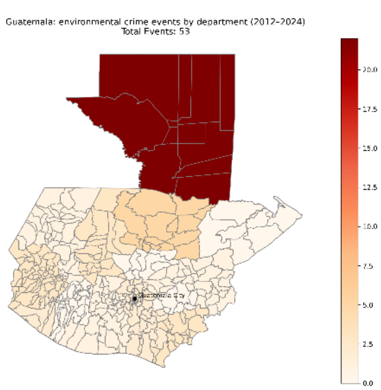
[2] This is a particularly challenging event type because many stories do not clearly distinguish whether the causes of displacement are environmental or something else.

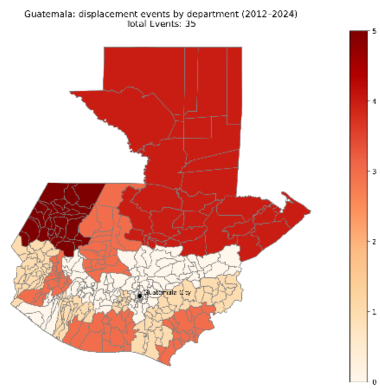
The approach above provides an enormous amount of original data for each country. Here we use a few examples to show how it varies over time. To simplify the presentation, we show three monthly time-series for Guatemala from 2012-2024 environmental crimes, environmental displacement, and environmental activism.

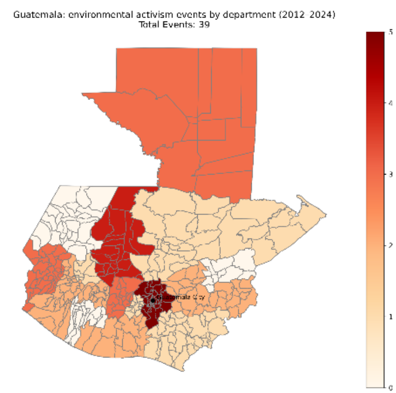


The time series above reveal interesting temporal patterns. Environmental crimes rise gradually over the period, while displacement shows distinct peaks corresponding to different disasters that displace people. For example, the peak in November 2020 corresponds to the devastating impacts of Tropical Depressions Eta and Jota. Environmental activism is also episodic, with a clear surge in May 2023, as national campaigns intensified around the death of six children due to acute malnutrition in Alta Verapaz. This time series variation opens up new possibilities for research *when* broader climate dynamics elicit social and political responses as reflected in population movements, citizen activism, government legislation, and the like.

While the temporal variation above is unique and interesting, our approach also allows for the capacity to distinguish *where* exactly within countries different kinds of environmental events take place. Below we map environmental crimes, environmental displacement, and environmental activism at the regional level in Guatemala in order to provide a sense of this spatial variation. The map of environmental crimes reflects the concentration of "ecocide" by palm oil plantations, narco ranching, and illegal logging in the Peten Department, an area with substantial gang presence and a history of very weak governance by the Guatemalan State. The graph of displacement, on the other hand, reflects a more diverse geographic distribution. In addition to environmental displacement in Peten, there are concentrations in the northern, indigenous and western portions of the country's dry corridor that have been experiencing profound drought and subsistence crises as a result of climate change. Finally, the third map on the far right shows the geography of climate activism. Perhaps unsurprisingly, activism is concentrated in a central corridor that encompasses the capital city and the tourist centers of Antigua and Lake Atitlan. All told, these three maps provide a snapshot of the rich opportunities to understand the distinct geographies of climate adaptation that transcend direct measures of rainfall, drought, etc.







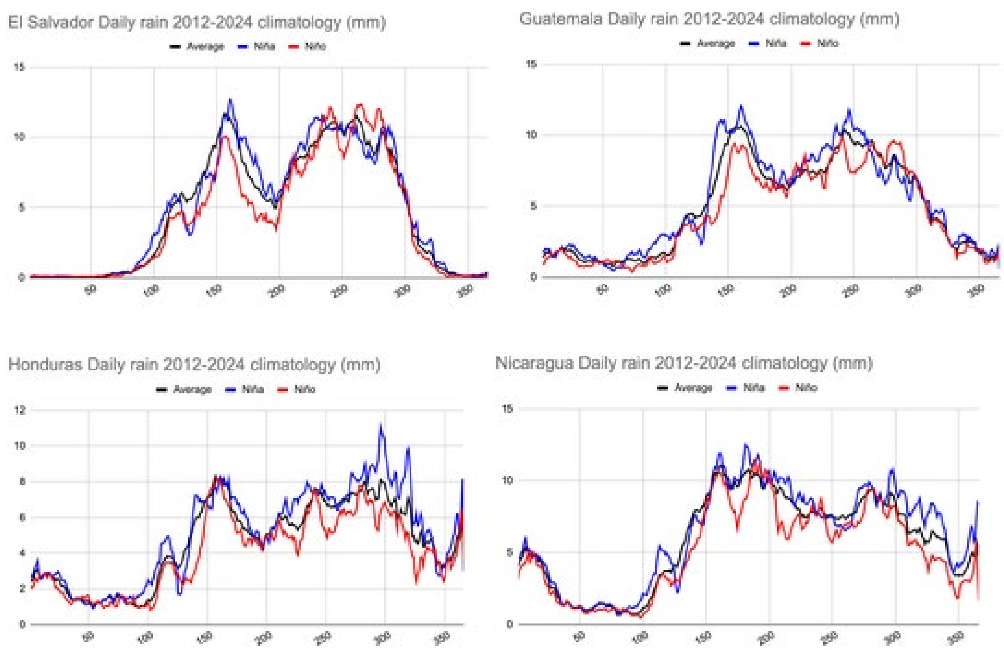
Climate and Natural Disasters

The Dry Corridor in western Central America, spanning parts of Honduras, El Salvador, Guatemala, and Nicaragua, is highly vulnerable to food insecurity, worsened by frequent droughts, extreme temperatures, irregular rainfall, and extreme weather events, particularly influenced by El Niño –Southern Oscillation (ENSO) natural variability and climate change. The region is warmer than adjacent areas, and rainfall variability is greatest within the region's 'Dry Corridor' compared to the surrounding region. It experiences very distinct wet and dry seasons. The wet season features two rainfall peaks—one in spring and another in late summer or early fall—separated by a mid-summer dry spell known as the canícula. The rainy months are, on average, the hottest.

The primary driver of climate variability in the region is ENSO, which is a recurring and naturally occurring climate pattern in the tropical Pacific Ocean that involves shifts in ocean temperature and atmospheric pressure. It has two main phases: El Niño, the warm phase, characterized by unusually warm ocean temperatures in the central and eastern equatorial Pacific; and La Niña, the cool phase, characterized by unusually cool ocean temperatures in the same region.

In the Dry Corridor, positive ENSO periods (Niño) typically lead to increased temperatures and reduced precipitation, especially during the summer. This intensifies the mid-summer drought (canícula), which can significantly affect crop development. These impacts are observable across temperature, precipitation, and natural disaster datasets. Drought responses are reflected in indices like the Standardized Precipitation Evapotranspiration Index (SPEI), which shows a negative correlation with ENSO: higher ENSO values (Niño periods) correlate with lower SPEI values (indicating more drought), while lower ENSO values (Niña periods) correlate with higher SPEI values (indicating excess water).

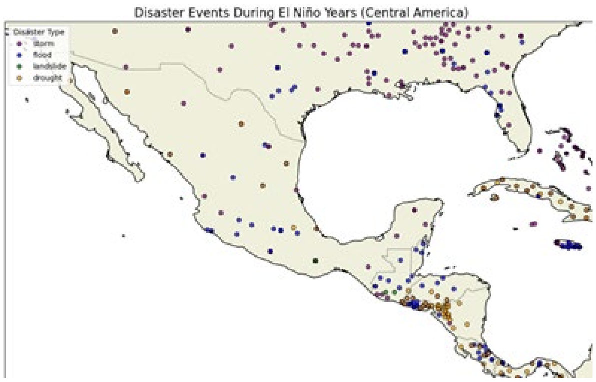
Conversely, during La Niña periods (negative ENSO values), temperatures are lower than average, summer rainfall is higher than average, and natural disaster databases show an increase in floods and storms. The following figure summarizes the time-series variation in rainfall associated with El Niño and La Niña across four Central American countries.[3]



These climate patterns are also intensifying natural disasters across both El Niño and La Niña phases. The two maps below show the spatial distribution of different kinds of disasters across the two cycles using the standard EM-DAT disaster dataset.[4] The left-hand map shows high incidence of drought during El Nino years, and the right-hand map shows an increase in flood and landslides during La Nina years.

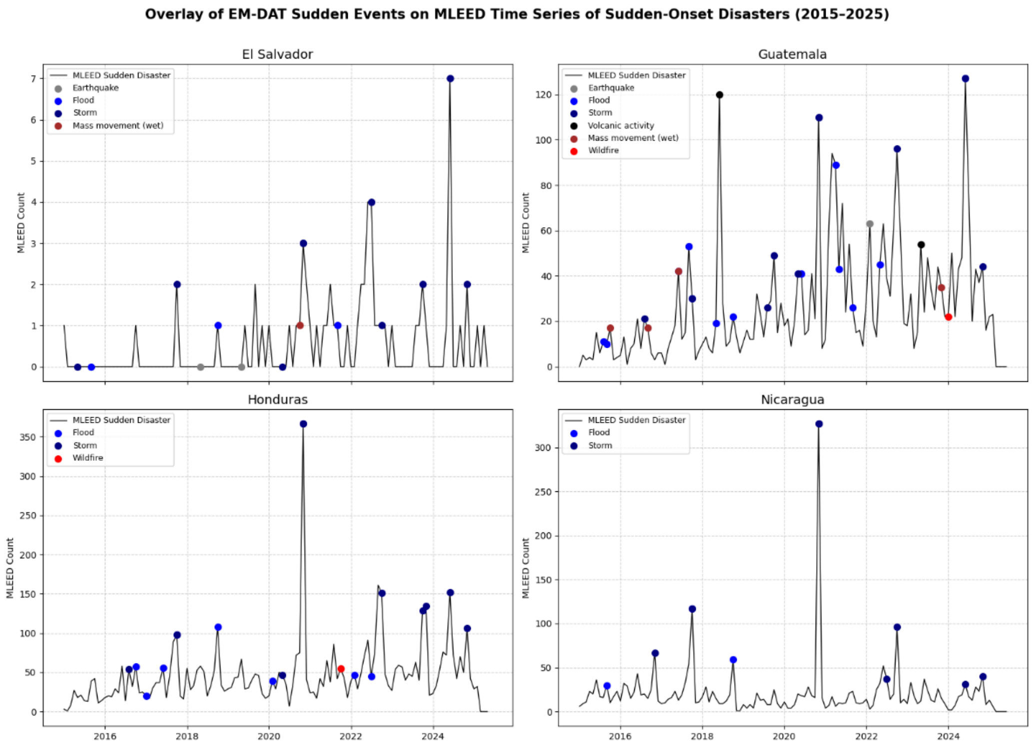
[3] El Nino/La Nina are measured here using ENSO (El Niño-Southern Oscillation) Data. The monthly ONI (Oceanic Niño Index) data is used, sourced from the NOAA Climate Prediction Center: https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt

[4] The Emergency Events Database (EM-DAT) reports on a broad range of natural and technological disasters and is maintained by the Centre for Research on the Epidemiology of Disasters (CRED): https://www.emdat.be/



Despite its ubiquitous use in climate research, there are important limitations in the EM-DAT data. First, it is highly reliant on the insurance industry, which has a particular interest in measuring insurable losses. Since insurance markets are less developed in the Global South, its coverage is weaker there. Second, data coverage depends partly on national disaster loss monitoring systems, which are weaker in the Global South, thus inducing a correlation between the measurement of disasters and national statistical capacity. Third, for many disasters EM-DAT provides little geographic information on where exactly they happened in countries and/or on the scale of disasters—it simply reports that a disaster happened in a particular country in a particular month. Fourth and finally, the EM-DAT project's biggest funder has been USAID; in USAID's absence, it is unclear if EM-DAT will continue to be collected.

Our original MLEED offers a potentially superior alternative. The figure below compares our monthly counts of reported sudden-onset environmental disasters from our MLEED data with events from the EM-DAT database; the EM-DAT data is shown as overlay points. The clear alignment between peaks in MLEED reporting and the EM-DAT events provides a strong external validation of the MLEED environmental sudden-onset disaster events. Across the four countries shown, EM-DAT events consistently coincide with visible surges in MLEED counts, indicating that it reliably captures the occurrence and timing of disasters. Note, however, that the MLEED has the advantage of reporting both more disasters (i.e. spikes that are *not* associated with EM-DAT dots), and the volume of MLEED counts provides some indication of the scope of disasters, which is mostly absent in EM-DAT data. We suspect that our original measures of disasters alone represent a significant contribution to research in the climate and agriculture spaces.

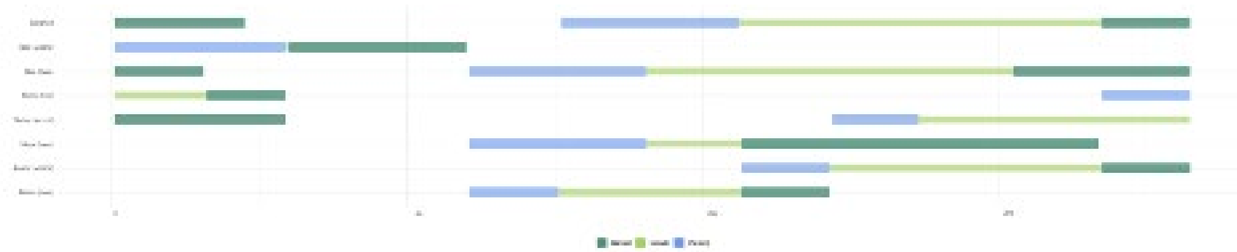


Climate and Agriculture

Agriculture in Central America faces many challenges exacerbated by climate change. First, the region's population (especially in the Dry Corridor) relies heavily on agriculture, particularly rainfed farming, which makes it extremely vulnerable to climate variability. Second, the region has generally poor soil, limiting agricultural productivity and further reducing food availability. Third, smallholder farmers have limited access to drought-resistant crops, modern irrigation systems, and climate-safe agricultural techniques. Often this is exacerbated by insecure land rights, which discourages long-term investments in climate-resilient practices. Fourth and finally, because of low agricultural productivity and limited resources, many families struggle to grow enough food for subsistence. Across the region there is a growing problem of acute hunger.

In Central America, agriculture is intrinsically linked to seasonal rainfall patterns, with crop cycles highly dependent on the timing and distribution of precipitation. The main planting season planting occurs between May and June (during the first rainy season), and harvesting starts in August. Critically, these main season crops are particularly sensitive to variations in the mid-summer drought (known as the canícula), whose timing and intensity can significantly disrupt growth and reduce yields.

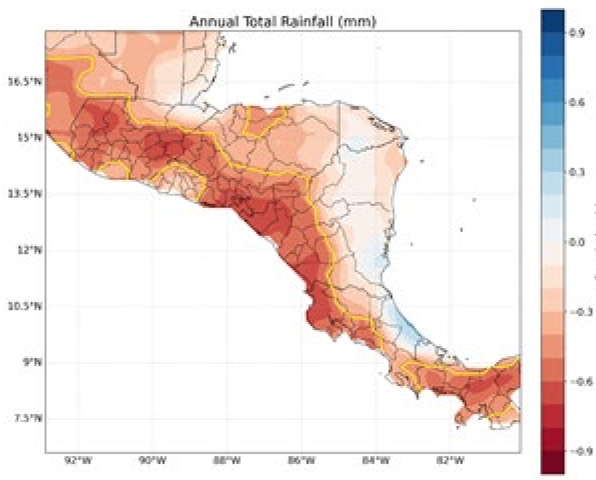
Staple crops include maize, rice, and beans, while key export crops are bananas, coffee, and palm oil. Maize and beans need consistent and well-distributed rainfall throughout its growing season, especially critical during the flowering. Extended dry periods or intense heat during this phase can significantly stress plants, leading to reduced growth and diminished yields, especially for maize and beans which are less tolerant of dry spells than some rice varieties. Excessive moisture during these periods can also diminish productivity. This figure provides a crop calendar showing when these climate sensitivities impact the agricultural cycle.

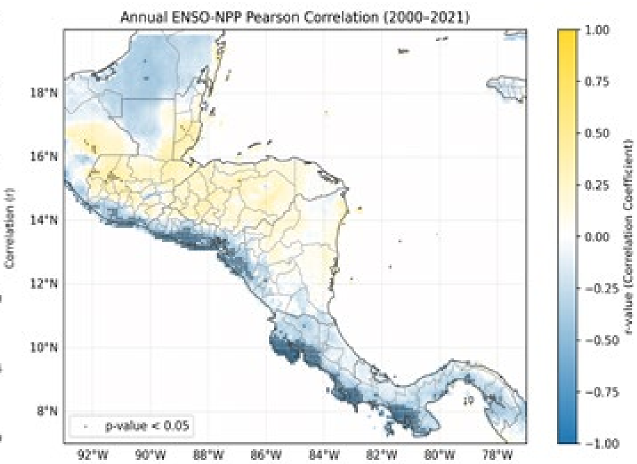


Source: [*Center for Sustainability and the Global Environment*](https://asheshwor.shinyapps.io/cropcal/) *- Wisconsin*
https://asheshwor.shinyapps.io/cropcal/

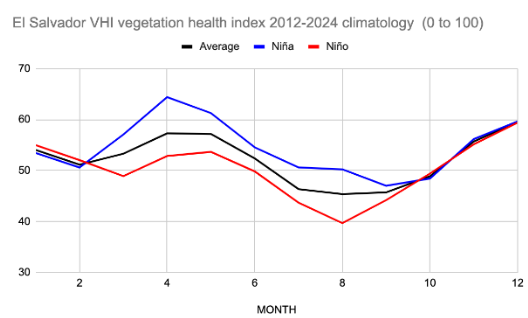
While natural climate variability remains the dominant driver of short-term changes, climate change is already having a significant impact on the region's agriculture. It has led to a marked increase in temperature, long-term drying as measured by the SPEI (drought index), and more frequent extreme rainfall events. In addition, climate change is altering the seasonal cycle especially within the Dry Corridor—deepening the mid-summer drought (similar to El Niño episodes) and delaying the onset and end of the second rainfall peak.

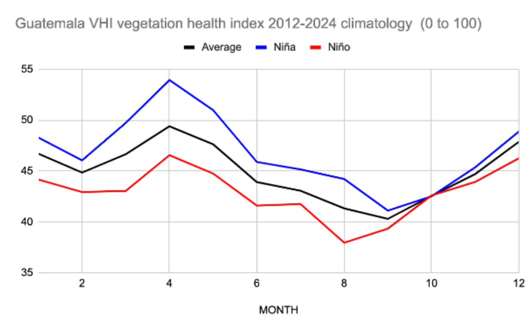
The two maps below show the spatial incidence of these climatic dynamics across the region. The map on the left shows the correlation between El Niño periods and rainfall, and the one on the right shows the correlation between El Niño and plant productivity. In the left-side map darker shades of orange indicate a stronger negative relationship between El Niño and rainfall. The darkest orange areas are those encompassing the region's Dry Corridor, where drought conditions have been worsening. The right-hand map shows the correlation between the ENSO/El Niño Index and Net Primary Productivity (NPP), a common measure of plant productivity. Unsurprisingly, Niño periods are associated with poorer plant productivity. These shifts, of course, have important implications for agricultural timing and harvesting.

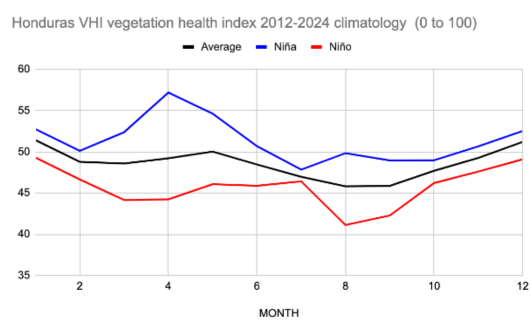


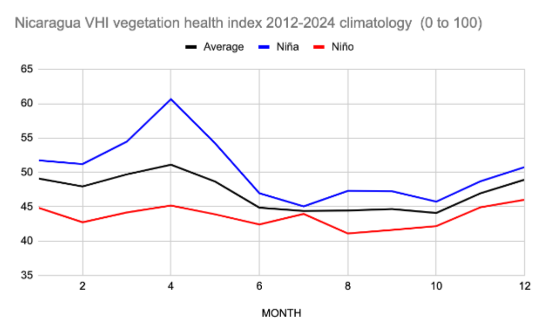


The geographic distribution of El Nino's impact on plant productivity is also clear in the following figures for El Salvador, Guatemala, Honduras, and Nicaragua. They compare another common indicator of vegetation health across calendar months for El Nino and La Nina periods. La Nina periods are characterized by considerably better plant productivity across nearly all of the agricultural cycle.

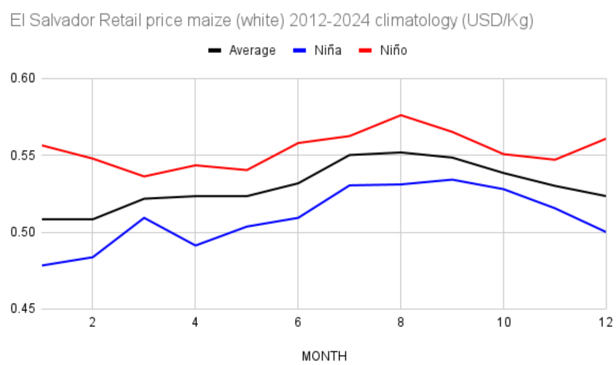








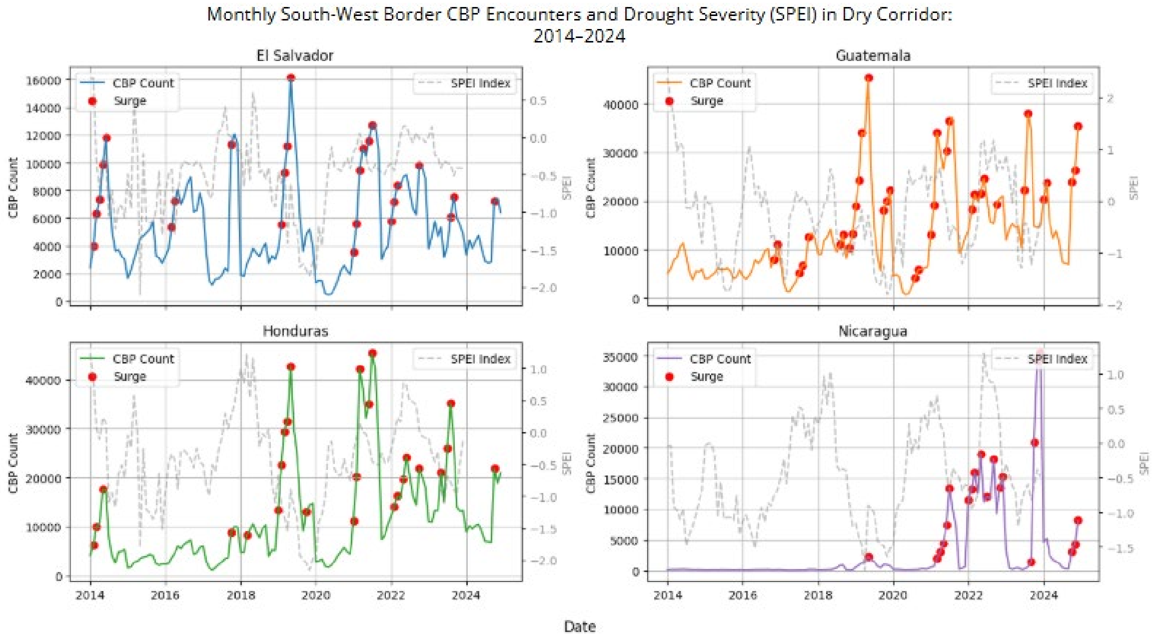
Unsurprisingly, this reduced rainfall and plant productivity during El Niño periods has important implications for the corresponding prices of key agricultural commodities and the livelihoods of farmers in those areas. The figure below provides an example of a pattern we see again and again across commodities and countries in the region, namely that El Niño periods (i.e. when drought is prevalent and plant productivity is low) are associated with higher agricultural prices across the year. Thus, just as productivity falls in response to climate, prices go up. This raises important questions about how farming households respond to these dynamics.



Climate, Displacement and Migration

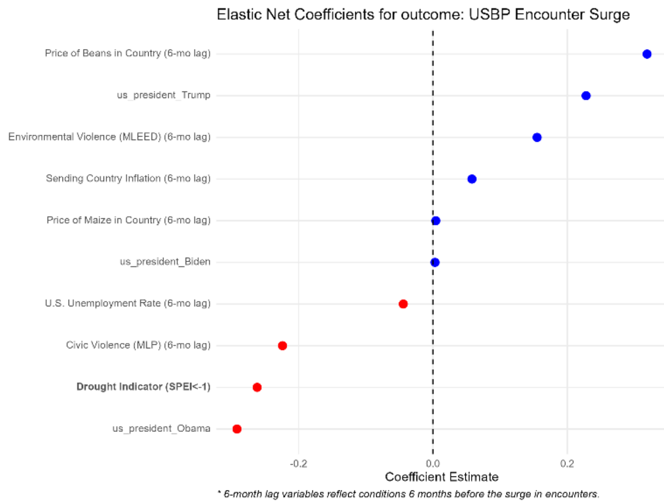
As climate change affects agriculture and livelihoods, migration is often seen as a potential adaptation strategy. Climate-related disruptions, particularly droughts, undermine food security and income generation, especially for rural households dependent on subsistence farming. Historically, many people from the Dry Corridor migrate north to the U.S. in search of better work opportunities and stability, as local conditions for farming become increasingly untenable.

In this section, we investigate the relationship between climate change, agricultural prices, and migration. Here, we have merged original data from the United States Department of Homeland Security (DHS) on the number of monthly encounters between border agents and migrants (disaggregated by country of origin) at the southern border of the United States. The Figure below illustrates the relationship between drought conditions (SPEI) and border encounters. Red dots indicate months of particularly frequent encounters, and it is these 'surges' that we model below. The plot suggests that migration surges often follow periods of drought, but the relationship varies by country. In El Salvador and Honduras, peaks in CBP encounters frequently coincide with negative SPEI values, which indicate drought conditions. For Guatemala, surges in encounters often coincide with drought conditions, but more recent years show persistent migration that appear independent of climate conditions. In Nicaragua, where migration spiked sharply after 2020, the connection to drought is less clear—pointing to the importance of additional political or economic drivers. Overall, the visual evidence suggests the relationship between drought and migration is complicated and varies across both time and space.



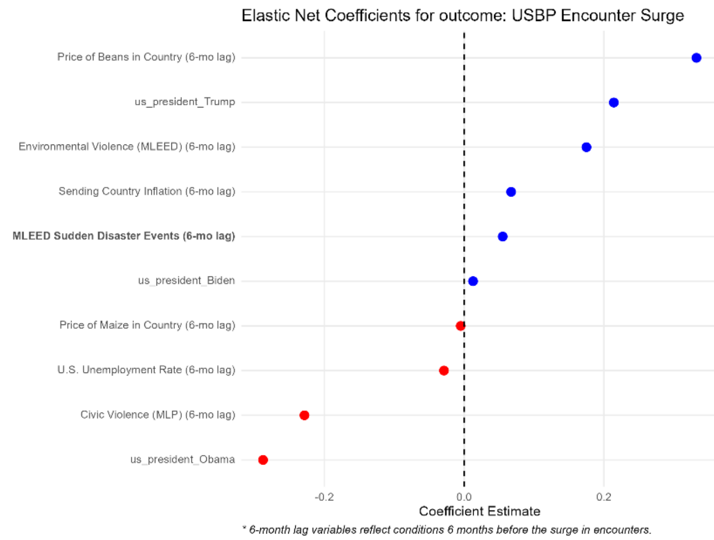
To investigate these patterns more systematically, we use Elastic Net regression models to identify climate, agricultural, and MLEED variables that are highly predictive of subsequent border encounters. Elastic net regression is a statistical tool that helps researchers make more accurate predictions when they have many potential factors (or variables) to consider. Unlike traditional methods that include all variables, elastic net is designed to select only the most important ones—those that truly help explain or predict an outcome.

The plots below show the estimated non-zero coefficients from Elastic Net models we use to explain monthly variation in U.S Border Patrol encounter surges, our main outcome of interest. These models focus on two main environmental predictors : A binary drought variable (SPEI< -1 in the preceeding six months) as a measure of slow-onset climate disasters, and the sudden-onset disaster event counts from the MLEED dataset as an indicator of sudden-onset disasters such as floods. As measures of distinctly agricultural dynamics, we use monthly prices of key commodities (beans and corn). Turning first to the results on drought, we find that the six-month lag structure provides the best results for capturing delayed migration responses to these slow and sudden onset climate shocks; that means that climate and agricultural dynamics in Central American countries take about six months to work themselves to the U.S. border. In this model, the binary drought indicator is associated with a much lower likelihood of subsequent migration surges. This suggests that prolonged drought may actually limit people's ability to move, at least in the short- and medium-term.



The other results in the figure above are also interesting. One can see clear US presidential cycles in US border encounters. But more important from the point of view of agriculture, higher prices for both beans and corn in Central American countries is associated with an increase in subsequent migratory surges toward the US. We interpret this as an income effect whereby higher agricultural incomes are needed to fund expensive migratory trips. Finally, we find that violence specifically associated with environmental change contributes to subsequent migratory surges.

Turning to our model that focuses on sudden-onset disasters, such as droughts, the plot below shows a positive relationship between our MLEED measure of disasters with subsequent Southwest border encounters. Considering that the six-month lag presents the strongest positive effect, this suggest that people may begin to migrate several months after a sudden disaster happens, perhaps as a result of the time it takes to mobilize the resources to attempt such a move. The other predictor variables behave similarly as in the model above, i.e. higher bean prices and environmental violence are conducive to migration to the US.



Overall, our results highlight how different types of climate shocks affect mobility on different timelines, with drought potentially trapping people in place, while disasters may lead to delayed but eventual movement towards the U.S. In addition, these relationships hold even after accounting for key economic and societal factors like violence and domestic inflation, which help reduce confounding and isolate the role of environmental shocks. In short, while violence is a contributing factor, it is the climate-induced challenges to food security and economic stability that are the primary drivers of displacement. Understanding the role of climate change and environmental factors in migration is essential, especially as climate-induced displacement is often overlooked in global immigration debates. Recognizing how climate change drives migration in the Dry Corridor is key to creating compassionate, long-term solutions to both environmental and immigration challenges.

Appendix:

Datasets to characterize climate (spatially aggregated to the country level):

- **ENSO (El Niño-Southern Oscillation) Data:** The monthly ONI (Oceanic Niño Index) data is used, sourced from the NOAA Climate Prediction Center: https://www.cpc.ncep.noaa.gov/data/indices/oni.ascii.txt
- **Drought Data (SPEI06):** Drought conditions are assessed using the Standardized Precipitation Evapotranspiration Index (SPEI06), a comprehensive index that combines precipitation (water supply) with potential evapotranspiration (water demand) over a 6-month timescale. This dataset has a 0.5-degree (approximately 50km) monthly resolution, extending up to 2023, and is based on SPEIbase v2.10 (SPEI package version 1.8.1). It is available from the SPEI Global Drought Monitor: https://spei.csic.es/spei_database_2_10
- **Extreme Temperature Data (ERA5-Land):** Temperature extremes, which significantly impact crop yields and farming practices in Central America, are monitored using data from ERA5-Land. This reanalysis dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF) provides land surface variables, including monthly maximum daily temperature (txx) and monthly minimum daily temperature (tnn), both in degrees Celsius. High maximum temperatures reduce crop yields and increase drought stress, while high minimum temperatures (tropical nights) can reduce yields via higher nighttime respiration and increased pest risks. The data is available through the Copernicus Climate Change Service (C3S) Climate Data Store: https://cds.climate.copernicus.eu/datasets/multi-origin-c3s-atlas?tab=download
- **Extreme Precipitation Data (ERA5-Land):** For extreme precipitation, the maximum daily rain during each month (rx1day) is utilized. This data also comes from the ERA5-Land reanalysis dataset from ECMWF. This particular variable might require deseasonalization for certain analyses.
- **DDisaster Data (EM-DAT):** Information on a broad range of natural and technological disasters is sourced from the Emergency Events Database (EM-DAT). This global database is maintained by the Centre for Research on the Epidemiology of Disasters (CRED): https://www.emdat.be/
- **Flood Data (Flood Observatory):** Specific flood-related data comes from the Dartmouth Flood Observatory. This observatory specializes in space-based measurement, mapping, and modeling of surface water. The main website is https://floodobservatory.colorado.edu/.
- **Cyclone Data (HURDAT):** Historical records for Atlantic and Northeast Pacific tropical storms and hurricanes are drawn from the Hurricane Database (HURDAT). This dataset is used to quantify cyclone occurrences and their maximum wind

intensity within the Exclusive Economic Zones (EEZs) surrounding Central American countries, providing a comprehensive view that extends beyond mere landfalls. The data is maintained by NOAA's Hurricane Research Division (HRD): https://www.aoml.noaa.gov/hrd/hurdat/Data_Storm.html

Datasets to characterize agriculture

- **NOAA Vegetation Health Index (VHI) Data:** This dataset provides global vegetation health products from NOAA's Center for Satellite Applications and Research (STAR), specifically the Vegetation Health Index (VHI). VHI is a proxy that characterizes vegetation health and combines estimations of moisture and thermal conditions, making it useful for assessing both types of stress. The data is originally weekly, at a 4 km resolution, but has been interpolated to monthly data. It is aggregated by country, province, and crop type (including maize, beans, palm oil, coffee, rice, and bananas. Source: NOAA's STAR global vegetation health products: https://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/vh_browse.php and https://www.star.nesdis.noaa.gov/smcd/emb/vci/VH/index.php
- **Food Prices Data:** Monthly food price data is obtained through the FAO's (Food and Agriculture Organization) Food Price Monitoring and Analysis Tool. This tool provides information on domestic food prices, which are crucial for understanding food security dynamics. Source: https://fpma.fao.org/giews/fpmat4/#/dashboard/tool/domestic