Project Gatorcane: An Analysis of the Effects of Municipal Building Codes on preventing Hurricane Damage in Miami-Dade and Broward Counties

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Modeling the Future Challenge

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1 EXECUTIVE SUMMARY

Due to the state of Florida's extensive coastline and geographical location, it is intrinsically vulnerable to the catastrophic effects of a hurricane hit [3] [4]. Hurricanes are among the most lethal, damaging, and destructive natural disasters on Earth. Those in positions of authority must prioritize minimizing hurricane damage in Florida because of the state's enormous and growing population [1], significant economy [2], and preeminent role as a hub of trade between the rest of the United States, the Caribbean, and South America. This is especially true in the southeast of Florida, where the state's largest metro area, Miami, can be found [5] [6]. A prominent commercial hub, It is known as "The Capital of Latin America," and has been shown to be the largest concentration of capital at risk to hurricane damage in the United States [7].

After the catastrophic Hurricane Andrew [8] [11], it was clear that something needed to be done. The Florida Building Code was developed and became effective in March 2002 as a direct result of Andrew [11]. This was the first time in the state's history that it had required and implemented statewide legislation concerning building requirements [11]. The statewide building code has undergone various updates and revisions since then [12]. However, a clause in the building code that permits further local amendments to building rules has been utilized by numerous counties and towns around the state [14]. This project focuses on these differences between the building codes of municipalities.

Our team examined the details of nearly 500,000 payments made by the Individuals and Households program (IHP) of the Federal Emergency Management Agency (FEMA) to residents of Miami-Dade and Broward Counties as a result of the three storms (Frances, Wilma, and Irma) that were determined to have had the greatest impact on the two counties in the previous 20 years [19]. To better understand the impact of particular municipal building regulations on hurricane damage in Miami-Dade and Broward Counties, this data was examined at the municipal level (among the 49 municipalities that qualified for analysis). After conducting this analysis, it was concluded that the local building codes in the subject area most effective at preventing hurricane damage could be found in the municipalities of Lauderdale-by-the-Sea, Coconut Creek, and Hillsboro Beach. On the flipside, the least effective building codes were found in the cities of Lauderhill, Lauderdale Lakes, and Hialeah.

We created housing permit issuance projections for the future in Miami-Dade and Broward Counties. When trends were taken into account, the recommendation was made for local governments throughout the country to adopt the building codes of municipalities that were found to be the most effective at preventing hurricane damage, or at least parts of those codes or their enforcement and regulation mechanisms. Regions adopting these codes would be able to experience little effects from any potential hurricanes that might hit the region, making the area's residents safer both now and in the future.

2 INTRODUCTION AND BACKGROUND INFORMATION

Florida is a state in the Southeast of the United States of America. It has more residents than any other state to the east of the Mississippi river and it is a very vibrant state with a fast-growing population and economy [1] [2]. It also has a coastline longer than any other state in the contiguous United States, and is the only state to border both the Atlantic Ocean and the Gulf of Mexico. However, Florida's vast shoreline (measuring nearly 8,500 miles according to NOAA [3]!) and its geographic position make it very vulnerable to damaging effects from hurricanes (the name given to tropical cyclones found in the Atlantic Ocean) [4].

Hurricanes are one of the most destructive and deadliest types of natural disasters found on the planet. This has made hurricanes and vulnerability to the damages of hurricanes a major concern for Floridians. Preventing damages from hurricanes has become increasingly important for not only 22 million Floridians, but also all people who live in the Americas. This is because Florida is growing and evolving into an ever-more important state that is one of the linchpins of the American economy and connects the United States to the Caribbean and South America [5] [6]. Damaging effects from hurricanes can have an especially negative effect on Florida's largest urban area, Miami, which has been measured by the National Bureau of Economic Research as the largest concentration of capital at risk to hurricane damage in the United States [7].

One of the most notable hurricanes in American history was Hurricane Andrew, which, in August 1992, made landfall in Miami-Dade County as a Category Five hurricane with sustained wind speeds of 165 miles per hour [8]. After the storm had passed, it was found out that it had cost the United States $26.5 billion in economic damage, the worst of which was found in the city of Homestead, 35 miles to the southwest of Miami [8]. The town of 27,000 people was directly struck by Hurricane Andrew, and approximately 9,000 of them fled in its wake [9]. Across Miami-Dade County, approximately 49,000 homes were destroyed and an additional 108,000 were damaged [8]. However, it has been estimated that if a similar storm were to occur today, damage would be $120 billion due to the effects of population growth, increased wealth concentration, and inflation [10].

Hurricane Andrew broke every record in the book for insurance losses, and caused what was, up to that point, Florida's worst insurance crisis in the state's history [11]. It also exposed major deficiencies in Florida's statewide law regarding building codes, set in 1974 [11]. This law allowed for all local governments to maintain a building code for the safety of its residents, but did not enforce any specific standards, an action left up to local governments [11]. As a direct result of the damages Hurricane Andrew caused, the Florida state legislature adopted the recommendations of a study conducted by the Florida Building Code Study Commission, and created the first minimum standard Florida Building Code (called the Florida Building Code 2001) that would go into effect in March 2002 [11].

Since then, Florida has maintained and updated its statewide standard building code six more times with (as of writing) the most recent update being the 2020 update, which went into effect on the last day of the calendar year 2020 [12]. Multiple hurricanes have made landfall in the state of Florida since the enacting and updating of these new building codes. Whereas research has been conducted that has found that the implementation of the statewide building code have seen a certain amount of success in preventing damages to residential housing built throughout the state of Florida after the year 2000 [13], the state of Florida still has lost over $300 billion since that year from hurricanes primarily affecting the state that are listed on the National Hurricane Center's list of Costliest U.S. Tropical Cyclones [16]. This proves that damages from hurricanes remain a major concern for Floridians, and provides credence to the idea that Florida's statewide building code can be improved to prevent further damages.

A provision exists in Florida state law which allows for counties and municipalities being allowed to make further improvements to their own local building codes (as long as these codes are stronger than the minimum state standard) [14]. Many counties and municipalities across the state have taken advantage of this provision in order to reinforce construction within their jurisdiction. Our team believes that through examining local building codes and analyzing damage data and storm data from hurricane strikes since 2000 (when Florida's first statewide building code was established), the municipal building codes are most and least effective at preventing hurricane damage can be identified.

After this, the results of the analysis were utilized to model the effects of instituting different local building codes at the present day to supplement future construction throughout Miami-Dade County and Broward County in different storm scenarios. This is especially important at the present moment since Florida is seeing a high amount of construction activity, issuing more building permits than 48 states every single year since 2012 [15]. To top it off, this already-high level of construction is on the uptrend: as of writing, there hasn't been a single month since January 2018 in which less than 10,000 building permits were issued in the state of Florida (and this number has increased steadily since the Great Recession) [15]. This means the building codes of today have the important responsibility of protecting the Floridians of tomorrow, many of whom will live in houses being built right now or in the coming years.

The truth is that poor building codes, where they exist, place a financial burden on every South Floridian because they must pay for hurricane damage, along with the rest of the state and the nation, with their taxes because federal and state programs frequently provide billions of dollars in funding for disaster relief. Every South Florida resident is also emotionally and personally burdened by subpar building codes, which may play a significant role in the deaths of family members, friends, and collaborators of several others, with immeasurable consequences. As a result, we strongly advocate that, for the benefit of both present-day Floridians and Floridians of the future, the municipal and county governments throughout the state, as well as the state government, give upgrading the state's construction codes a high priority.

3 DATA METHODOLOGY

Upon beginning the project, it was clear that many different pieces of information were necessary to conduct any analysis or make any model, as was planned. Some time was taken to assess which specific knowledge would be necessary for the project, and then it was determined how this data could properly be arranged into a numerical configuration that could mathematically and rigorously be analyzed. The data sources for the project are listed below.

OpenFEMA

Description

OpenFEMA is the Federal Emergency Management Agency (FEMA)'s network for publishing and transmitting data about disasters and disaster relief programs within the United States of America [18]. A vast amount of data concerning this information is available through OpenFEMA's API, which is organized in multiple datasets which can be downloaded as .CSV files or parsed directly through computer programs [18].

The dataset which was used for the project was called "Individuals and Households Program - Valid Registrations - v1" [19]. This dataset provides detailed applicant-level information about 20.6 million property damage claims made to the Individuals and Households Program (IHP) going back to the year 2002 [19].

There are 70 variables provided for each claim made, covering the specific disaster causing the damage, the geographic location of the damaged property (by county, city, and ZIP Code), information about the property damage (such as the extent of damage recorded on the roof and foundation of the household, utility availability, as well as the extent of destruction), information about the residents of a property (including details on the number of applicants, their age ranges, and the household's income), and information pertaining to government assistance (such as the amount of money given to the applicant) [19].

The Individuals and Households Program (IHP) is a program administered by FEMA which provides direct financial assistance to people who have had damage to their property caused by disasters and emergencies and who have insufficient or zero insurance [19] [20]. This program does not bring properties back to their pre-disaster condition and does not serve the purpose of insurance [19] [20].

Rationale

Any analysis meant to determine the effects of building codes on hurricane damages will require a robust and detailed dataset providing damage totals in each particular geographic area and jurisdiction, information that was extractable from the dataset on claims made to the IHP program.

One critique of the usage of this dataset is that it completely overlooks people who obtain reimbursement for disaster-related property damage from private insurance firms. While data is available from these companies, it comes at a cost not in the budget of this study. Secondly, it is best to use data from FEMA's IHP program since it enables us to examine the financial impact of catastrophes from a governmental standpoint. It is also very helpful from the viewpoint of the general populace because tax revenues are used to fund government spending [21], and even while many property owners purchase insurance from private companies, these transactions have no impact on how tax monies are distributed.

Methods

Since there were 20.6 million lines in the .CSV file obtained for this dataset, Microsoft Excel was unable to open it. This is why Python and Java programming scripts were employed to reduce the size of the .CSV file (by removing claims made due to non-Hurricane disasters, by removing claims where the government did not grant any money to the household, and by removing claims made by householders in areas not under the scope of this study). These scripts were then used to create reports on the number and cost of claims in each municipality for each specific storm.

One major aspect of this stage of the project was “Data Cleaning”, where the dataset was gone through by hand (using a combination of Excel and programming scripts written in Python) and was combed through for misspellings of the names of cities, towns, and villages that were being analyzed. Due to the way the dataset was structured, the direct spellings of cities by residents by hand were given to us in this dataset. While the overwhelming majority of claimants spelled the name of their municipality correctly, the vast size of the dataset meant that an average of 5.4 different spellings existed for each analyzed municipality, with large cities such as Miami and Fort Lauderdale giving rise to nearly 20 misspellings each. In ambiguous cases, a holistic approach was taken, taking into account the ZIP Code of the claimant, information available online, and the researchers’ general knowledge of the area. If ambiguity still existed as to which city it belonged to, the claimant was simply removed from the analysis. Confidence is high that near zero errors and misclassifications were made throughout this process.

The variable available on this dataset which relied on the most was called “ihpAmount” (described as the “Total financial IHP award for Housing Assistance (HA) and/or Other Needs Assistance (ONA), in U.S. dollars”). This was the only variable used due to the fact it directly accounted for the cost the government was required to pay to individuals as a result of the storm.

Although this does not reflect the total amount of damages done to property (as the IHP is not an insurance program which returns buildings to their pre-disaster condition), there was no single variable or combination of variables that displayed total damage done to a property throughout the dataset. This caused us to increase reliance on the variable access was available to. Once again, this is the optimal situation since ihpAmount most accurately describes the direct cost to the government of property damage to individual residential houses during a storm.

The American Community Survey

Description

The American Community Survey (ACS) is a program conducted by the U.S. Census Bureau that was initiated in 2005 [22]. Approximately 3.5 million American households each year receive an invitation to fill out detailed information about their households and the people inside their households [22], and every year since the program has started (with the exception of 2020 due to the COVID-19 pandemic) over 85% of households invited to respond do so in full [23]. With these responses, the U.S. Census Bureau aggregates the data and creates over 1,400 detailed data tables (along with margin of error) pertaining to specific demographic and economic indicators throughout detailed geographies [24].

Rationale

The property value of residential structures inside a specific geographic area was one complicating factor that was recognized early on as something that needed to be taken into account. This is a factor that differs greatly across Miami-Dade County and Broward County and has significant implications for the project: if a location has a higher property value, there is a greater likelihood that a property will sustain larger amounts of measurable financial damage during a hurricane, and a larger grant is likely to be given. Thus, if property value is adjusted for, any skews brought on by variations in population, population change, wealth, and inflation are effectively removed. Data from both the American Community Survey and the Decennial Census (which is covered on the next page of this document) were used to determine the total property values of all residential buildings within each analyzed municipality in each year of a hurricane.

This was done by multiplying the estimated number of houses in each year of a storm by the estimated median property value of a residential building in a geographical area.

Methods

One specific piece of information on the "place" (municipality) level from the American Community Survey was retrieved and used for research. The table is Table B25077 (Median Value), which provides the median property value of residential housing in a certain geographical area [25]. No info is available regarding the mean property value of residential housing in an area, which is why median values were used.

The American Community Survey provides both a one-year survey and a five-year survey to disseminate their data, and this analysis took advantage of the five-year American Community Survey (which provides lower margins of error and more detailed geography levels but has a slower release time) [26]. Since the oldest five-year American Community Survey available was taken in the years 2006-2010 (average response in 2008), this data (after adjustment for general housing price inflation) is what was used for all storms that occurred before 2008 (the only storms which qualify for this are Hurricane Frances in 2004 and Hurricane Wilma in 2005). This data was downloaded through the U.S. Census Bureau's data portal in https://data.census.gov [27].

The method used for adjusting for general housing price inflation in the two counties is by taking data from the Federal Reserve Bank of St. Louis (the FRED), which has reported an "All-Transactions House Price Index" for many counties in the United States since 1975, including Miami-Dade and Broward [28] [29]. The change in this index from 2004 to 2008 and from 2005 to 2008 in the corresponding county was used to determine a reasonable estimate of the median property value in a city in those years.

As an example: the city of Miami was found to have a median residential property value of $278,600 in 2008. The FRED's house price index in Miami-Dade County in 2008 was 217.36, while in 2005 and 2004 it was found to be 201.47 and 163.08 respectively. So to determine an estimate of the median residential property value in the city of Miami in the year 2005, (201.47 / 217.36) * 278,600 was calculated.

Decennial Census

Description

The Decennial Census is a detailed enumeration of the population and housing units of the United States which occurs every ten years on years which end in a zero [30].

Rationale

The property value of residential structures inside a specific geographic area was one complicating factor that was recognized early on as something that needed to be taken into account. This is a factor that differs greatly across Miami-Dade County and Broward County and has significant implications for this project: if a location has a higher property value, there is a greater likelihood that a property will sustain larger amounts of measurable financial damage during a hurricane, and a larger grant is likely to be given. Thus, if property value is adjusted for, any skews brought on by variations in population, population change, wealth, and inflation are effectively removed. Data from both the American Community Survey and the Decennial Census (which was covered on the previous page of this document) were used to determine the total property values of all residential buildings within each analyzed municipality in each year of a hurricane. This was done by multiplying the estimated number of houses in each year of a storm by the estimated median property value of a residential building in a geographical area.

Methods

The number of housing units in each municipality were retrieved by utilizing the Table H001 / H1, a table provided for the last three censuses (2000, 2010, and 2020) providing the number of homes in a specific geographical area in a census year [31] [32]. Then, linear interpolation was used to calculate an estimated number of houses in each county and city-level geography on each year a storm hit (2004, 2005, 2017).

Due to a shortage of estimates for the number of homes between census years, particularly for smaller cities and in years before 2010, this was the best option for collecting estimates of the number of homes in a region. As the Building Permit Survey only includes building permits, which may be issued years before a building is actually constructed, that data was not used.

National Hurricane Center

Description

The National Hurricane Center (NHC) is a branch of the United States National Weather Service responsible for tracking and forecasting tropical cyclones (hurricanes, tropical storms, and tropical depressions) in oceans surrounding the United States, including the Northern Atlantic. It has kept large datasets and massive archives regarding every tropical cyclone in the Northern Atlantic basin since 1851, including its location, intensity, and movement. This data is collected from a variety of sources, including satellites, buoys, and aircraft reconnaissance. The NHC uses this data to generate various products and advisories, such as forecasts, warnings, and watches, that provide critical information to the public.

Rationale

A major factor which has a high possibility to skew any analysis if not accounted for is the strength of a hurricane at a particular location. Hurricanes have their highest wind speeds and rainfall rates in the eyewall of the storm (the region directly surrounding the eye) which means that the highest potential for damage is in the eyewall [42]. In sprawling urbanized regions such as Southeast Florida, different parts of a metro area can face diverging conditions during a hurricane and as such, see dissimilar levels of damage.

Most damage caused by hurricanes in Miami-Dade County and Broward County has been caused by high wind speed and not by storm surge, flooding, and rainfall. Although storm surge, flooding, and rainfall are typically noted as the most damaging aspects of hurricanes [43], this is not the case in Southeast Florida. The Atlantic Coast of Florida is much less susceptible to storm surge than Florida's Gulf Coast due to different hydrography in the surrounding region [44]. This compounds the fact that no hurricane since 2000 has struck Miami-Dade or Broward. Hurricane effects (such as wind and rainfall) impact Southeast Florida either from landfalls on the Southwestern coast (such as Irma in 2017 and Wilma in 2005) or landfalls on the East Coast far enough North where — although the effects of wind and rain are felt — storm surge and flooding is not a major factor (such as Frances in 2004).

This is further reflected in the relatively minuscule total cost of flood damages found in the OpenFEMA dataset. The OpenFEMA dataset has a variable named "floodDamageAmount" which is used to signify the cost of property damage caused by floodwaters. Among the storms analyzed in Miami-Dade and Broward, flood damages only account for 4.5% of the total IHP grant issued, even though the statewide figure is 13.2% for the same storms. Even Hurricane Andrew, the harbinger of building codes in South Florida, was noted for its lack of flooding [47].

Although we acknowledge the danger posed by flooding, rainfall, and storm surge, it is unlikely to be a concern in Miami-Dade and Broward compared to other parts of Florida. Moreover, even if an analysis was attempted, data is largely unavailable due to a lack of significant flooding, rainfall, and storm surge events caused by hurricanes in Southeast Florida recently. Conclusively, the largest threat is wind, and this is the one variable that our analysis adjusts for on the municipal level.

Methods

The Wind Intensity Rating (WIR), an index developed using data from the NHC, was used to measure the intensity of the winds each storm produced in each covered municipality. The strength and duration of the sustained wind speeds (defined as occurring for at least one minute; all mentions of "wind speed" thereafter refer to sustained wind speed) are combined to get this index.

A study conducted in 2009 determined that for a variety of factors, the duration of sustained wind speed has a linear effect on hurricane damages caused by (relatively) low to moderate wind speeds [36]. This covers the scope of all storms examined in this paper since neither Miami-Dade County nor Broward County have seen significant portions of sustained wind speeds above the Category One Hurricane force level since the year 2000).

Another study conducted in 2012 determined that wind speed is a major determinant in measurable financial damage, as damages caused by tropical storms and hurricanes increase at a rate of 5% per meter per second of wind speed. Meaning that for every increase in wind speed by +1 m / s, the damage cost increases by 5% [37].

Since the aim was each municipality having a WIR for every storm, the first step in achieving this task was to create single geographical points which could represent municipalities for ease of analysis. Since weighted population centers are not available on the municipal level by the U.S. Census Bureau, it was settled that using the geographic center of municipalities (excluding water area) calculated by the free software application QGIS with its centroid tool was the optimal solution. A centroid — as defined by Mississippi State University — is "the point corresponding to the geometric center of an object" [33]. Municipality boundaries were taken from the U.S. Census Bureau's 2022 TIGER/line dataset [34].

The National Hurricane Center provides data on the length of time locations experienced wind speeds from 34 knots to 49 knots (low Tropical Storm-force), from 50 knots to 63 knots (high Tropical Storm-force), and from 64 knots upwards (Hurricane force winds). This data was extracted in two methods:

For storms since the year 2008, the NHC GIS Archive was used. It provides cartographic information in the form of shapefiles on the 34-knot, 50-knot, and 64-knot wind fields of every tropical system every three hours (when they are close to land, which is true in every analyzed case) [35]. This data was downloaded and interpreted using QGIS to determine how many hours each city centroid fell inside each wind speed category. This was done by observing whether or not the estimated wind field in each advisory overlapped with the city centroid and marking it in its appropriate wind speed category (34–49, 50–64, 64+).

Although the NHC's GIS Archive worked well as a method of ascertaining the strength of wind speeds of storms that have impacted the United States recently, the National Hurricane Center only began generating wind field maps in 2008, so for hurricanes that impacted the United States before 2008, a different approach was needed. Fortunately, the National Hurricane Center also maintains another dataset called HURDAT, which provides fixes every six hours on the locations, intensities, and other information on each tropical cyclone in the Atlantic going back to 1851 [38].

For all hurricanes since the 2004 season (which includes every storm in the analysis), HURDAT provides 34-knot, 50-knot, and 64-knot wind radii for each quadrant of the system (Northeastern, Southeastern, Southwestern, and Northwestern). In QGIS, the location of the center of each system at the time of each location fix the radius variables provided in HURDAT were used to draw circles centered around the storm center with the appropriate radii. Then, the appropriate wind field a city centroid was found in was recorded.

Since HURDAT only provides data on six-hourly fixes, this made it inconsistent with three-hour data from the NHC GIS Archive. To fix this, linear interpolation was used to determine new latitudes, longitudes, and wind radii of each of the three categories in each of the four quadrants of the system. After this, wind field analysis with these new figures was conducted the same way as occurred with the six-hour HURDAT data.

Now that the length of time each city experienced wind speeds of (34–49, 50–63, 64+) was calculated, WIR could be calculated. We define 3 hours of time under 34–49 knot conditions as being 1 in raw WIR. Converting 50 and 64 to meters per second and applying the formula used for determining the potential effect of wind speed on hurricanes gives us the following indexes:

- 3 hours of time under 34–49 knot conditions gives a WIR of 1
- 3 hours of time under 50–63 knot conditions gives a WIR of 1.5
- 3 hours of time under 64+ knot conditions gives a WIR of 2.1

Adding together the specific WIRs for each wind category, this gives us the municipality's total WIR during the storm. For example, during Hurricane Wilma, the city of Miami experienced:

- 34–49 knot conditions for six hours ((6 / 3) * 1 = 2)
- 50–63 knot conditions for six hours ((6 / 3) * 1.5 = 3)
- 64+ knot conditions for three hours ((3 / 3) * 2.1 = 2.1)

Adding 2 + 3 + 2.1 gives us a raw WIR of 7.1 for the city of Miami during Hurricane Wilma.

A final note on WIR: It is meant to compare and contrast the wind damage in different municipalities during the same storm. Results are not generalizable enough to compare information from different storms due to different landfall patterns, directions of approach (and direction of wind speed), and numerous other factors which are storm-specific.

Building Permits Survey

Description

The Building Permit Survey is a program run by the U.S. Census Bureau which provides data and statistics regarding new privately-owned residential construction for geographies on the state, county, and municipal level. Data is available by month and by year [41], and as of writing extends from January 1990 to January 2023 in the case of most geographies.

Rationale

Information from the Building Permit Survey is crucial to determine the number of housing units which are likely to be built over the next few years, data which is essential for us to create mathematical models on any possible effect local building code improvements could have on housing units which are constructed in the near future. This data will be used to better formulate the risk analysis and to create recommendations.

Methods

Building Permit Survey data was retrieved through the Data Visualization tool provided on the U.S. Census Bureau's website [45]. Data regarding the number of housing units built in Miami-Dade and Broward Counties in each year since 1990 was downloaded.

4 MATHEMATICS METHODOLOGY

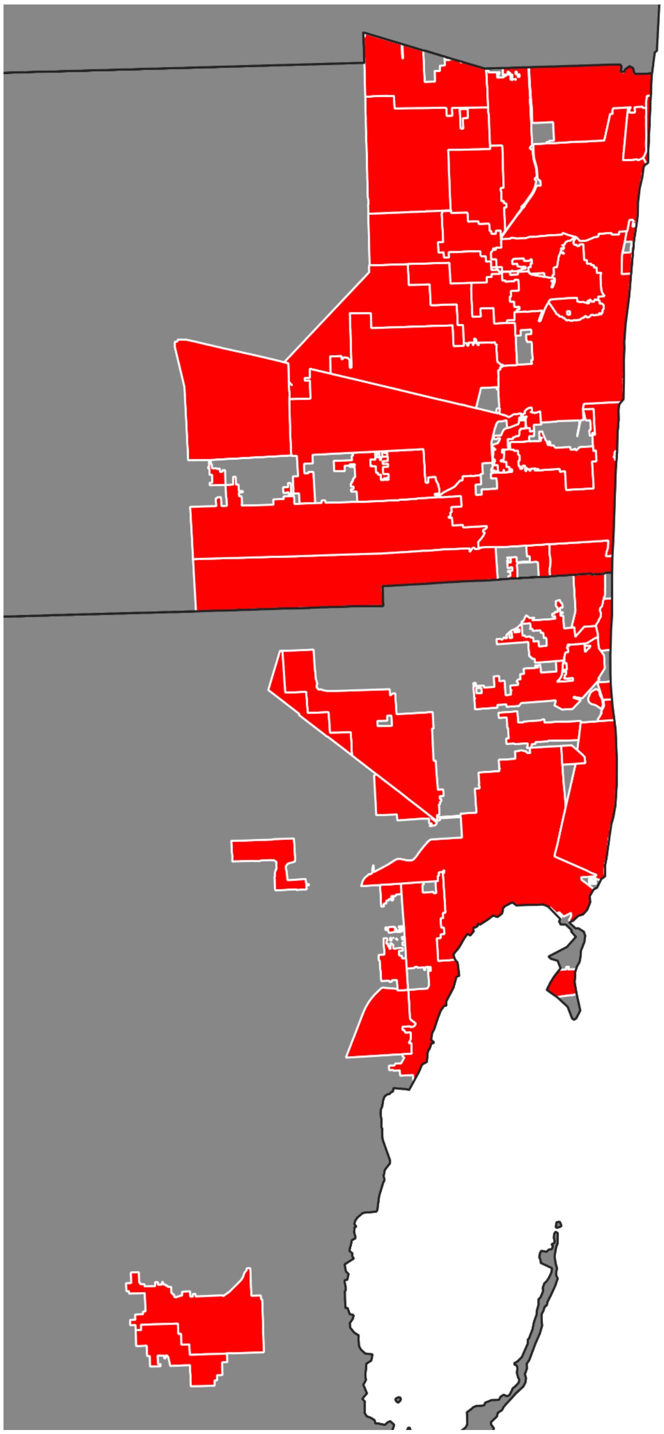
Determining Geographies

In order to determine which geographies were to be analyzed, the credibility formula with a confidence level of 95% and a "Maximum departure from expected" value of 5% was applied. This allowed us to determine that any cities in Broward County and Miami-Dade County which had fewer than 1,537 households at any point since the year 2000 did not have enough households to conduct a meaningful statistical analysis [46]. Further exclusions were made on any incorporated places that have been established since the year 2000 (for example West Park, incorporated in 2005). This is because these places not only lacked data on the number of households within themselves at the time of the 2000 census, but also would have no capability of creating a local building code applying to homes within their jurisdiction.

Census-designated places made up another category of excluded geographic areas. The only geographies that were considered in this analysis were incorporated and organized cities, towns, or villages since such local governments have the authority to uphold and enforce building standards in a way that Census-Designated locations (which frequently have shifting boundaries) do not.

Finally, the city of Opa-Locka in Miami-Dade County was excluded from the analysis due to data from that city being considered unreliable. The city reported 6,432 claims on residential buildings for Hurricane Wilma in 2005 despite only 5,739 houses being estimated to exist in the city in that year. The city has not grown dramatically since 2005, with Decennial Census data from the year 2020 showing the city only contained 6,210 households (still a smaller number than the number of claims in 2005). This proves that this is likely to be a pure data error and not indicative of significant population growth.

After making these exclusions, this left us with 49 cities, towns, and villages that were able to be analyzed. They are mapped below and listed by the total property value of all residential households within municipality borders in the year 2017 (the most recent year for which data was estimated).



City Name	Property value of all homes
Miami	$ 64,715,617,080.00
Fort Lauderdale	$ 33,448,663,800.00
Miami Beach	$ 29,710,978,200.00
Pembroke Pines	$ 18,791,771,700.00
Hollywood	$ 18,321,147,000.00
Coral Gables	$ 18,095,879,140.00
Hialeah	$ 17,477,064,360.00
Coral Springs	$ 16,710,722,610.00
Miramar	$ 12,825,643,360.00
Plantation	$ 12,671,252,970.00
Pompano Beach	$ 12,519,593,130.00
Davie	$ 12,495,486,960.00
Weston	$ 11,322,685,440.00
Aventura	$ 9,364,599,360.00
Key Biscayne	$ 8,685,413,100.00
Sunrise	$ 8,127,231,070.00
Deerfield Beach	$ 7,704,413,040.00
Sunny Isles Beach	$ 6,919,005,520.00
Parkland	$ 6,414,355,920.00
Pinecrest	$ 6,316,643,020.00
Hallandale Beach	$ 6,042,664,320.00
Tamarac	$ 5,682,201,360.00
Homestead	$ 5,663,225,880.00
Coconut Creek	$ 5,131,568,750.00
Margate	$ 4,714,175,920.00
Lauderhill	$ 4,642,576,400.00
North Miami	$ 4,598,331,160.00
Oakland Park	$ 4,386,424,000.00
Cooper City	$ 4,212,487,720.00
Bal Harbour	$ 4,169,009,640.00
North Miami Beach	$ 3,285,379,840.00
Dania Beach	$ 3,147,364,440.00
Lighthouse Point	$ 3,141,375,180.00
South Miami	$ 2,994,574,930.00
Lauderdale-by-the-Sea	$ 2,958,183,900.00
North Lauderdale	$ 2,482,554,570.00
Surfside	$ 2,339,057,250.00
Wilton Manors	$ 2,302,987,240.00
Miami Springs	$ 2,210,496,480.00
Miami Shores	$ 2,186,751,800.00
Lauderdale Lakes	$ 1,860,146,580.00
North Bay Village	$ 1,519,794,900.00
Hialeah Gardens	$ 1,496,810,280.00
Bay Harbor Islands	$ 1,178,525,670.00
Sweetwater	$ 1,053,740,290.00
West Miami	$ 993,430,720.00
Hillsboro Beach	$ 989,085,720.00
Florida City	$ 612,277,520.00
Pembroke Park	$ 315,461,880.00

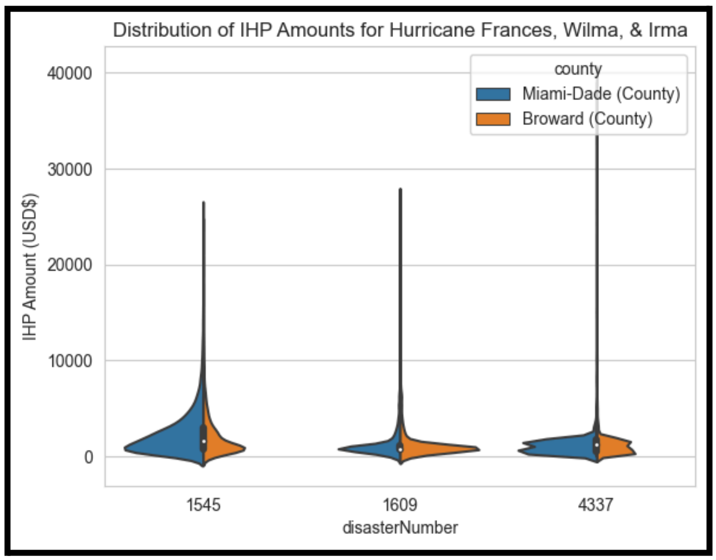
Determining Disasters

In the OpenFEMA database, only three storms existed where any IHP grants were issued in Miami-Dade or Broward Counties: Hurricane Frances of 2004, Hurricane Wilma in 2005, and Hurricane Irma of 2017. These three storms combined to cause 438,651 claims costing the government $586.5 million (when only including claims where the government granted over $0.00) in the two counties. Info on the number of IHP grants made in Miami-Dade and Broward for damages caused by each storm and the cost of these grants is displayed in the table below:

Hurricane Name	**Number of IHP Grants in Miami-Dade**	**Cost of IHP Grants in Miami-Dade**	**Number of IHP Grants in Broward**	**Cost of IHP Grants in Broward**	**Number of IHP Grants in both counties**	**Cost of IHP Grants in both counties**
Frances, 2004	12,933	$31.2 M	6,790	$14.4 M	19,723	$45.6 M
Wilma, 2005	67,536	$92.8 M	86,034	$118.1 M	153,570	$210.9 M
Irma, 2017	178,794	$223.4 M	86,564	$106.3 M	265,358	$329.6 M

The violin chart on the right shows an analysis of the distribution of costs of individual IHP grants the government provided by county. The Y-Axis provides the FEMA official disaster code. Below a short list showing a translation of codes used in the violin chart can be found:

- 1545: Hurricane Frances
- 1609: Hurricane Wilma
- 4337: Hurricane Irma



This chart is not intended to show the difference in the significance of the hurricanes to each other. Instead, it compares the number of claims in each county for a particular storm and displays the probability that a claim will be of a certain amount for that particular storm.

For instance, the likelihood that the cost of an IHP grant will exceed $10,000 in both counties as a result of Hurricane Frances is 1.45% while during Hurricane Irma's it is 0.52% and for Hurricane Wilma's impact its 0.72%. It is important to recognize the impact of extreme claims as they have the potential to significantly affect the government's financial stability.

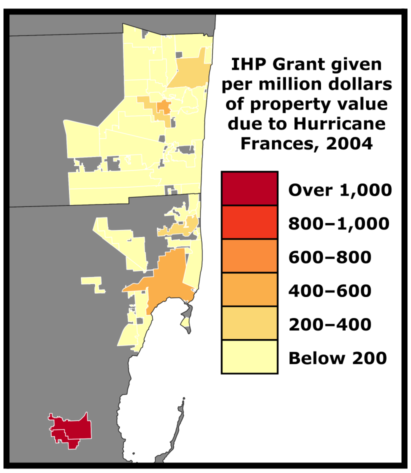
The government can better understand the hazards in building standards and create new ones to lessen those risks by examining these claims and discovering patterns in the places from where they originate.

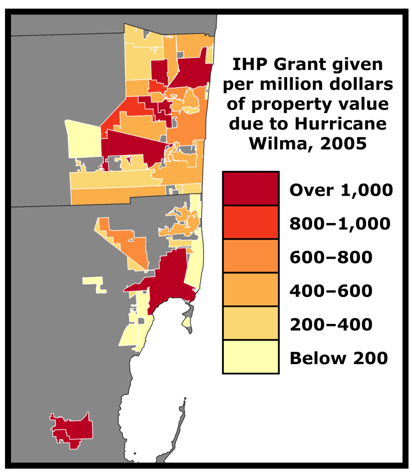
Determining Damage

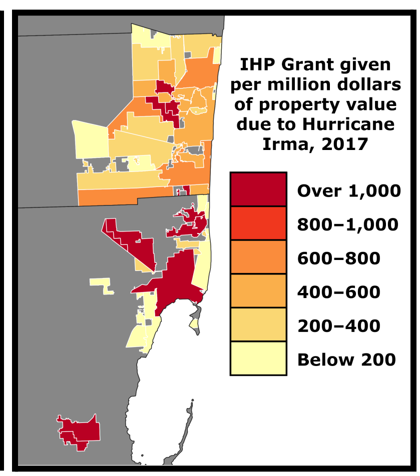
Now that all the data had been collected, and now that geographical areas to be covered and hurricanes to research had been decided, the relative cost of the damage caused by each hurricane in each city was able to be determined.

Using gathered data, the total IHP amount granted to claimants within a municipality was divided by the total assessed value of all properties in each municipality for each hurricane. This provided an estimate of the damage each hurricane caused to the municipalities as a result.

For example, claimants in the city of Miami were granted $130.2 million by the IHP program due to Hurricane Irma in 2017. In the same year, it was estimated that the total property value of all residential buildings within the city was $64.7 billion. This means that, in the wake of Hurricane Irma, the IHP program granted an estimated $2,011.60 for each $1,000,000 of residential property value in the city of Miami, or just over 0.2% of the total property value of the city. The three maps below show these figures for each of the three Hurricanes analyzed on the municipality level.

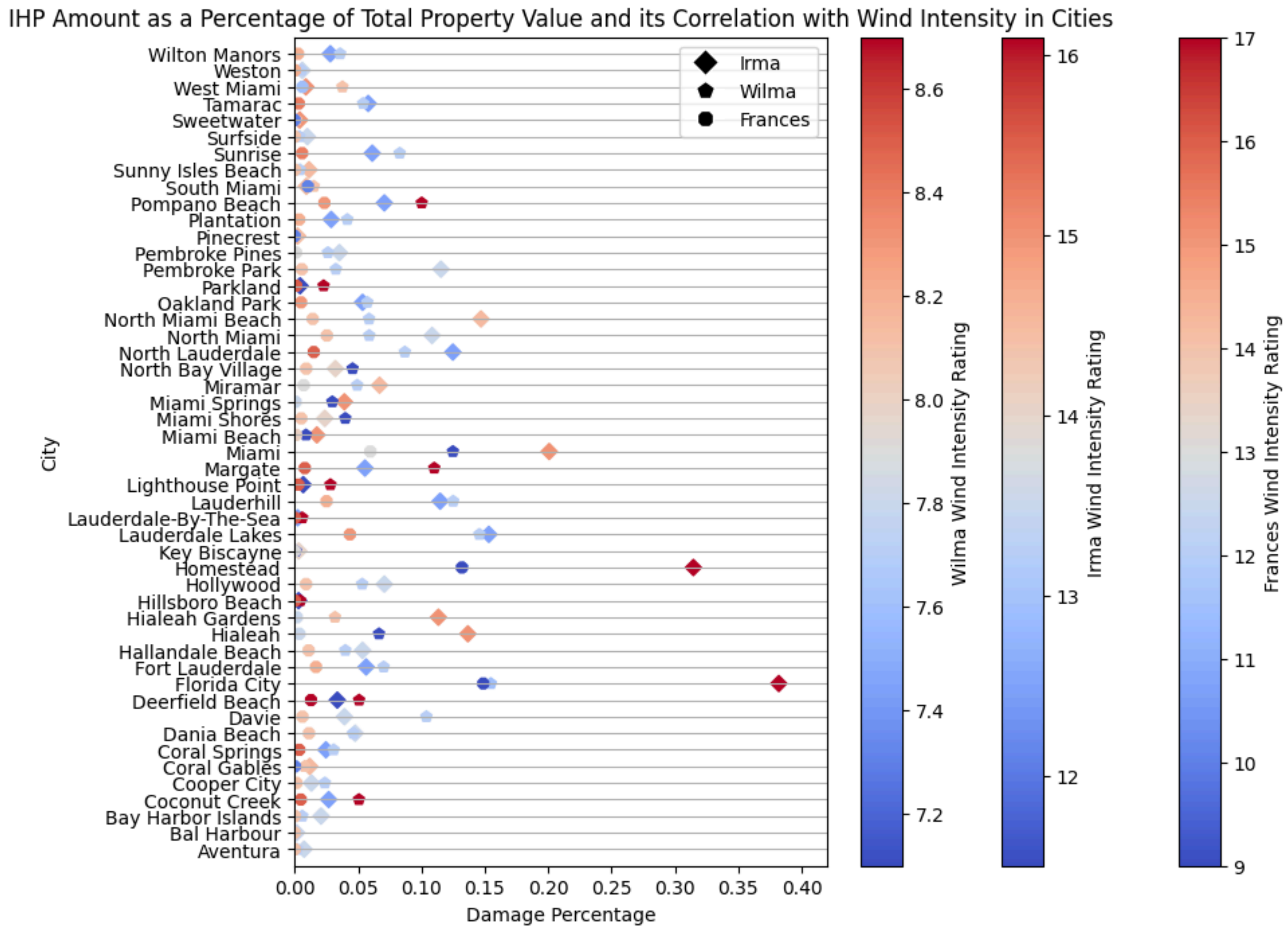






Correlation between Damage and Wind Intensity

Something that clearly exists here is a strong correlation between the WIR (Wind Intensity Rating, more info in Section 3. Data Methodology) of a municipality for a particular storm and the relative amount of damage adjusted for property value. This correlation is displayed in the scatter plot below:



The X-Axis here is the cost of the IHP grant issued to claimants in a municipality as a percentage of all the property value in a municipality. The Y-Axis is the names of cities in descending alphabetical order. The three scales on the right side provide the raw WIR for each storm. This is because each storm has its own WIR scale and WIRs cannot be compared between storms, but only between municipalities affected by the same storm (as was covered in Section 3. Data Methodology).

To mathematically determine how resistant each municipality's building code was to long-lasting high-speed winds, the decision-making technique known as an Analytic Hierarchy Process (AHP) [39] was employed to create a formula that would generate a score (henceforth referred to as "Building Code Efficacy Score", or BCES) recording the efficacy of each municipality's building code when adjusting for WIR. This formula weights the "Damage Percentage" (the cost of the IHP grant issued to claimants in a municipality as a percentage of all the residential property value in a municipality) and WIR equally. It can be found below:

$$BCES = (0.5 * WIR) + (0.5 * (1 - DamagePercentage))$$

The BCES provides higher numbers, or ratings, to municipalities that gave lower Damage quotients and had higher WIRs. The procedure was carried out for every municipality three times, one using the data from each of the three hurricanes (Frances, Wilma, Irma). Then, through the numbers acquired from this procedure, three rankings of BCESs were created, one pertaining to each storm. The three rankings of each municipality were added, and then re-ranked the cities based on the new “composite ranking”. Tiebreakers are determined by giving a better rank to the municipality(ies) which has a higher combined BCES for the three systems.

For example, the city of Miami had the 39th-highest BCES of the analyzed cities in the case of Hurricane Frances, the 49th-highest in the case of Hurricane Wilma, and the 9th-highest in the case of Hurricane Irma. This means its “composite ranking” could be calculated by adding 39 + 49 + 9 to get 97. This is the 45th-lowest number of any city and means that Miami’s “composite ranking” is #45, meaning that out of 49 cities, Miami had the 45th most effective building code.

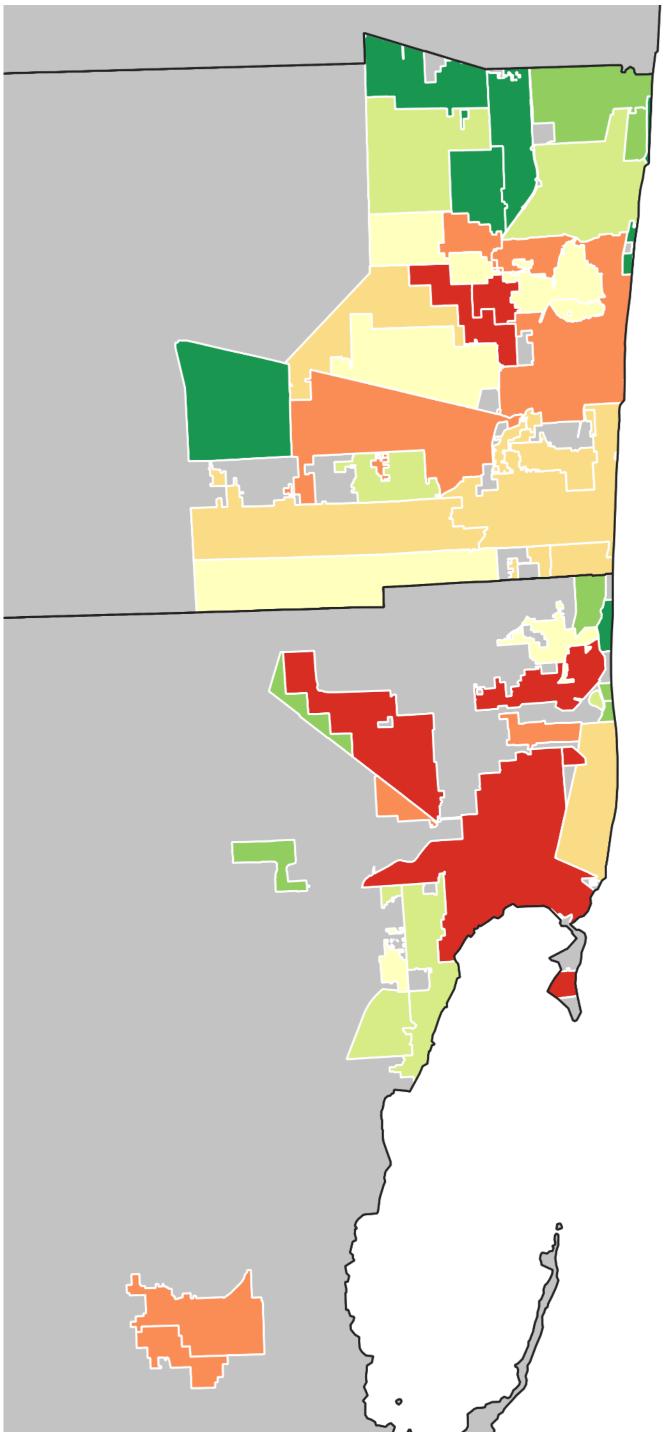
Once again, a lower composite ranking signifies a more effective local building code.

The reason a simple raw average of the three BCESs is not taken is to avoid skewing the final ranking towards or away from the damages caused by any one hurricane. This is especially the case due to WIR being a variable heavily affecting BCES. Since WIRs for Hurricane Wilma are significantly lower than they are for Hurricane Frances or Hurricane Irma (as Hurricane Wilma spent a relatively small amount of time impacting Florida), this means BCES scores for Hurricane Irma and Hurricane Frances are universally higher than those for Hurricane Wilma. This would create a distortion in the final data and rankings away from municipalities which saw their building codes perform well under Hurricane Wilma.

The final composite ranking of municipality building code efficacy for every city can be found in the map on the next page. There are seven color classes, each of them representing seven cities. For example, the darkest green represents the seven best-performing cities (Composite Ranks of #1 to #7), the next shade of green represents the next seven best-performing cities (Composite Ranks of #8 to #14), etc. etc. This continues all the way down to the darkest shade of red which represents the seven worst-performing cities (Composite Ranks of #43 to #49).

The five municipalities in Miami-Dade County and Broward County with the most effective building codes at preventing hurricane damage are: Lauderdale-by-the-Sea, Coconut Creek, Hillsboro Beach, Sunny Isles Beach, and Margate.

The five municipalities in Miami-Dade and Broward Counties with the least effective building codes at preventing hurricane damage are: Lauderhill, Lauderdale Lakes, Hialeah, North Miami, and Miami.

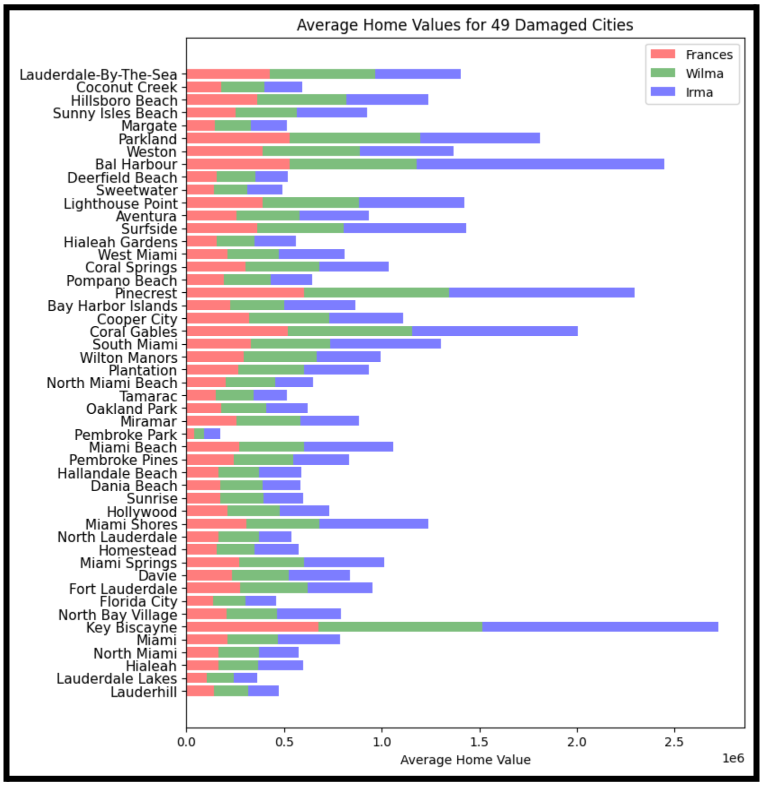


City Name	Composite Rank
Lauderdale-By-The-Sea	1
Coconut Creek	2
Hillsboro Beach	3
Sunny Isles Beach	4
Margate	5
Parkland	6
Weston	7
Bal Harbour	8
Deerfield Beach	9
Sweetwater	10
Lighthouse Point	11
Aventura	12
Surfside	13
Hialeah Gardens	14
West Miami	15
Coral Springs	16
Pompano Beach	17
Pinecrest	18
Bay Harbor Islands	19
Cooper City	20
Coral Gables	21
South Miami	22
Wilton Manors	23
Plantation	24
North Miami Beach	25
Tamarac	26
Oakland Park	27
Miramar	28
Pembroke Park	29
Miami Beach	30
Pembroke Pines	31
Hallandale Beach	32
Dania Beach	33
Sunrise	34
Hollywood	35
Miami Shores	36
North Lauderdale	37
Homestead	38
Miami Springs	39
Davie	40
Fort Lauderdale	41
Florida City	42
North Bay Village	43
Key Biscayne	44
Miami	45
North Miami	46
Hialeah	47
Lauderdale Lakes	48
Lauderhill	49

5 RISK ANALYSIS

As covered in previous sections (particularly Section 2. Introduction and Background Information), hurricanes pose a massive risk to Miami-Dade County and Broward County, causing billions of dollars of property damage and forcing the federal government to provide hundreds of millions of dollars in aid. Even worse, it is all too common for hurricanes to take a human toll and cause deaths. Hurricane damage in the two studied counties is most often caused by high wind speeds for a multitude of reasons (as was explained in Section 3. Data Methodology). In order to preserve lives and safeguard citizens' quality of life, it is crucial for governments to examine their building codes to ensure no weaknesses remain.

Correlations

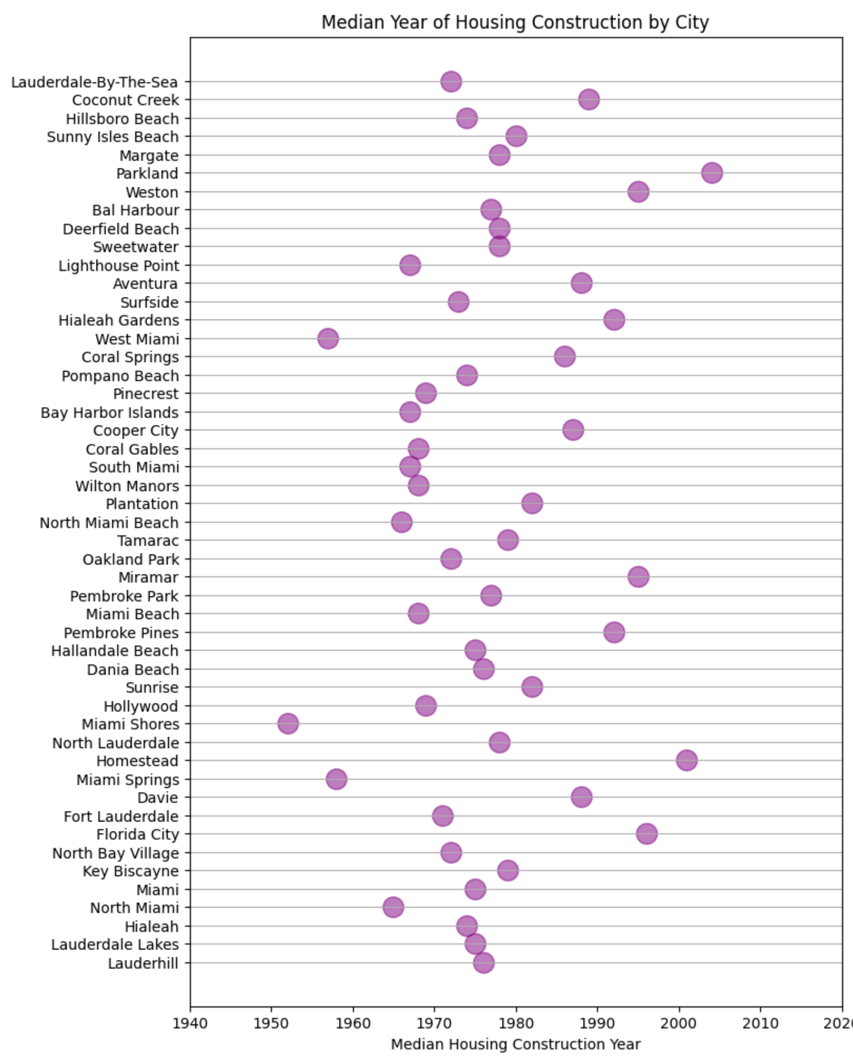


The composite ranking indicator which was calculated in the final part of the previous section (4. Mathematics Methodology) was used to attempt to identify possible correlations between the strength of building codes and other variables. The method through which this was done was by employing statistical research to evaluate the strength of these relationships. Two of these investigated variables were the median age of buildings in a particular municipality and the median price of residential housing in a particular municipality.

An examined tendency was the relationship between the median property value of residential housing in a municipality and the efficacy of its local building code. Homes constructed with less expensive materials and which are in less affluent areas may lack additional safety features like high-impact windows. To better understand the changing wealth of the communities under consideration, the bar chart on the right side of this page was generated using data previously used in this same study from the American Community Survey. This data had to do with the median values of residential households retrieved through Table B25077 [25].

The following step was performing a correlation analysis, a technique for evaluating the strength of a relationship between two variables, resulting in a correlation coefficient ranging between -1 and 1. A negative number indicates a negative correlation, a positive number indicates a positive correlation, and a number close to zero indicates no correlation. A weak negative correlation of -0.27 between the composite rank of the municipality's building code efficacy and the median residential home value was found. This means that a minor tendency exists for local building codes to be stronger in cities with a higher median home value. However, local governments of less affluent cities should take this as a very serious concern as otherwise they cannot properly safeguard their citizens who have less means to do so than more affluent South Floridians living in wealthier cities.

The correlation between a municipality's composite ranking and the median year its housing stock was built was also looked into. Given that buildings are constructed in accordance with the most recent construction codes, it is crucial to address this. While newer structures will have stricter building rules, older buildings will have less strict building codes. It was hypothesized that municipalities where the average house was built earlier were more likely to have building codes that are very ineffective against preventing hurricane damage.



However, this idea was proven wrong. The results of the correlation analysis showed a very weak correlation (-0.15) between the two variables. This implies that the ranking has a very, very slight tendency to fall as the median year of construction is farther back in time. Once again, though, the extreme weakness of this association must be emphasized, indicating a certainty that additional factors affect the efficacy of building codes. A possible reason for a lack of correlation here is that all houses built in a municipality must adhere to the local building code it is under the jurisdiction of, no matter what year it was built in, as long as the building code of that municipality was in place. This also dispels a misconception that enhancing local building codes cannot make much difference in areas where housing stock was constructed decades ago.

The statistical methodology did not reveal any obvious association, but it was noted that six of the eight municipalities in Miami-Dade and Broward dominated by beaches are included among the top 15 municipalities with the most effective building codes at preventing hurricane damage: Lauderdale-by-the-Sea, Hillsboro Beach, Sunny Isles Beach, Bal Harbour, Lighthouse Point, and Surfside. The two beach towns which performed poorly were Miami Beach and Key Biscayne. A possible reason for this is that in beach towns, it is more likely to find builders prioritizing good work and local government officials strengthening local building codes in anticipation of hurricane strikes from the Atlantic Ocean. All of these beach towns are the municipalities in South Florida which are most obviously susceptible to hurricane damage and would be the first municipalities to feel the effects of any storm due to their geography.

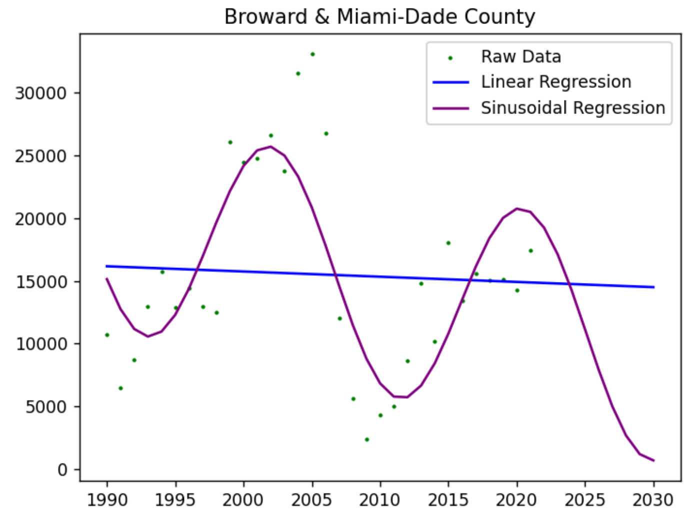
Overall, though, struggles to reveal factors which significantly correlated with the Composite Rankings of Building Code Efficacy in Hurricane conditions prove one thing above all else: any city, town, or village can benefit from enhancing its local building code. This is true whether it is inland (such as Weston) or coastal (such as Lauderdale-by-the-Sea), whether the homes in it were constructed long ago (such as Lighthouse Point) or very recently (such as Parkland), whether it is affluent (such as Hillsboro Beach) or working-class (such as Sweetwater).

At the same time, however, any factors a city may have, such as its affluence, the recentness of its residential construction, or its geographical location will not help it if it does not have strong local building codes and systems to enforce those building codes in place. This can be seen as among cities which were determined to have the least effective building codes, they came from all different geographic regions, levels of wealth, and age of housing stock, and all of them were quite different from each other in different cases.

Future Risks

It is important for local building codes in Southeast Florida to be strengthened in light of residential construction which is going to be built in the near future. Over the coming decades, many Floridians will live in construction that is being built right now, and if the construction is done under shoddy standards, the residents of these houses will be at risk of financial and personal losses for themselves, their families, and their communities.

In order to enumerate the necessity of this to prove the urgency of building code improvement, a regression model pertaining to the number of houses being built yearly in each city was built. The expected numbers of housing units that would have been built between 2024 and 2030 in certain cities was modeled and took the sum of the extrapolation. Through such analysis, it was determined that approximately 43,021 new building permits are estimated to be issued in both Miami-Dade and Broward Counties over the years 2024 to 2030. (It is important to note that 2024-2030 is extrapolation, and hence it is *highly* speculative. Though it appears to be consistent with what's happened in the past two decades, nothing can be said for certain).



The Y Axis on the table to the top-right of this page refers to the estimated number of housing permits allowed in the specified year on the X axis. The blue line indicates the linear regression used to understand the trend of this data, and the purple line represents the sinusoidal equation.

Two regression models were created to analyze the given data. The libraries Numpy and Scipy were used to perform this regression. As for the equation representing the sinusoidal regression, it can be modeled as $a * sin(b * x + c) + m * x + d$. This equation was used since it proved to regress quite nicely onto the given data, since it appeared to be periodic to a certain extent. Every city in the two selected counties was analyzed with this model, and each one had a lower MSE with the sinusoidal model compared to the linear regression, and . Also, the mean squared error provided by the regression model proved to be low compared to that of a simple linear regression, so it proved to be more accurate.

Finally, a major point to consider is that as a result of the effects of climate change. In the coming decades, it will cause these already terrible natural disasters to yield higher rainfall totals and cause them to be more likely to become intense storm systems [40]. To top it off, due to the effects of rising sea levels, coastal flooding will become a larger and larger concern as time goes on, and in areas of low elevations such as Southeast Florida, these outcomes and developments spurred on by climate change could become a major issue for future inhabitants. This is yet another reason that it is urgent for municipalities in Miami-Dade and Broward Counties to pre-emptively improve and enhance their building codes now, rather than later (along with municipalities and governments throughout the rest of the state and country).

6 RECOMMENDATIONS

We now propose several recommendations that can be made for municipal governments to follow, not just in Southeastern Florida, but also statewide and nationwide. Our group advises municipal governments to modify their local building codes to take elements from or match the codes in the cities of Lauderdale-by-the-Sea, Coconut Creek, Hillsboro Beach, Sunny Isles Beach, and Margate. These five cities had building codes which all performed admirably and had a positive effect in reducing damages.

Such changes are especially important for the municipal governments of Lauderhill, Lauderdale Lakes, Hialeah, North Miami, and Miami to embrace. The sooner these changes are made, the better, especially in light of increased construction activity and the projection that 43,021 new residential units will be built across Miami-Dade and Broward Counties between 2024 and 2030. This especially needs to be emphasized for the city of Miami, which is estimated to see far more new housing permits (~29,000) issued than any other analyzed municipality.

If the municipal building codes are not upgraded, these new residential units will be built extremely susceptible to hurricane damage requiring governmental aid to alleviate. This raises the potential of communities being put in a hazardous state of financial ruin, with the potential for many deaths in the case of direct hurricane hits.

However, these modifications need not only be placed onto these five cities. Rather, every city in Broward County and Miami-Dade County should make the utmost effort to mandate safer housing for its residents. While short-term this may cause a small amount of economic pain, in the long run, the leaders of any municipality adopting these codes will have secured not only financial savings, but also save lives. Such successes could lead to development.

Another recommendation which can be made is also that municipalities with building codes ranked poorly should adopt similar mechanisms and methods of enforcing building code standards, and similar building permit issuance and approval mechanisms as the municipalities which rank highly do. Of course, it is recommended for municipalities to do this to a reasonable degree, as due to a lack of resources or other important extenuating factors not accounted for, it may not be possible for all municipalities to adopt these mechanisms.

It must be acknowledged that the results of this analysis may not be applicable everywhere. For instance, building codes that work well for keeping residents of inland cities such as Coconut Creek, Margate, Parkland, and Weston safe may not work as well for coastal beachfront cities such as Miami Beach. In the same line of thought, different coastal areas should have building codes optimized for their location. As an example, the city of New Orleans has different requirements than most coastal cities due to a majority of the city being located below sea level. Therefore, a certain amount of flexibility in building codes is urged to ensure the best adjustments are made to fit with local conditions.

7 CONCLUSION

This model predicted how many homes would be built up to 2030. Also, the best building codes were determined and suggestions were made as to which ones new structures ought to follow. Future hurricane danger is a concern due to global warming, therefore it's critical that the government do everything in its power to ensure that inhabitants of South Florida are protected with safe housing.

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