**Hurricanes and Their Impact on the Gulf Coast**

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**Background and objectives**

The Gulf Coast region of the United States has a history of being severely affected by hurricanes, which are complex natural phenomena involving multiple spatial and temporal factors. Hurricanes can vary in their intensity, paths, and impacts, making them a subject of considerable geographic interest. Coastal flooding, often exacerbated by hurricane-related storm surges, is a key concern in this region due to its potential for widespread damage. Therefore, we have outlined three key objectives we wish to address in our project.

First, the project aims to analyze historical hurricanes along the Gulf Coast, tracking how often they occur, their strength, and their paths over time. This involves mapping where these hurricanes traveled and the areas they affected. The goal is to clearly show the patterns and changes in hurricane activity through both maps and data. Understanding these patterns is crucial for better predicting future hurricanes and preparing for them.

Secondly, another important part of the project is looking at how hurricanes affect people living on the Gulf Coast, especially in densely populated and urban areas. It identifies which communities are more at risk due to frequent hurricanes and looks into the broader social and economic effects of these storms. The aim is to use this information to help these communities be better prepared and have stronger responses to hurricanes.

Lastly, this part of the project focuses on how hurricanes might affect critical infrastructure like hospitals, power plants, and transport systems. It examines the relationship between the location of this infrastructure and areas that hurricanes often hit. Essentially identifying places where infrastructure is most at risk can help in planning and building stronger, more resilient systems. This is key to ensuring these essential services can withstand the impact of hurricanes.

**User requirement analysis**

Basically, we hope to implement a simple and streamlined process to make the best use of the geodatabase. The user should be able to simply load a backup of the database we created to PostgreSQL on their end. Then, they should be able to conduct queries of all kinds to obtain meaningful insight to achieve the three objectives we have previously mentioned. Additionally, the user should be able to easily connect the database to ArcGIS Pro to perform visual analysis based on previous queries. As a result, a thorough investigation into critical aspects of this topic can be done by anyone, anywhere.

**Database Design:**

Since we are implementing a geodatabase, the focus of the design is the choice of feature classes (seven of them) which are all under one feature dataset. One for historical hurricane tracks was central to the project, so it was included. Those for hospitals, oil refineries, power plants, and natural gas processing plants were included to provide insight about the economic aspect hurricane events. Of course, a feature class including U.S. cities with a population of over ten thousand was necessary to evaluate the impact of storms on human life. Lastly, the a feature class including state boundaries was necessary, especially when conducting queries, in order to filter data relevant to the Gulf Coast region.

The nature of the entities of our database is unique. Hurricane tracks are an abstract concept and have no physical implications in the real world. This certainly holds true regarding the entities we are interested in: cities, hospitals, power plants, oil refineries, etc. As a result, there seems to be no necessity for topological rules or any meaningful relationships. Furthermore, because of the data’s large scope and relative simplicity, we also felt there was not much point in implementing domains and subtypes. These points are further reinforced by the fact that the geodatabase is built and meant to be used through PostgreSQL. Thus, the main focus of the database will be on its application through the use of spatial queries and visualizations, which we will go into detail later.

So, when it comes to the ER Diagram, there is not much useful information it can provide. Simply, it would just be the *hurricane* entity, having an M-N relationship with the rest of the entities (with their own unique attributes). Actually, for each of the different types of infrastructure, it would also have a relationship with cities and states. Not only that, but cities and states have relationships with each other. This unnecessarily complicates the design, even though in practice it is relatively simple. As mentioned before, these relationships are almost meaningless in our implementation. Therefore, we believe it is not needed for the implementation and is not included here.

Similarly, there will be several new (and relatively pointless) relations created in logical schema because of these M-N relationships. Also, none of these entities would have foreign from each the other. In theory, they should, but, in practice, for this project, it is not. Once again, due to previously discussed reasons, this will not be of much use to our project and will not be included here.

**Database implementation:**

For this project, we included 7 feature classes: hurricanes, usa\_major\_cities, states\_shapefile, hospitals, petroleum refinery, powerplants\_us\_eia, naturalgas\_processingplants\_us\_2012. More information about these classes can be found in the table below.

|  |  |  |  |
| --- | --- | --- | --- |
| **Name** | **Source** | **Geometry** | **Relevant Attributes** |
| hurricanes | MapCruzin.com | line | name, year, wind\_mph |
| usa\_major\_cities | ArcGIS Hub | point | name, population, families |
| states\_shapefile | ArcGIS Hub | polygon | state\_name, state\_code |
| hospitals | HIFLD database | point | name, id, address, beds |
| petroleum\_refinery | EIA | point | site\_id, company, state |
| powerplants\_us\_eia | EIA | point | plant\_code, plant\_name |
| nautralgas\_plants | Stanford Digital Repository | point | plant\_name, state |

Table 1. Important Information about the feature classes used.

For the actual implementation, we would need to find the corresponding shapefiles online from organizations like ESRI and EIA (Energy Information Administration). Since these datasets are already populated, we then simply imported them to a newly created database on PostgreSQL — ensuring to assign the appropriate SRID value for each. Then we conduct queries and visually verify the result ArcGIS pro to understand the behavior of these classes. Here we check for incomplete data and issues with formatting and spatial information. We repeat these steps as needed until the database is sufficiently functional.

**Database Applications**

In this part, we will try to answer some questions regarding the objectives we have mentioned at the beginning of this paper. This way, we will be able to gauge the usefulness of the database when it comes to acquiring insight about hurricanes and the Gulf Coast. We can achieve this by running several queries on PostgreSQL with increasing complexity and producing a couple of visuals at the end.

First, we might be wondering, for a specific state and season, which hurricanes made landfall, and what were their maximum speeds over land? The query to answer the question and the subsequent result is displayed below.

1. A screenshot of a computer

   Description automatically generated
2. A screenshot of a computer program

   Description automatically generated

Figure 1. (a) The spatial query used. (b) The resulting table after running the query.

As we can see from the results, 2004 seems to be a destructive season for Florida — two major hurricanes landfalling with wind speeds of at least 120 mph (miles per hour). Indeed, the 2004 Atlantic season was one of the costliest of all time. Hence, this query explored the first objective with regards to Florida in 2004.

When considering hurricanes of all seasons, we might ask: which ones have made landfall over Texas? How many cities were affected? What is the combined population of these cities? For this, we need to use a spatial query that selects cities within a fixed distance of a hurricane’s historical track. In this example, we used an arbitrary, conservative distance of 25 miles, which is 0.362 degrees. We use degrees here since the spatial reference of the *hurricanes* table uses angular units.

1. A screenshot of a computer code

   Description automatically generated
2. A screenshot of a data

   Description automatically generated

Figure 2. (a) The spatial query ran for this question. (b) The resulting table.

Now we can see, historically from this dataset, 23 storms have made landfall over Texas. And for one of them, there does not seem to be any cities affected under our criterion. Hurricane Alicia, a Category 3 hurricane in 1983, seems to be the most impactful with over 9 million people affected. There are 11 other hurricanes with a total population of affected people surpassing 1 million. Thus, it seems that Texas, overall, has been impacted by hurricanes over the past century or so. This addresses the second objective we have mentioned, which was assessing population impact.

What about infrastructure? For all Gulf Coast-landfalling hurricanes, how many locations of different types were affected? As with the previous query, we use arbitrary values for the distance an infrastructure needs to within of the hurricane track. Multiple left joins were used so that, even if a hurricane has not affected any infrastructure, it will still be included in the result.

1. A screenshot of a computer code

   Description automatically generated
2. A screenshot of a computer

   Description automatically generated

Figure 3. (a) The spatial query used for this example. (b) The resulting table of 64 rows (only first 21 are shown).

From this dataset, we see there are 64 hurricanes that made landfall over the Gulf Coast. 16 of them affected more than 100 hospitals, 6 affected more than 150 power plants, and 8 had affected more than 25 natural gas processing plants. For a relatively small sample size of 64, these are significant results. This query in specific relates to the third objective we have established: infrastructure vulnerability assessment.

Transitioning to more a visual analysis, we consider all hurricanes and their impacted areas in the region — what is the overall, combined impact area during the entire period? To answer this question, a complex query involving several steps is required. Specifically, we need to unionize the buffers of each hurricane track that made landfall over the Gulf Coast. Then, we would need to intersect the result with the states in the region (Texas, Louisiana, Mississippi, Alabama, Florida). We save the end result as a table, which we can view as a feature class in ArcGIS Pro.

1. A screenshot of a computer code

   Description automatically generated
2. A map of the united states

   Description automatically generated

Figure 4. (a) The spatial query that creates a table for the result. (b) The table viewed in ArcGIS Pro.

As expected, for the relatively small states of Louisiana, Alabama, Mississippi, and for the narrow state of Florida, almost all the state has been affected by at least one storm. Even for a big state like Texas, almost all the southern and eastern portions have been affected by hurricanes as well. This gives us an idea of the potential scope of the impact of hurricanes in the region. Once again, the first of our objectives is addressed here.

Finally, we can use ArcGIS Pro on its own to produce interesting and telling visuals. The previous query does not necessarily tell us about the frequency with which these areas have been hit by hurricanes. Basically, how can we visualize the concentration of hurricane landfalls in the region? ArcGIS Pro has a useful geoprocessing tool called *Kernel Density* which does exactly that. Naturally, we need to use the tool on the *hurricanes* feature class.

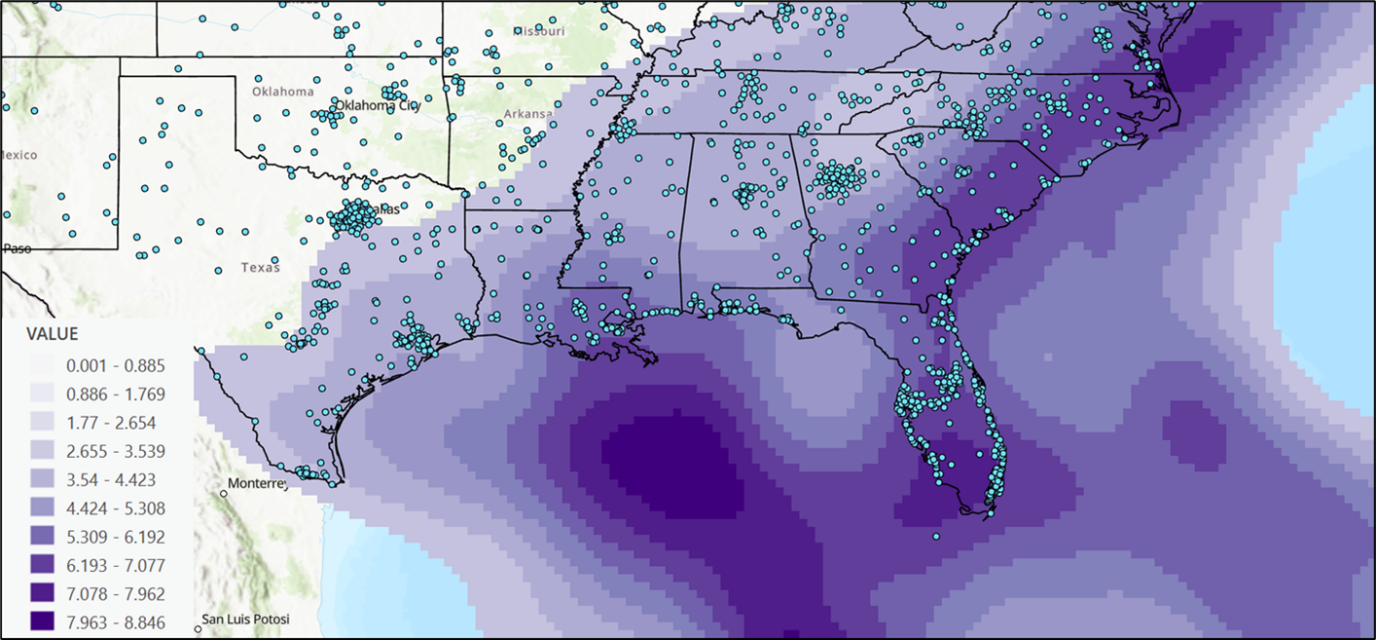


Figure 5. A kernel density map representing the concentration of hurricane landfalls in the region.

From the map, we can see that the Baton Rouge and Florida Keys areas have been affected the most in the region, with 6 landfalls or more in the past. This observation is expected and well-known among hurricane experts. More interesting, almost the entire coast has historically suffered at least 3 landfalls. In this way, we are able to identify specific areas which we might want to investigate through further queries. Thus, this is another example of how we can answer questions involving temporal hurricane analysis, the first objective.

**Discussions**

The biggest challenge, by far, was obtaining suitable data for the hurricane tracks. In recent times, NOAA (National Oceanic and Atmospheric Administration) has been protective of their data. As a result, it is extremely difficult to find up-to-date datasets. For the ones that are out there, most of them are point classes or, oddly, have invalid geometries. The dataset that I did end up using does not have these issues, but it only has hurricane tracks for landfalling Atlantic basin hurricanes before 2005. This is not a significant issue, because we are only interested in hurricanes that made landfall over the region anyway. Ideally, for future iterations of the project, we would love to incorporate an up-to-date dataset with a breadth of information.

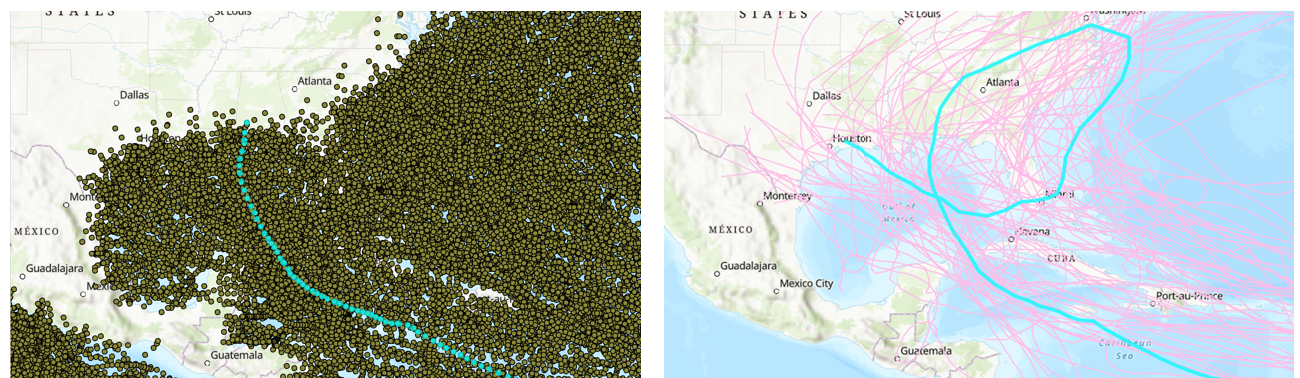


Figure 6. Another issue of finding hurricane datasets. Discrepancies in data. Different tracks shown for Hurricane Ivan (2004).

Since all the other feature classes are centered around the *hurricanes* one, they all need to have its spatial reference system. So, trying to make that happen was a tedious task. We could have worked with different spatial reference systems, but, for the sake of time and smoothness of subsequent queries, it is more ideal to have all the same.

The second objective we mentioned earlier is pivoted on the socio-economic aspects of hurricane events. We would like to have data about the income, development, and demographics of the region in order to examine the potential long-term impact. However, it was difficult to find free, public datasets that can be easily integrated in our current database. But it is definitely an aspect of the project we would look to implement in the future.

A crucial aspect to any database is the need for filtering and/or cleaning the data. Doing so, we can identify any potential discrepancies or errors in the formatting in the data. However, once again, due to time constraints and the scope of our data, it was not feasible to take this step. Thankfully, querying the database seemed to work well regardless. Of course, it is something to look into as the database grows in complexity in the future.

To refine the database for better usability in ArcGIS Pro, regarding data integrity, we could implement range domains for the coordinates/wind speeds of the hurricanes and coded value domains for the different types of infrastructure. Furthermore, we could implement subtypes for the hurricane tracks when it comes to their wind speeds and respective categories. Of course, we can also add non-spatial components to the infrastructure and population aspects of our database.

**Conclusion**

Overall, we consider this project a success — the big picture revealed itself, both quantitatively and qualitatively. As we have seen throughout the report, a variety of questions regarding our objectives have been answered through different queries. Our database is comprehensive enough so that we can tailor queries according to year, state, infrastructure of interest. In fact, we could obtain even more detailed analysis based on more complex queries, especially after gaining a greater in-depth understanding of PostGIS. However, further refinement and expansion of the database is required to realize its full potential.

The theme regarding our shortcomings is the lack of accessibility to sufficient datasets — the root of all previously discussed issues. It seems like organizations are becoming more protective of their data as technology advances and reaches more people. Perhaps, in the future, collaboration with relevant organizations could be extremely beneficial in increasing the usability and scalability of the database. More datasets can be added to expand beyond the current scope of our project and achieve more meaningful objectives and outcomes.

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