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Visualizing Uncertainty in Predicted Hurricane Tracks

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Hurricane Prediction Visualization

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Abstract

Although the past 30 years have seen major advances in the scientific understanding of hurricane forecasting, there has been a lack of systematic research on people's comprehension of displays used to show these forecasts. One of the primary visual aids is the *error cone*, also known as the *cone of uncertainty*, an example of which is shown in Figure 1. The center line represents the predicted hurricane track. The width of the cone is determined by considering historical forecast errors over a five year sample, and represents a 67% likelihood region for the hurricane track .

One of the primary challenges of this model is that that most people have difficulty in understanding the probabilistic concepts that are used to communicate uncertainty. For example, it tends to give the impression to those inside the cone that they have an exaggerated chance of being in the hurricane's path, while those outside of the cone tend to feel a false sense of security.

To address this, we have developed a new method of visualizing the possible projected paths of hurricanes using the current projected path of a given hurricane as well as the historical data of previous hurricane paths, displayed in Figure 2. The goal is to maintain a display that shows a wide range of possible outcomes, while maintaining the statistical characteristics of the error cone.
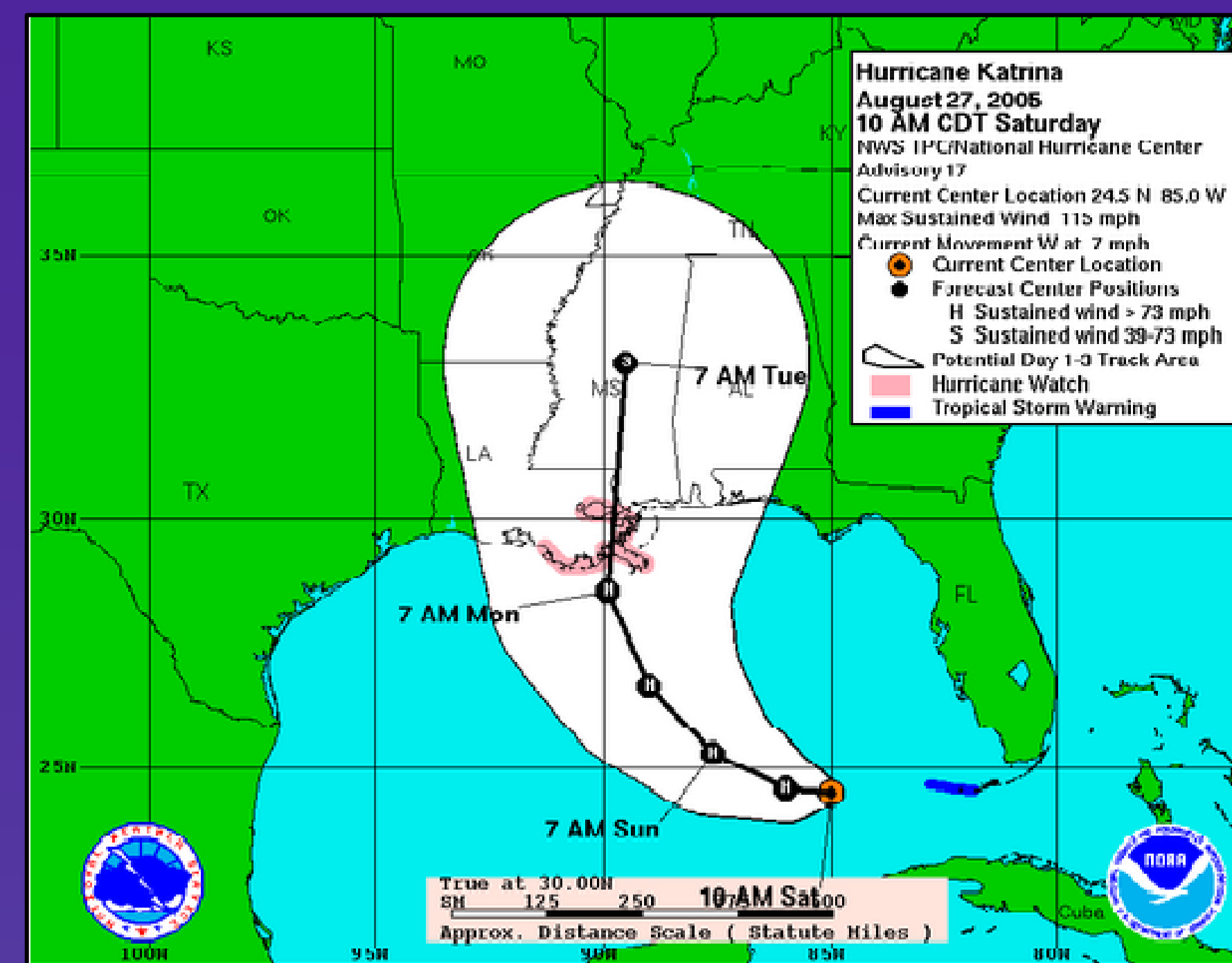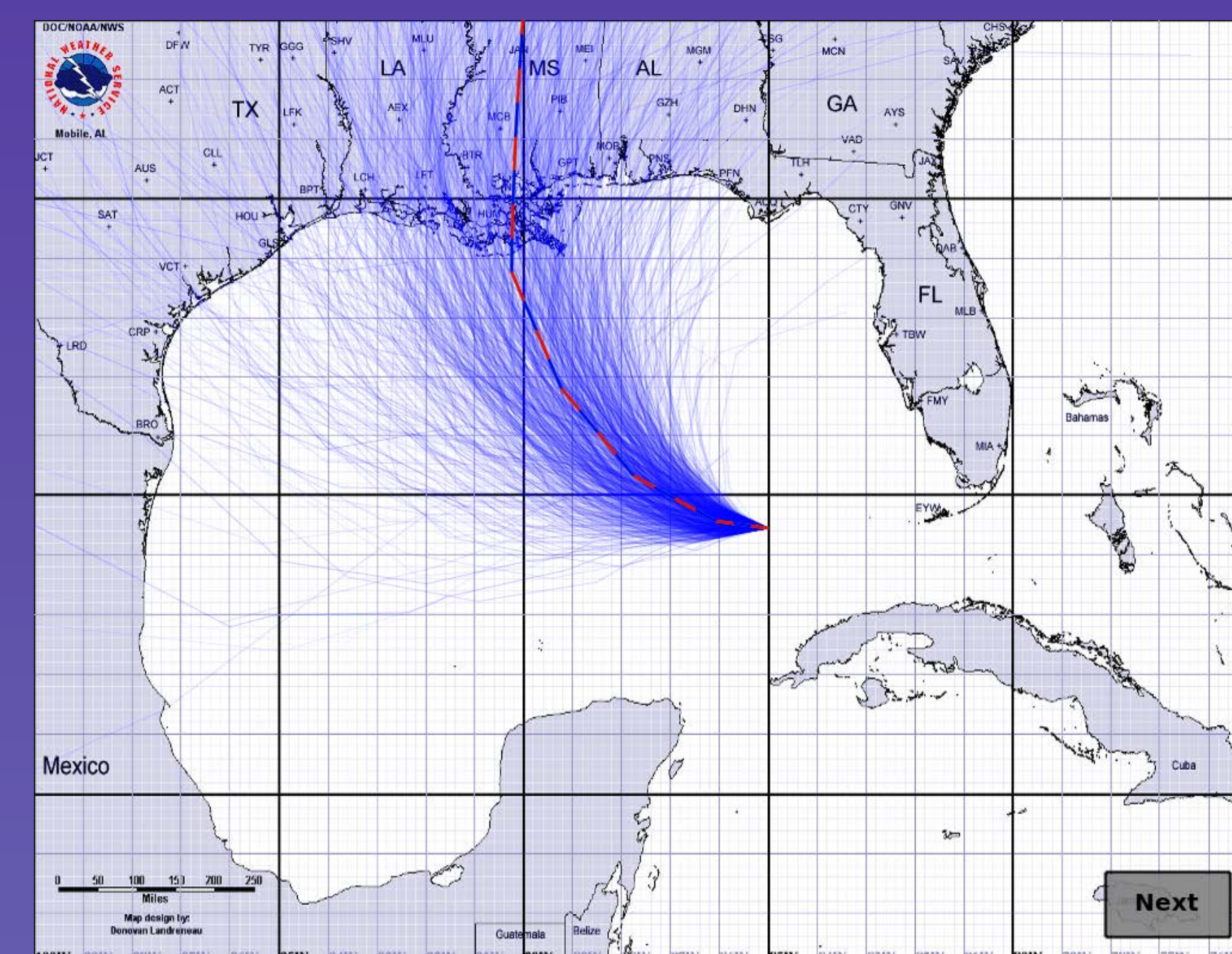
Figure 1: Error Cone for Hurricane Katrina

Figure 3: Projected Paths for Hurricane Katrina

Visualization

To show the wide variety of hurricane paths consistent with the predicted path, we rapidly and continuously generate a set of representative paths using the algorithm described above.

These paths are overlaid on top of each other, as shown in Figure 3. Combined, they create a web of paths with statistics consistent with the cone of uncertainty. To keep the paths from becoming too cluttered and indistinguishable, old paths fade out over time.

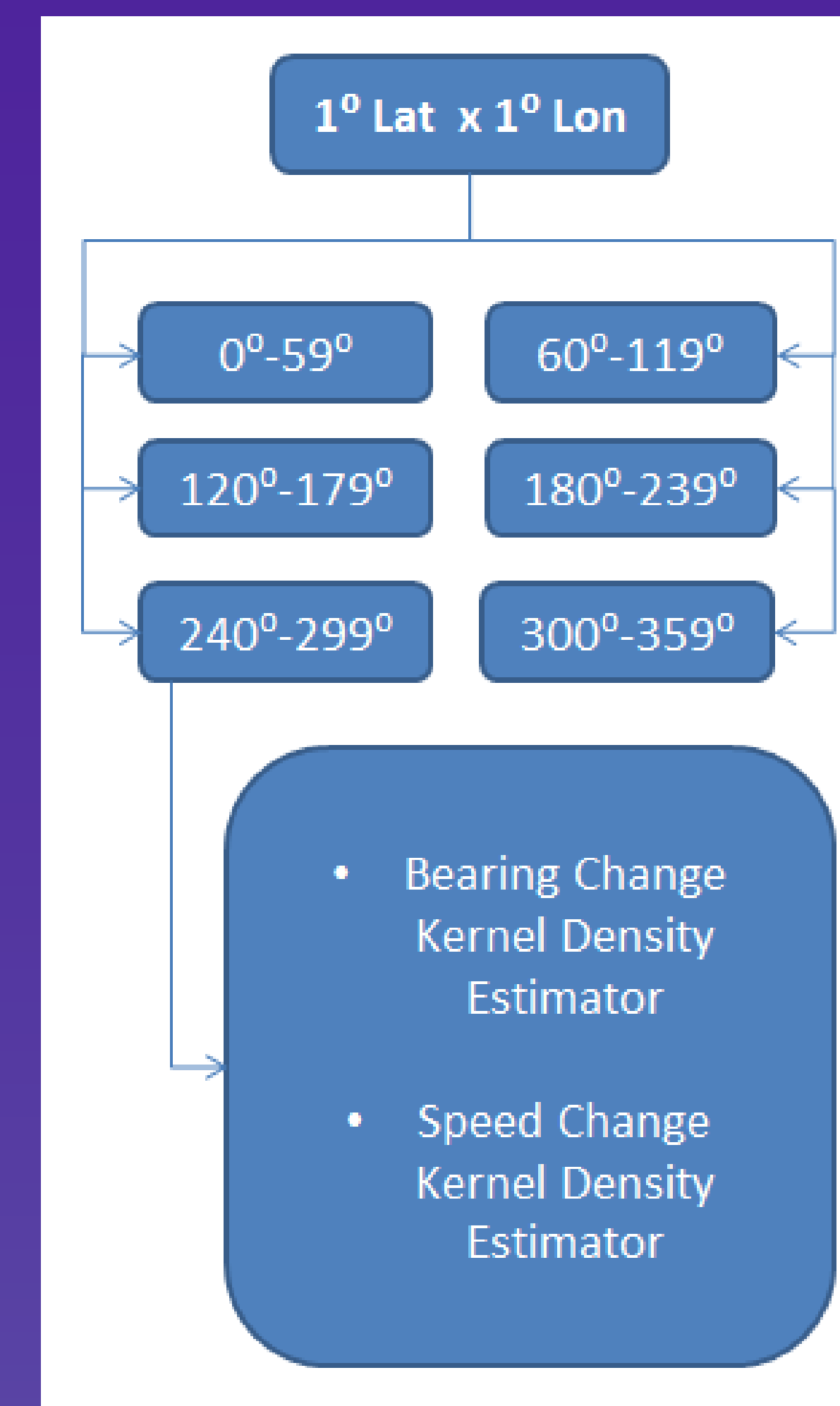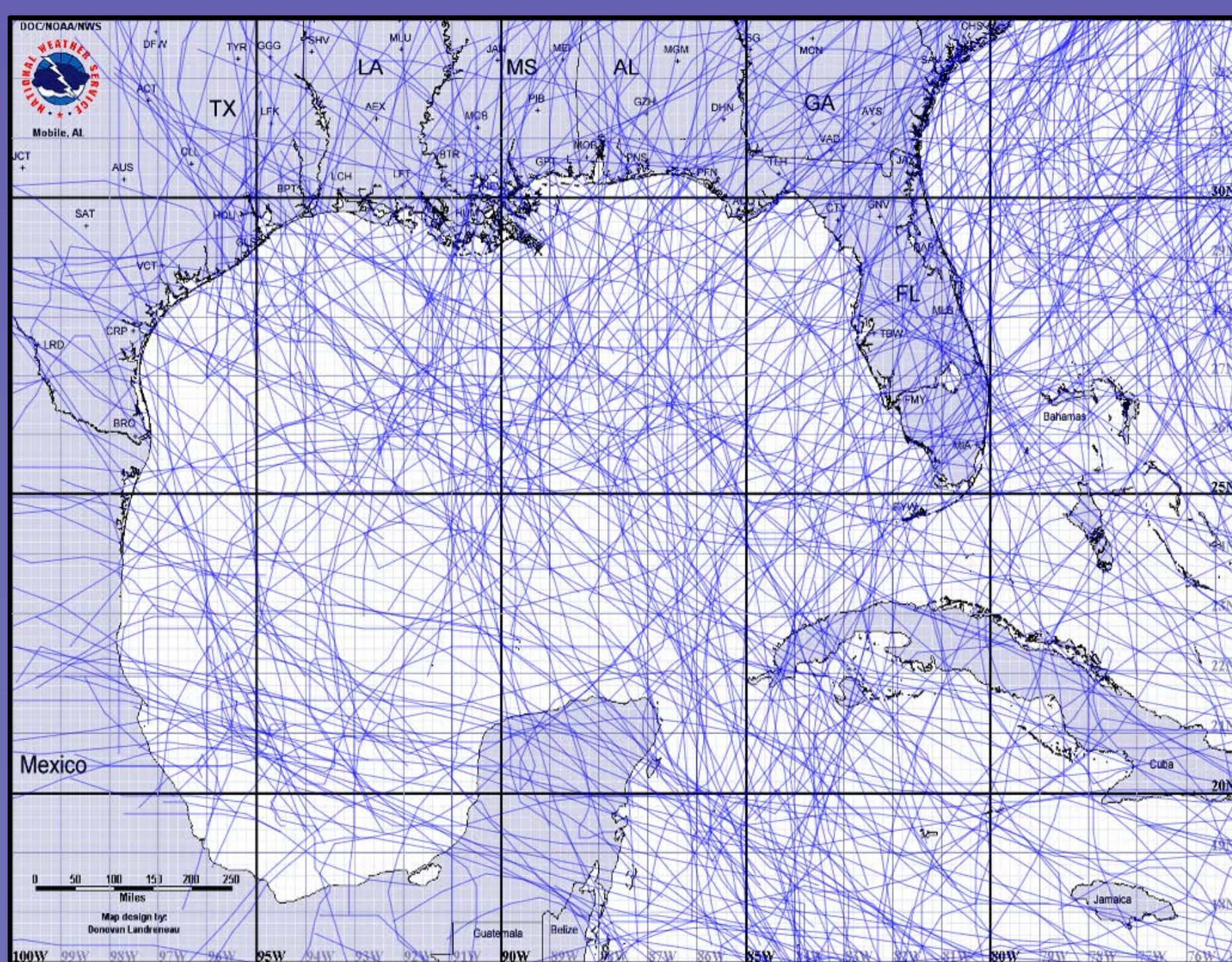Figure 2: Historical Path Data Since 1945

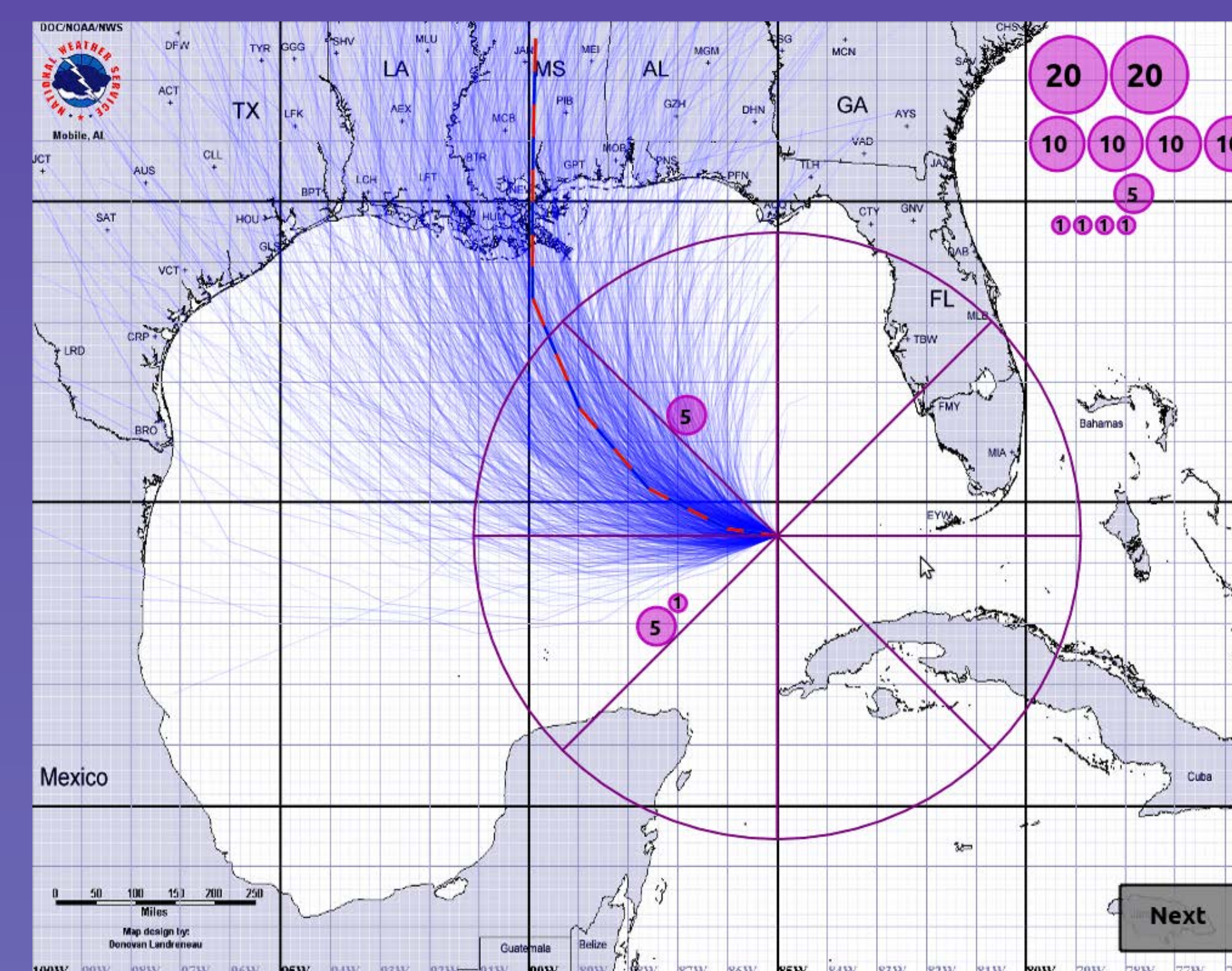Figure 4: Data Structure for Historical Paths

Figure 5: Planned Experiment

Path Construction

Generation of a single projected hurricane path starts with the current location, speed and bearing. The algorithm uses current advisory data and historical information from past hurricanes, dating back to 1945, to predict a change in location, speed, and bearing after a three hour time step. Repeating this process for a total of 69 hours yields a single projected hurricane path.

The predicted data from an advisory is used to create two time varying probability density functions for each three hour segment of the predicted path. One function represents the range of bearing changes contained inside the error cone at a specified time segment, while the other represents the range of speed changes. Each half of the probability density function governs one half of the error cone, with the predicted path's value falling in the middle.

The historical data is used to construct two kernel density estimators, which are stored in the data structure as described in Figure 4. It is organized as a two dimensional grid where each cell covers one degree of latitude and one degree of longitude. Each grid cell contains a set of bins that spans a 60 degree range of bearings. We determine which grid cell each historical hurricane enters. The bearing and speed differences between each entry point and exit point are stored in the bin in the cell that corresponds to the entry bearing. For each of these bins, a kernel density estimator is used to build a probability density function around these speed and bearing differences

When generating a projected path segment, the current ensemble of generated paths is used to determine whether to use historical or predicted data to find the next bearing and speed change. When more than 68 percent of the generated paths lie in the cone, then we use historical data, otherwise we use the predicted data. If historical data is to be used, the current latitude, longitude, and bearing of the generated path determines which probability density functions to sample from our data structure. If predicted data is to be used, the current elapsed time of the generated path determines the appropriate probability density functions to sample. We then randomly generate a bearing difference and speed difference that are drawn from the selected distribution functions.

The bearing and speed differences are used to calculate which direction the hurricane will travel from its current location, and how its speed changes. Using the new speed and bearing, we project ahead one time step. This process is repeated until the entire path has been generated.

The goal of this technique is to create a wide diversity of possible hurricane tracks while having the statistical information of our ensemble of generated paths match that of the error cone.

Future Work

Our next step will be to verify whether the resulting visualizations are beneficial in communicating the idea of the probabilistic nature of hurricane paths. This will be done with a user study that aims to test for any differences in how users estimate the hurricane strike probability distribution when using our method compared to the error cone. Users will be asked to place a set of numbered chips on a circle centered over an advisory's hurricane position to indicate their estimate of the probability that the hurricane will exit the circle in given sector, as shown in Figure 5.

We also plan to use this method as a base for other visualizations. One possible visualization would be to superimpose our method over the error cone, so that both summary statistics and detailed outcomes can be viewed. One such variation would be to generate paths for a time duration that matches the evacuation time frame for a particular area.

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