Wind Speed Estimates for Hurricane Evacuation

Developing a Method to Determine the Changing Uncertainty in Wind Speed and Track Predictions as a Hurricane Approaches Landfall

Geoffrey Dilg

Mentors: Dr. Rachel Davidson, Dr. Palm Apivatanagul

November 18, 2010
1. Introduction:

The vast majority of people across the United States have heard of Hurricane Katrina. Hurricane Katrina was an especially devastating and powerful example of the many hurricanes that occur every year. Unlike tornadoes, hurricanes and tropical storms develop offshore. From there they may continue out at sea until they dissipate, or they may travel towards land, make landfall and continue onwards until dissipating. When they do make landfall, they can cause large amounts of damage through a combination of high wind speeds and flooding. However, because they develop off-shore, hurricanes and tropical storms can be tracked and monitored, a fact which, in the ideal, may allow proper time and warning for necessary evacuations to take place.

When a hurricane is approaching the shore, decision-makers have to make important choices that will determine whether or not people are able to safely evacuate the impacted area. A key aspect of making evacuation decisions is knowing how long to wait before issuing the evacuation order. If decision-makers wait too long, people in critical areas will not have enough time to evacuate; but if they do not wait long enough, they will not have an accurate enough location for the hurricane's landfall and therefore not enough information about which populations to evacuate and where to safely direct them. This could result in inefficient or even incorrect evacuation choices. If resources are allocated incorrectly, those who need the most help may not be able to receive it when the time comes. The ability to choose well between various evacuation alternatives often hinges critically upon predictions of the hurricane's severity in each of the possible geographic areas.
2. Project Description:

Considering the importance of accurate information in evacuation planning, the final goal of my project is to develop a new method that will be implemented in a program aimed at aiding in the determination of when and where to evacuate people in anticipation of a hurricane making landfall. In developing this program, I will be using a combination of Matlab and Geographic Information Systems (GIS) software, and will be using North Carolina as a case study area. I have access to a large data file, containing trajectory and wind-speed data for 15,000 synthetically developed hurricane scenarios, which I will use to determine, for the given location, how the estimated maximum wind speeds and the uncertainty associated with those estimates change as a hurricane approaches. I will write a code, using Matlab, which will perform the necessary calculations and then compile the data for presentation. I can then use GIS software, such as Manifold, to interpret the data in the form of a map showing a county in the state, the hurricane’s expected maximum wind speed there, and the uncertainty associated with that estimate. As the hurricane progresses, increasingly more accurate predictions can be computed.

Once I am able to apply this method to a specified location on shore (for each time step), I will then expand the process to be able to make predictions for each county in the state. The final product will give wind speed estimates for each location on-shore, and show the uncertainty associated with each prediction. Since the novelty in this method lies in the uncertainty measurements – its ability to calculate and show how the uncertainty of the predictions changes over time – this final stage of the project is very important. Figure 1 is a visual representation of what the program will accomplish.
Figure 2.1, Schematic representation of model output

The first panel of Figure 1 shows the location of the hurricane at the beginning of the observation (t = 0); the second panel shows the location of the same hurricane after 6 hours (t = 6); and the last panel shows the location of the hurricane after 12 hours (t = 12). The small graph above each panel shows the probability density function (pdf) of the maximum wind speed for the specified location based upon the current location of the hurricane at each time increment. As can be seen, the pdf curve narrows over time. This shows the decreasing uncertainty of the maximum wind speeds that will be experienced by that particular area over time.

In the beginning, as I am developing the code, only a small sample of the data will be used to test the program. This will allow for a more manageable trouble-shooting and refining process. Once I am certain that the code is working properly, I will apply it to the full collection of data for
North Carolina. In the end, extensive testing and trial performance will have to be done to ensure the accuracy and serviceability of the model in predicting hurricane patterns. The process also involves consulting reports of past hurricane events and comparing their outcomes to those predicted by the model to test accuracy and reliability.

3. Research Question:

Using data from simulated hurricanes, can a program be developed which can give reasonable estimates of wind speeds and the uncertainty associated with these wind speed estimates as a hurricane approaches the shore of North Carolina, thus aiding in evacuation planning?

4. Objectives:

First, I will develop a method to calculate the change in the estimate of wind speed and the change in the uncertainty surrounding that estimate for each location in the onshore study region as a hurricane approaches landfall.

Next, I will implement the new method in a program using Matlab software.

Finally, I will apply this program to the state of North Carolina as a case study. At first, I will focus on developing the method for one specific hurricane origin offshore and one specific location onshore in order to limit the amount of parameters that must be considered and controlled in generating and evolving the program. As I plan to continue this research for my senior thesis, I will work on extending the method to be applicable for any offshore origin and all onshore locations in the study region.

5. Literature Review:

HURREVAC is one of the more prominent programs currently in existence that aids in evacuation decision-making. It stands for “HURRicane EVACuation” and is a “...restricted-use
computer program funded by FEMA and USACE for government emergency managers to track
hurricanes and assist in evacuation decision-making for their communities” (HURREVAC). The
program pulls real-time forecast data from the National Weather Service and the Tropical Prediction
Center/National Hurricane Center to determine when tropical storm winds will arrive in an area. It
then extracts data about that particular area from a local Hurricane Evacuation Study in order to
calculate the Evacuation Clearance time of that area. It then subtracts the Evacuation Clearance time
from the expected arrival time of tropical storm winds to determine a suggested Evacuation
Decision Time.

There are a variety of other programs in existence that seek to aid in evacuation decision-
making. However, HURREVAC is widely used in the United States, and is one that makes estimates
about wind speeds in a way similar to the program I will be working on, which is why I chose it as
an example for this literature review. The key difference between HURREVAC and my method is
that mine will show the uncertainty associated with a given prediction, allowing one to see how that
uncertainty changes as the hurricane approaches landfall. This is significant because the probability
that a prediction is correct plays a determinant role in deciding how to act upon that data.

6. Data:

I will draw upon two sources of data for the creation, implementation and presentation of
this program. The first source is a set of 15,000 simulated hurricanes, which the program will draw
upon to make its estimates. The second source is data from past hurricanes such as Floyd, Bertha,
and Fran, which I will use to test and demonstrate the program.

To be able to implement the program in a real world situation, it will also become necessary
to consult existing information on the availability and location of evacuation shelters throughout the
case study region. Toward this end, I will also be making extensive use of several of the most up-to-
date catalogues of North Carolina's shelter locations.
7. Methodology:

As preparation for my involvement in this project, I have previously gone through a number of hurricane reports. This research formed a part of another assignment, related to the overall hurricane evacuation project, for one of my mentors, and these reports will provide some of the basis for my continued work on the project.

There is a database of approximately 15,000 synthetic hurricanes available for use in this program. To begin with, I will consider only a small portion of these hurricanes for testing and implementing my program, which will help to simplify the process as I work on improving the code for the program. Once I have a successfully running code, I will expand my input data to use more of the hurricanes from the database. This will allow the program to provide a more complete idea of what conditions to expect in case of an approaching hurricane.

In terms of the development of the program itself, as mentioned above, I will be using a combination of Matlab and Geographic Information Systems (GIS) software. The Matlab program will be used for computing the relevant information, whereas the GIS software, such as Manifold, will be used to present this information in the visual form of a map. This map will show a wind speed prediction, and an associated uncertainty, at the given location on shore.

8. Additional Comments:

The hope with this project is that it will eventually act as an important aid in evacuation decision-making by assisting our understanding of what to expect in each potentially affected region. Such decisions rely heavily upon predictions of the expected severity in each area. With this program, those who must choose if and when to evacuate a region will have at their disposal a representation of how the uncertainty in maximum wind speeds estimates changes as a hurricane approaches, allowing direct tradeoff between evacuating early when uncertainty is high and evacuating later when uncertainty is reduced, but there is less time to move. This program will be
able to aid in a real time event because it projects estimates for final wind speeds that will be experienced by different areas of a state based upon the hurricane's current location and conditions.
Findings:

1. Input

For this project, I am using a database of synthetic hurricanes that form the basis for the program's estimations and conclusions. Each synthetic hurricane in the database has its own file containing each 6-hour time step of that particular hurricane and other pertinent information. Another set of files contains wind speed information for each zip code in North Carolina. Each zip code has its own file with wind speed information from each of the synthetic hurricanes that affects that area. I will be combining the information from these two sets of files to calculate the wind speed estimate at each location, and the associated uncertainty, based on the current location of the hurricane that is being monitored.

2. Model

In order to implement my method I will be developing a program in Matlab. This program will take the data from the synthetic hurricane database as input and store it for use. It will then establish a small grid made up of equal sized cells centered on the origin point of the hurricane that is currently being monitored. This grid will give the program the criteria upon which to decide which hurricanes will be included in the list of candidate hurricanes for use in calculating the wind speed estimate and its associated uncertainty. Because the database includes the maximum wind speed that each hurricane will cause at the designated location on-shore, calculating a wind speed estimate from the current location is quite feasible. However, the program will also take the next step and calculate it for each of the cells adjacent to the cell of the hurricane's current location.

The reason for performing this calculation is to aid in planning, assessing risk, and determining uncertainty. This calculation will be performed by determining the list of candidate hurricanes for each of the adjacent cells and calculating a wind speed estimate for each cell, for the
location on shore. Through this, we can show several different possibilities of how the hurricane could develop, as well as how much the wind speed estimate for a given location could change if planners were to wait an additional 6 hours before making a decision. Showing the different possibilities gives planners an idea of how the anticipated impact of the hurricane may change and allows for the development of several possible evacuation plans before the final decision time arrives. We will also be able to calculate an uncertainty level associated with each grid cell possibility.

The final version of this project, which will be completed as my senior thesis by the end of my senior year, will be applied to every zip code in North Carolina. The finalized versions of some aspects of the model are still being considered and discussed. For example, there is still a question as to whether it would be more advantageous and accurate to replace the grid cell system with a series of quadrants based on circles of incremental radii. In this scenario, a Polar coordinate system, as opposed to a Cartesian coordinate system, would be used. This and other aspects of the program have yet to be finalized and will likely be tested and tweaked throughout the process of creating the program.

3. Output

The program will output data in a tabulated format that can be used by GIS software to represent the data visually. The idea is to output a series of maps, which decision makers can use to aid in their evacuation planning process. There will be a map containing the wind speed estimates and their associated uncertainty, for each zip code, based on the origin square of the grid. Another two maps, containing wind speed estimates and their associated uncertainty for each zip code, will be generated for each of the adjacent grid cells that contain candidate hurricanes. These maps will provide valuable information for decision makers.
4. Example

As a way to illustrate the use of this program, I have decided to use a hypothetical scenario in which the program is applied to an oncoming hurricane but only nine historic hurricane tracks are used instead of the 15,000 synthetic hurricanes. Figure 4.1 shows the nine hurricane tracks with a grid system laid down to exemplify what the grid system itself will be like:

![Figure 4.1, NOAA historical hurricane tracks](image)

In this case, we take square A2 to be our origin square, containing all of the nine synthetic hurricanes as candidate hurricanes since they all start within that square. As we can see, the adjacent squares, to the origin square, containing hurricane tracks are B2 and A3. These two grid cells will form the basis for the next step of possibility mapping. The data from these squares will be used to build an event tree of hurricane occurrence. Figure 4.2 shows an event tree for the current hurricane set built from the starting point, at time step = 0, to the fourth time step.
We can see in the diagram how the event tree branches off at each time step. Although a visual representation of the event tree will not be included in the model’s output, the general theory and approach will be applied to the grouping of different possible outcomes in subsequent time steps and to how I will be determining the probability associated with each possible scenario.

5. Related work performed

While working on my main project, I was simultaneously working on a shelter-mapping project related to the overall hurricane evacuation project, of which my main project forms a part. This secondary assignment consisted of two different tasks. The first was mapping out evacuation destination information from past hurricane events in North Carolina, using GIS software. I had previously compiled the evacuation destination information last semester. My task involved pulling
North Carolina census map data and track information from each of the past hurricanes, and then combining that with the evacuation destination data in a single map. The purpose of this part of the project was to observe on a map where and how far away people were likely to evacuate from the path of the hurricane. Figure 5.1 shows an example of what one of the maps ended up looking like.

![Figure 5.1, Mapped evacuation destinations during Hurricane Floyd](image)

The second part of the project involved mapping out one of two previously compared lists of evacuation shelters in North Carolina. I had already gone through and compared these lists last semester, cross-checking the data to find which shelters were included on both lists and which only appeared on one or the other. This summer, for this particular project, I was given the task of geocoding both lists and mapping both of them out to further compare them and to have a map of
shelter locations for use in the overall hurricane evacuation project. Although GIS has a geocoding option and is able to perform the operation automatically, my software was only able to successfully geocode roughly half of each list. As a result, the rest of the list was manually geocoded using “Google Earth”. Figure 5.2 shows the mapped addresses.

![Figure 5.2, Mapped shelter addresses](image)

Though this information does not relate directly to my main assignment of developing a program, it does relate directly to how this program will be implemented. The wind speed estimates, hurricane path predictions, and the associated uncertainties are the relevant pieces of information that my program will provide. This information can then be used to determine the areas that will be the most likely to need an evacuation order. The very next step is when shelter information becomes critical. Once the areas to be evacuated are determined, decision-makers and residents alike will need clear information as to nearby, secure shelter locations and the amount of time it will take to move everyone from the most severe areas of impact to these relatively safer destinations.
6. Conclusions and future work

Many aspects of this project are still being discussed and considered. Even now, I suspect that there are a vast number of considerations that won’t come up until I am deep into development of the program. As I mentioned in the proposal section of this final report, I plan on continuing my work on this project as a senior thesis next year. Within the next year, I hope to fully develop the program and apply it to the entire state of North Carolina. Using what I have gained from this summer REU program, I also hope to represent the data in such a way that it is both quickly and easily read, and can be useful to evacuation planners.
Works Cited:


References:


