Reconstructing the Path of Hurricane Isabel Using Wind And Pressure Data

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Abstract

The path of Hurricane Isabel was reconstructed using the variables pressure, wind speed, and wind direction. The 36-hour time period between 12AM on September 18, 2003 and 12PM on September 19, 2003 was selected for formal analysis and separated into six six-hour time periods. Maps were constructed for average pressure, average wind speed, average wind direction, pressure range, and wind speed range in order to display Hurricane Isabel’s path. Maps displaying average pressure revealed the path of Isabel through the lowest average pressure values and maps displaying high average wind speed values and counter-clockwise circulation displayed the general circulation of Hurricane Isabel after landfall. All three variables were necessary to get an accurate picture of Hurricane Isabel’s path.
Acknowledgements

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Introduction

The path of Hurricane Isabel will be reconstructed using the variables pressure, wind speed, and wind direction. Maps will be made displaying average pressure, average wind speed, average wind direction, pressure range, and wind speed range. The stations displaying the lowest average pressure and the highest average wind speeds are important to observe because they are key predictors of Hurricane Isabel's path. The circulation of Hurricane Isabel is also important to observe when examining the average wind direction throughout the time period selected for formal analysis. The three selected variables will clearly demonstrate the path of Hurricane Isabel within the 36-hour time period surrounding Isabel's landfall on September 18, 2003.
Impacts of Tropical Cyclones

Tropical cyclones can wreak havoc on areas that they come in contact with. Not only do tropical cyclones have important impacts on the human population and the physical environment, but they also play a role in economic interactions both locally and worldwide. Human fatalities, the destruction of communities, and economic losses and gains are just some of the effects of tropical cyclones.

Tropical cyclones are severe rotating storms that occur during the warm seasons over most of the tropical and subtropical oceans of the world (Pike, 2001). They are low-pressure systems with organized convection (thunderstorm activity) and definite cyclonic surface wind circulation (Holland, 1993). The most commonly used names for tropical cyclones are hurricane (in the North Atlantic Ocean, and the Northeast Pacific Ocean), typhoon (in the Northwest Pacific Ocean), and cyclone (in the Indian Ocean), as shown in figure 1.

In order for a tropical cyclone to form, certain conditions must be met. The formation of a tropical cyclone begins with thunderstorms that exist over the ocean. The seawater must be at least 80°F to a depth of 150 feet or more, the air must be warm and humid, and upper-level winds should be weak and preferably blowing in the same direction the developing storm is moving (Abbott, 1999). An area of low pressure must exist that is at least 300 miles from the equator that can draw in converging winds and thunderclouds that rotate in a counterclockwise direction (NOAA, 2003). Hurricanes cannot form within five degrees of the equator because the Coriolis force is too weak there and cannot initiate the wind motion (Lutgens & Tarbuck, 2001).
Common Areas Where Hurricanes Form

Fig. 1. Map of common areas where hurricanes form, typical paths they travel, and annual percentage of the Earth’s large cyclones occurring in each region. They are called different names in various parts of the world.
The strengths and damages of tropical cyclones are described through the Saffir-Simpson scale (Table 1). The scale places cyclones into categories based on barometric pressure, wind speed, and storm surge. The categories then help to determine the likely damages linked with a particular cyclone (Lutgens & Tarbuck, 2001).

**Saffir-Simpson Hurricane Damage Potential Scale**

<table>
<thead>
<tr>
<th>Category</th>
<th>Barometric Pressure (mb)</th>
<th>Wind Speed (mph)</th>
<th>Storm Surge (feet)</th>
<th>Damages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>over 980</td>
<td>74-95</td>
<td>4-5 ft.</td>
<td>Minimal</td>
</tr>
<tr>
<td>2</td>
<td>965-979.9</td>
<td>96-110</td>
<td>6-8 ft.</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>945-964.9</td>
<td>111-130</td>
<td>9-12 ft.</td>
<td>Extensive</td>
</tr>
<tr>
<td>4</td>
<td>920-944.9</td>
<td>131-155</td>
<td>13-18</td>
<td>Extreme</td>
</tr>
<tr>
<td>5</td>
<td>less than 920</td>
<td>over 155</td>
<td>over 18</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

*Table 1. Saffir-Simpson Hurricane Damage Potential Scale
Source: Abbott, 1999.*

Knowledge about how tropical cyclones function is important in predicting different aspects of tropical cyclones, such as the path and strength of a cyclone. One of the first insights to how a tropical cyclone works occurred in 1821. William C. Redfield became the first person to detect the internal circulation pattern of a hurricane when he walked through the area hit by a hurricane that struck New England. He discovered that all of the trees blown down in one area had fallen with their tops pointing toward the northwest, but 70 miles away the tops of the downed trees pointed toward the southeast, in the opposite direction (Stevens, 1999). By making this discovery, the motion of a cyclone was discovered.

James P. Espy is another scientist who, in 1821, studied the convection of a tropical cyclone. This was his argument:

“As the earth’s surface warms, the air becomes more highly charged with water vapor. As the warming air rises, it carries..."
this vapor with it. The farther it rises, the lower the atmospheric pressure, and the air expands. As it expands, it grows colder. If it rises high enough, the cold condenses some of the water vapor, forming clouds and a storm is born," (Stevens, 1999).

Both Redfield and Espy made crucial discoveries that are still used today about the formation and rotation of a tropical cyclone.

Hurricane Opal (1995) has been studied for its intensity and the factors that contributed to its intensity. After looking at issues such as the potential spinning of air masses from a middle-latitude trough, the angular momentum of the lower tropospheric inflow layer, the possible role of central heat transfers along the eyewall, and the warm ocean temperature anomalies of the northern Gulf of Mexico, it was found that a decrease in the slope of angular momentum occurs above the regions of maximum convective heating (Bedi et al, 1998). The study of Opal showed that another contributor to its intensity was the import of angular momentum along the lower-tropospheric inflow channels of the storm, which permitted the high angular momentum to advance toward the storm’s interior thus contributing to its intensification (Bedi et al, 1998).

Wind and pressure data are needed from within both the inner core of the storm as well as the surrounding environment (Pike, 1985). The data received from the inner core are necessary for center positioning and intensity estimates, and data from the environment are important because the motion and intensity of a hurricane are influenced by changing wind and pressure patterns that are far away from their centers (Pike, 1985). The vertical wind shear has been found to have a negative correlation with intensity change in tropical cyclones at all stages of their life cycle (Corbosiero & Molinari, 2002).

Since a tropical cyclone has a three-dimensional structure which changes with its vertical level, several levels of data are needed for a reasonable complete description of the storm and its environment. Trends in the quality and quantity of available data and in
analysis methods have been a focus of attention in many studies (Pike, 1985). Better tracking and forecasting for future storms can be done with more data that are available and analyzed. The data for tracking and forecasting storms come from sources such as ship reports, aircraft reports, upper-air balloon soundings, land and island stations, satellite observations, and radar reports (Pike, 1985).

Hurricanes Jimena (1991) and Olivia (1994) were studied for their effect of vertical shear on structure and intensity. The wind shear, which is a key inhibitor of tropical cyclone intensification, was found to have controlled the convective structure of both storms. Most of the updrafts and radar echoes formed in the downshear quadrant of the storm and advected around the eye with 60-80% of the swirling wind, which is consistent with current research (Black et al, 2002).

The years 1995 to 2000 experienced the highest level of North Atlantic hurricane activity in the historical record and the present high level of hurricane activity is likely to persist for an additional 10-40 years, as a result of the increase in North Atlantic sea-surface temperatures and the decrease in vertical wind shear (Goldenberg et al, 2001). As a result of the increase in North Atlantic hurricane activity, the United States is more vulnerable to tropical cyclones now than at any time in its history. Millions of people vacation along the coastline and are exposed to the threat from tropical cyclone wind, rain, storm surge, and severe weather (Marks et al, 1998). The major hurricanes account for just over 20% of the tropical storms and hurricanes that strike the United States, but they cause more than 80% of the damage (Goldenberg et al, 2001). Wind damage from these tropical cyclones affect larger areas than storm surge and can lead to larger economic losses; Hurricane Andrew had winds that produced over $25 billion in damage over southern Florida and Louisiana (AMS, 2000; Lutgens & Tarbuck, 2001). Errors in wind, storm surge, and rainfall forecasts have prevented the communities affected by
tropical cyclones from accurately defining the most vulnerable regions to expedite required preparations well in advance of the projected landfall (Marks et al., 1998), thus allowing for greater storm damage.

One of the highest priorities in hurricane research is the improvement in wind field and intensity forecasting. With the increase in tropical cyclone-related damage increasing dramatically, it is important that forecasting techniques be improved and more research done to help improve the forecasting of intensity of wind, rain, storm surge, and severe weather near landfall (Marks et al., 1998). Wind fields of several of the 1995 hurricanes have been studied to improve the wind field and intensity forecasting. Hurricanes Marilyn, Erin, Roxanne, Opal, and Luis were found to have caused losses totaling almost $8 billion, most of the damage resulting from interactions of the wind with topography or seas surface response to wind stress leading to storm surge and waves (Houston & Powell, 1998). As forecasters develop more confidence in forecasts of surface winds, rainfall, storm surge, and severe weather, more accurate and/or precise warnings are possible (Marks et al., 1998). Wind data such as speed and direction, which are variables examined in this thesis, are important for reconstructing the wind fields of land falling hurricanes as well as for establishing the extreme wind climatology of a location (Houston & Powell, 1998).
Methodology

A. Study Area

The study area for Hurricane Isabel is located along the eastern half of North Carolina into Virginia, Maryland, and Pennsylvania (Figures 2 & 3). The study area is chosen because Hurricane Isabel made landfall in North Carolina and then proceeded into Virginia and through the Eastern Great Lakes region.

![Figure 2. Hurricane Isabel's track.](Source: http://www.nhc.noaa.gov/archive/2003/ISABEL_graphics.shtml)

The disproportional stratified point sample method is used to determine the sixty-three sampling locations across the study area. This method of sampling involves separating a target area (Mid-Atlantic U.S.) into identifiable subgroups (states), which are called strata (Burt & Barber, 1996; McGrew & Monroe, 2000). This method of sampling is appropriate because it accommodates to changes in Hurricane Isabel’s path, it can decrease the likelihood of obtaining an unrepresentative sample, and it reduces the sampling error (Burt & Barber, 1996). This study area is selected because it is directly
affected by Hurricane Isabel and the strata that are selected to be oversampled are the states where Isabel traveled through, such as North Carolina, Virginia, and Pennsylvania.

B. Data

Hourly wind speed (miles per hour), wind direction (compass directions), and barometric pressure (millibars) are acquired for September 16-September 20, 2003. The data are collected from the Automated Weather Service (AWS). This time period is selected because Isabel was beginning to affect the weather in North Carolina and Virginia, particularly along the coastline, days before the hurricane actually made landfall (Hurricane Isabel made landfall on September 18, 2003 at 5PM). Isabel remained a hurricane until 6AM on September 19, when it was downgraded to tropical storm status.

Fig. 3. Study Area.
Roanoke Rapids, Bunnlevel, and Zebulon, North Carolina, along with Mercersburg, Pennsylvania, are chosen to identify the occurrence of the greatest changes in barometric pressure and wind direction. These stations are selected because they capture the northern and southern boundaries of the study area (Fig. 4). Time-series graphs are constructed for these stations to determine where the greatest drops in pressure occur between September 16-20, 2003, and the graphs show that September 18 and 19 display the greatest drops in pressure, which can be seen between the vertical lines on the graphs (Fig. 5-8). Roanoke Rapids, NC is selected to analyze the changes in wind direction during the time period from September 16-20, 2003 (Fig. 9). This station is selected because it is the closest station to the direct path of Isabel (Fig. 2 & 4).
wind direction for the time period between 12AM on September 18-12PM on September 19, 2003 is also examined because the time-series graphs for pressure show that the greatest drops in pressure occur between this time period, therefore it is necessary to examine if there is a defined wind direction for this time period also (Fig. 10).

The time period selected for formal analysis is between 12:00AM on September 18, 2003 and 12:00PM on September 19, 2003. This particular time period is chosen because it displays the greatest drop in barometric pressure, along with a well-defined wind direction, as displayed in figures 5-10. Hurricane Isabel traveled through North Carolina between the hours of 12PM and 9PM on September 18, and then into Virginia beginning at 9PM on September 18, 2003.

![Pressure at Roanoke Rapids, NC](Figure 5. Pressure at Roanoke Rapids, NC 9/16/03-9/20/03.)
Figure 7. Pressure at Durham, NC 9/16/03-9/20/03.

Pressure at Durham, NC

Figure 6. Pressure at Zebulon, NC 9/16/03-9/20/03.

Pressure at Zebulon, NC
Figure 8. Pressure at Mercersburg, PA 9/16/03-9/20/03.

Roanoke Rapids, NC Wind Direction (9/16/03-9/20/03)

Figure 9. Wind Direction at Roanoke Rapids, NC 9/16/03-9/20/03.
C. Selecting the Stations

In order to examine the readings between 12:00AM on September 18 and 12:00PM on September 19, the hourly readings are extracted as a subset of the larger set into Microsoft Excel. Stations need to have a minimum of 33 readings for the 36-hour in order to maximize the reliability of the results. Sixty-three stations are selected for formal analyses which have at least 33 readings.

D. Calculations

The 36-hour time period is divided into six six-hour increments. The reason for doing so is to clearly demonstrate the changes in wind speed, wind direction, and barometric pressure throughout the 36-hour time period, while reducing the "noise" that
accompanies hourly data. Dividing the time period into six-hour increments reduces the amount of data while still allowing a person to identify trends. Maps of hourly mean data and hourly range data between stations are constructed. For each set of six-hour increments, one map is plotted for each of the two variables.

1. Maps of Hourly Mean

The mean, or average, is selected as a statistical variable for mapping the wind direction, wind speed, and barometric pressure for each six-hour time period. Mean, or average, is defined as the value obtained by dividing the sum of a set of quantities by the number of quantities in the set,

\[ \text{Mean} = \frac{\sum x_i}{n} \]

where \( x_i \) = individual variables, and \( n \) = the number of values (Triola, 2002). The mean is being mapped because it displays the average value during each six-hour time period for wind direction, wind speed, and barometric pressure.

2. Maps of Hourly Range

Range is selected as a statistical variable for mapping the wind speed and barometric pressure. Range of a data set is a measure of the dispersion of the data and is defined as the difference between maximum and minimum values,

\[ \text{Range} = x_{\text{max}} - x_{\text{min}} \]

where \( x_{\text{max}} \) is the maximum value and \( x_{\text{min}} \) is the minimum value in a data set (Triola, 2002).
Range is being mapped because it demonstrates the span of the wind speed and barometric pressure during each six-hour time period. If the range is large, then the hurricane likely came through the station, and if the range is small, the hurricane did not affect the station during that particular time period. Range will not be calculated for wind direction because it cannot be calculated since its values are the cardinal directions.

E. Plotting the Data

The results of the aggregated mean and range calculations are placed into a new file to be saved as a DBF IV file that can be used in ArcMap. ArcMap 8.3 is used to show change through time across space. The DBF IV files that were created in Microsoft Excel are joined to the shapefile entitled weather_stations (Fig. 11). Joining a file means adding on the fields of one table to those of another through a common item. It is usually used to attach more attributes, which are pieces of data, to the attribute table of a geographic layer (Ormsby et al, 2001). A shapefile is a vector file format that is used to store the location, shape, and attributes of geographic features, such as cities (Kennedy, 2001). Each variable is joined individually to the weather_stations shapefile and the active weather stations are exported to a new file that is displayed in ArcMap.
Fig. 11. Joining two sets of attribute tables with common values.

<table>
<thead>
<tr>
<th>Station</th>
<th>ID</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALXD1</td>
<td>1023.9173</td>
<td>5:59AM</td>
<td>NOVA Alexandria Campus</td>
</tr>
<tr>
<td>ALXD2</td>
<td>1021.9419</td>
<td></td>
<td>George Mason ES</td>
</tr>
<tr>
<td>ANNAP</td>
<td>1022.5627</td>
<td></td>
<td>St. Anne’s Day School</td>
</tr>
<tr>
<td>ARLIN</td>
<td>1023.24</td>
<td></td>
<td>Arlington Science Focus</td>
</tr>
<tr>
<td>BELTN</td>
<td>1025.2155</td>
<td></td>
<td>Liberty HS</td>
</tr>
<tr>
<td>BETON</td>
<td>1022.6192</td>
<td></td>
<td>Grace Miller ES</td>
</tr>
<tr>
<td>BRNSC</td>
<td>1024.7075</td>
<td></td>
<td>Brunswick HS</td>
</tr>
<tr>
<td>BRRYV</td>
<td>1024.256</td>
<td></td>
<td>Clarke County HS</td>
</tr>
<tr>
<td>BTHED</td>
<td>1022.7885</td>
<td></td>
<td>Landon School</td>
</tr>
<tr>
<td>BTMDL</td>
<td>1022.7321</td>
<td></td>
<td>Sparrows Point HS</td>
</tr>
</tbody>
</table>

The exported files are used to create isoline maps using the inverse distance weighted (IDW) method. The inverse distance weighted method is an interpolation technique that determines cell values in a grid or image with a set of sample points that have been weighted so that the farther a point is from the cell being evaluated, the less important it is in calculating the cell’s value (Kennedy, 2001). The IDW method is used because it is the most common method of data interpolation and is representative of the data. Isolines are created through the IDW method for each six-hour time period for each variable, except for average wind direction. When the isolines have been created, adjustments are made to each individual map.
F. Map Adjustments

Each map is constructed using the natural breaks (jenks) method so that the highest and lowest values for each variable can be clearly examined. There are seven classes for average wind speed, wind speed range, and pressure range. There are eight classes for average pressure and average wind direction. Each variable has consistent break values throughout the 36-hour time period, so changes in values for each variable can be clearly noted.

In order to determine the natural break values and number of classes for each variable, frequency tables are constructed. A frequency table lists the categories of values, along with the counts of the number of values that fall into each class (Triola, 2002). Frequency tables are constructed for average pressure, average wind speed, average wind direction, pressure range, and wind speed range for the 36-hour time period (Fig. 12-16). The number of classes and break values for each variable are selected according to where the natural breaks occur within the set of values. When the number of classes and natural break values are calculated, each set of maps is adjusted to reflect these changes.

The maps displaying average wind direction display the data through wind bars. A wind bar points in the direction from which the wind is blowing (Grenci and Nese, 2001). Wind bars are selected as the method for displaying average wind direction.
because patterns in wind direction can be easily detected through this approach. Wind bars are also the most common method of displaying wind direction.

The time periods for each map are displayed in terms titled nighttime, morning, afternoon, and evening. Each term represents a six-hour time period throughout a day, as displayed in table 2.

<table>
<thead>
<tr>
<th>Time</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-6AM</td>
<td>nighttime</td>
</tr>
<tr>
<td>6-12PM</td>
<td>morning</td>
</tr>
<tr>
<td>12-6PM</td>
<td>afternoon</td>
</tr>
<tr>
<td>6-12AM</td>
<td>evening</td>
</tr>
</tbody>
</table>

Table 2. Terms for each 6-hour time period throughout the day.

![Average Pressure Frequency](image)

Figure 12. Average Pressure Frequency 12AM 9/18/03-12PM 9/19/03.
Figure 13. Average Wind Speed Frequency 12AM 9/18/03-12PM 9/19/03.

Figure 14. Average Wind Direction Frequency 12AM 9/18/03-12PM 9/19/03.
Figure 15. Pressure Range Frequency 12AM 9/18/03-12PM 9/19/03.

Figure 16. Wind Speed Range Frequency 12AM 9/18/03-12PM 9/19/03.
Results

A. Maps of Hourly Mean

1. Pressure

The maps displaying average pressure show the path of Hurricane Isabel clearly. There is a distinctive pattern of low pressure that begins in the Southeastern portion of North Carolina and moves through the Eastern half of Virginia. The pressure is lowest between 12AM and 11:59PM on September 18. This is the time that Isabel was on land and still at hurricane status. The locations that display their lowest average pressure below 1003mb (for any six-hour time period) are those that were along the direct path of Hurricane Isabel. Stations that possess average pressures greater than 1003mb for the entire 36-hour time period are stations that were not along the direct path of Hurricane Isabel.

2. Wind Speed

Maps displaying average wind speed show that the highest average wind speeds occur along the coasts of Delaware, Maryland, and parts of Virginia and North Carolina. Roanoke Rapids, NC, a location that the eye of Isabel passed through, posted average wind speeds between 8-12mph for the time period 12PM on September 18-6AM on September 19. The time period from 12-5:59PM on September 18 shows that the average wind speeds are at their greatest during this time.
3. Wind Direction

Maps displaying average wind direction show winds moving in a counterclockwise direction. Initially, most of the wind is coming from the NE-E-SE. After Isabel makes landfall (12PM September 18), the wind direction in North Carolina begins to shift from an E-NE direction to an S-SW direction, and eventually to a W-SW direction by 12PM on September 19.

B. Maps of Hourly Range

1. Pressure

Maps displaying pressure range show similar results as those displaying average pressure. The pressure ranges are the greatest on September 18 because Isabel was at hurricane strength during the majority of this day. The time period of the greatest pressure range is between 12PM and 11:59PM, because Isabel made landfall at 12PM and was at hurricane strength during most of this time period. The pressure range maps show the path of Hurricane Isabel clearly.

2. Wind Speed

Maps displaying wind speed range show that the range of wind speed is the greatest along Delaware and the Eastern halves of Maryland, Virginia, and North Carolina. The wind speed range maps display similar results as those displaying average wind speeds, but the wind speed range covers a larger land area.
Analyses of pressure, wind speed, and wind direction reveal the path of Hurricane Isabel. By dividing the 36-hour time period between September 18 and September 19, 2003 into six six-hour increments, the path of Hurricane Isabel can be clearly seen through the maps displaying pressure. The strength of the hurricane is displayed through the various levels of wind speed; the wind direction patterns can also be observed throughout the 36-hour time period.

A. Pressure

A distinct relationship can be noted between average pressure and pressure range. Locations where the average pressure was low also displayed a high range in pressure. The eye of a hurricane possesses the lowest pressure of the storm; therefore the locations displaying the lowest average pressures throughout the 36-hour time period are those closest to the eye of Isabel. The locations where the range was the greatest also were locations that were close to the eye of Isabel. This can account for the sudden drops in pressure that can occur between the outer edge and the eye of a hurricane, “From the outer edge of the hurricane to the center, the barometric pressure has sometimes dropped 60 millibars, from 1010 to 950 millibars. The lowest pressures ever recorded in the Western Hemisphere are associated with these storms,” (Lutgens & Tarbuck, 2001). By examining figures 17a-d and 18a-d, the path of Hurricane Isabel can be detected, based on the decrease in average pressure and the high ranges in pressure.
Fig. 17. Average Pressure readings between 6AM 9/18/03 and 6AM 9/19/03.
Morning Pressure Range 9/18/03

Pressure Range (mb)
- 11 - 12
- 9 - 10
- 7 - 8
- 5 - 6
0 - 2

(a). Morning (6AM-12PM).

Afternoon Pressure Range 9/18/03

Pressure Range (mb)
- 11 - 12
- 9 - 10
- 7 - 8
- 5 - 6
0 - 2

(b). Afternoon (12-6PM).

Evening Pressure Range 9/18/03

Pressure Range (mb)
- 11 - 12
- 9 - 10
- 7 - 8
- 5 - 6
0 - 2

(c). Evening (6PM-12AM).

Nighttime Pressure Range 9/19/03

Pressure Range (mb)
- 11 - 12
- 9 - 10
- 7 - 8
- 5 - 6
0 - 2

(d). Nighttime (12-6AM).

Fig. 18. Pressure Range readings between 6AM 9/18/03 and 6AM 9/19/03.
B. Wind Speed

The majority of the high average wind speed values occurred along the coasts of Delaware, Maryland, Virginia, and North Carolina. The average wind speeds are the greatest along the coast because of the counter-clockwise circulation of the hurricane. The winds that are the strongest occur along the right side of the hurricane because they are moving in the same direction as the storm’s movement, therefore the strongest winds occur along the coast. The winds on the left side of the storm are blowing opposite the direction of the storm movement so the wind speed, which is away from the coast, is less. (Lutgens & Tarbuck, 2001). A hurricane gets strength from the oceanic waters and the winds on the right side of the storm are those coming from the water, as displayed in figures 19a-d.

The highest ranges for wind speed covered a greater area of land than the high readings for average wind speed. Since the average wind speed was the average for a six-hour time period, the average may not reflect completely accurate readings of wind speed. A location that had a high wind speed range reading could have had high wind speeds for two or three of the hours, but significantly lower readings for the rest of the time period, therefore displaying a lower average wind direction than what actually occurred.
Morning Average Wind Speed 9/18/03

Average Wind Speed (mph)

(a) Morning (6AM-12PM).

Afternoon Average Wind Speed 9/18/03

Average Wind Speed (mph)

(b) Afternoon (12-6PM).

Evening Average Wind Speed 9/18/03

Average Wind Speed (mph)

(c) Evening (6PM-12AM).

Nighttime Average Wind Speed 9/19/03

Average Wind Speed (mph)

(d) Nighttime (12-6AM).

Fig. 19. Average Wind Speed readings between 6AM 9/18/03 and 6AM 9/19/03.
C. Wind Direction

The wind direction throughout the 36-hour time period moved in a counter-clockwise direction, which is the same as the rotation of a hurricane. Before Isabel made landfall, the majority of the wind was coming from the NE-E direction. Gradually the wind pattern began to shift to a SE-S wind, and eventually onto a SW-W direction as the, now tropical storm, moved into Pennsylvania and eventually Canada.

As Hurricane Isabel approached land, the counter-clockwise circulation allowed for the winds along the coast to come from the N and NE-E direction until landfall occurred. This also accounts for the high average wind speeds along the coast of the United States from Hurricane Isabel.

In order to get an accurate picture of Hurricane Isabel’s path, all three variables (pressure, wind speed, and wind direction) need to be examined and compared. Although one variable by itself can show the possible path of Isabel, it alone cannot be as accurate as studying multiple variables.

The maps displaying pressure, wind speed, and wind direction clearly show the path of Hurricane Isabel, but they also leave many opportunities for error. The average wind direction values can be skewed because of the values for wind direction. Average wind direction is measured in degrees and winds coming from the North occur between 0-22 degrees and 338-359 degrees. If the wind was coming from the North for a six-hour
time period, and some values were between 338-359 degrees and other values were between 0-22 degrees, the average wind direction would show that the winds were coming from a more Southerly direction, instead of the North.

Similar to average wind direction, error can also result from average values for six-hour time periods. While examining the values for average pressure and average wind speed, the values recorded for a six-hour time period can be altered because of a 1-2 hour time period where the values were overly high or low. If this were to happen, the value for average pressure or average wind speed would not accurately reflect the values for the six-hour time period. To account for this possibility, range values were calculated for pressure and wind speed. The range values help to explain why a particular station has a middle-range value; if the range is high, this could mean that the station has several low readings, and then had a few overly high readings, which affected the average value.

The number of readings a station has can also account for error in the data. Stations that have at least 33 out of 36 readings were selected for formal analysis, and if a station was missing two or three readings within a six-hour time period, the average and range values could be directly affected. Holes in a data set leave open the possibility for error, in both positive and negative ways.
Conclusion

Hurricane Isabel’s path was reconstructed using pressure, wind speed, and wind direction. Isabel made landfall at 5PM on September 18, 2003 in North Carolina and proceeded into Virginia and through the Eastern Great Lakes region. The 36-hour time period between 12AM September 18, 2003 and 12PM September 19, 2003 was selected for formal analysis and separated into six six-hour time periods. Maps were constructed for average pressure, average wind speed, average wind direction, pressure range, and wind speed range in order to display Hurricane Isabel’s path. Maps displaying average pressure revealed the path of Isabel through the lowest average pressure values and maps displaying high average wind speed values and counter-clockwise circulation displayed the general circulation of Hurricane Isabel after landfall. All three variables were necessary to get an accurate picture of Hurricane Isabel’s path.

Many levels of follow-up work can be done to improve on reconstructing the paths of hurricanes. A variety of variables, such as temperature and precipitation, can be used similarly to pressure, wind speed, and wind direction, in order to reconstruct a hurricane’s path. Correlations can also be done to assess similarities and differences between stations, as well as between different variables. It is also important to obtain as many stations with sufficient readings as possible in order to ensure an accurate sample. The larger the sample size, the easier it is to accurately reconstruct and analyze the path of a hurricane.
Glossary of Terms

advect- to transfer a property of the atmosphere by the horizontal movement of an air mass.

angular momentum- an angular measure of the motion of a body equal to the product of its mass and velocity.

environment- conditions that surround an individual or community.

intensity- the amount of strength, power, or force an object has.

troposphere- the lowest region of the atmosphere between the earth's surface and the tropopause; has decreasing temperature with increasing altitude.

trough- an elongated region of relatively low atmospheric pressure, often associated with a front.

vertical wind shear- a downward shift in wind direction and speed between different altitudes.
Bibliography


Appendix A:

Average Pressure
Nighttime Average Pressure 9/18/03

Average Pressure (mb)

- 973-993
- 993.01-998
- 998.01-1003
- 1003.01-1008
- 1008.01-1013
- 1013.01-1018
- 1018.01-1023
- 1023.01-1028
Average Pressure (mb)

- 973-993
- 993.01-998
- 998.01-1003
- 1003.01-1008
- 1008.01-1013
- 1013.01-1018
- 1018.01-1023
- 1023.01-1028
Appendix B:

Average Wind Speed
Nighttime Average Wind Speed 9/18/03

Average Wind Speed (mph)

- 0-4
- 5-8
- 9-12
- 13-16
- 17-20
- 21-24
- 25-44
Morning Average Wind Speed 9/19/03

Average Wind Speed (mph)

- 0-4
- 5-8
- 9-12
- 13-16
- 17-20
- 21-24
- 25-44

N W E S
Appendix C:

Average Wind Direction
Nighttime Average Wind Direction 9/18/03

Average Wind Direction (degrees)

- N 0 - 22, 338 - 360
- NE 23 - 67
- E 68 - 112
- SE 113 - 157
- S 158 - 202
- SW 203 - 247
- W 248 - 292
- NW 293 - 337
Average Wind Direction (degrees)

- N 0 - 22, 338 - 360
- NE 23 - 67
- E 68 - 112
- SE 113 - 157
- S 158 - 202
- SW 203 - 247
- W 248 - 292
- NW 293 - 337
Afternoon Average Wind Direction 9/18/03

Average Wind Direction (degrees)

- N  0 - 22, 338 - 360
- NE 23 - 67
- E  68 - 112
- SE 113 - 157
- S  158 - 202
- SW 203 - 247
- W  248 - 292
- NW 293 - 337
Evening Average Wind Direction 9/18/03

Average Wind Direction (degrees)

- **N** 0 - 22; 338 - 360
- **NE** 23 - 67
- **E** 68 - 112
- **SE** 113 - 157
- **S** 158 - 202
- **SW** 203 - 247
- **W** 248 - 292
- **NW** 293 - 337
Nighttime Average Wind Direction 9/19/03

Average Wind Direction (degrees)
- N 0 - 22; 338 - 360
- NE 23 - 67
- E 68 - 112
- SE 113 - 157
- S 158 - 202
- SW 203 - 247
- W 248 - 292
- NW 293 - 337
Morning Average Wind Direction 9/19/03

Average Wind Direction (degrees)

- N 0 - 22, 338 - 360
- NE 23 - 67
- E 68 - 112
- SE 113 - 157
- S 158 - 202
- SW 203 - 247
- W 248 - 292
- NW 293 - 337
Appendix D:

Pressure Range
Morning Pressure Range 9/19/03

Pressure Range (mb)

- 0-2
- 3-4
- 5-6
- 7-8
- 9-10
- 11-12
- 13-26
Nighttime Pressure Range 9/18/03

Pressure Range (mb)

- 0-2
- 3-4
- 5-6
- 7-8
- 9-10
- 11-12
- 13-26
Appendix E:

Wind Speed Range
Nighttime Wind Speed Range 9/18/03

Wind Speed Range (mph)

- 0-4
- 5-8
- 9-12
- 13-16
- 17-20
- 21-24
- 25-44
Afternoon Wind Speed Range 9/18/03

<table>
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<td>25-44</td>
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</tbody>
</table>
Nighttime Wind Speed Range 9/19/03

Wind Speed Range (mph)

- 0-4
- 5-8
- 9-12
- 13-16
- 17-20
- 21-24
- 25-44
Morning Wind Speed Range 9/19/03

Wind Speed Range (mph)

- 0-4
- 5-8
- 9-12
- 13-16
- 17-20
- 21-24
- 25-44