Purpose

This project models the movement of Hurricanes in the Atlantic Ocean. Scientists have developed models to track the path of hurricanes and continue to improve them. Over the years the US model has been competing with the European model. The European model has proven to be more accurate. Hurricanes are based on a variety of factors including winds, sea surface temperature and rotation. Our goal is to create a simulation that tests the importance of sea surface temperature against pressure in the development, and track of hurricanes. We hypothesize that sea temperature will have a larger importance based off of the fluid properties of air, and water. Water will retain energy far better than air, and allow for greater amounts heat transfer to power the storm.

Entities, Variables, and Scales

This model represents hurricane generation, and tracks. The code uses turtles as hurricanes. One time step is equal to a day.

Our global variables include:
SeaSurfaceTemp
Pressure
Land
indexsst = sea surface temperature index
sstlist = sea surface temperature list of layers
indexpp = pressure index
pplist = pressure list of layers
atemp = value of psst at time interval a
btemp = value of psst at time interval b
dif = Difference between psst a and b
hsize = Hurricane size

We also wanted to set a slider to test variation of importance for sea surface temperature compared to pressure. This was an intended function that we were unable to implement. Sea surface temperature and pressure data sets were acquired from NOAA. The sea surface temperature was in weekly increments which we split into daily layers. The pressure data was

broken out into monthly increments, and fit for our purposes of this study. We created a grid, or

scope of hurricane generation in the Atlantic Ocean within ArcMap. This grid of pressure and

sea surface temperature ranged from -2.5 to 50 latitude. For our purposes the model will run

approximately 92 ticks, or days to test storm generation. We also set up a neighborhood variable

in order to check for the nearby sea temperature. This was done to limit the scope that the turtle

would ask and simulate the nearby values impacting the track as the hurricane moved forward.

Process Overview

In our model the turtles generate in the ocean at a random location, which can be

modified for testing the tracks of know hurricanes for 2018. This happens in the to-setup

function. This portion establishes the files for the sea surface temperature raster layer for the

month, sets the environment, and the pressure index. We also set the pen-down function in order

to draw the track overtop off our area of interest. This is inside of the to-move function. The

move function establishes the neighborhood for the turtle to look at nearby cells preferably for

the highest sea temperature. As the turtle moves forward the neighborhood moves with the turtle

out to the next cell and generates a new window (This will be explained better in the next section

under "Window Patch"). We also set code into our process that would kill/dissipate the strength

or increase the strength over time, and die once it hit land.

Design Concepts
Basic Principles
Hurricanes are a natural phenomenon that occur in a number of areas across the globe. In

the United States we refer to them as such, but they are also known as cyclones, and typhoons in

other areas of the world. They generate, primarily, during the summer season (with respect to the

northern or southern hemisphere). In the Atlantic Ocean storms begin off the coast of Africa, and

eventually charge up when they near tropical waters (between 8 and 20 degrees latitude). This is

driven by the Bermuda high which is a wind jet that sits below the Jetstream, and pushes storms westward. This is a force that generates approximately 60% of hurricanes in the Atlantic.

There are many other forces to consider when estimating, or predicting hurricane generation. Seasonality, and the Coriolis Effect bring the necessary swirl counterclockwise in the Northern hemisphere for the iconic eye of the hurricane. Two other factors that are related are the pressure cells, and the Jetstream. The strongest hurricanes have the lowest pressure, typically measured in millibars. Pressure flows from high to low, and the eye has the lowest pressure of the system, and is the calmest portion of the storm. For reference, Hurricane Michael (2018) made landfall with a central pressure of 919mb as a category 5. Most category 1 hurricanes have a pressure much closer to 995mb. While pressure systems may seem to be highly important, most pressure cells are impacted by the Jetstream. The Jetstream ebbs and flows up and down based on the insolation angle and Coriolis. Both wind speed, and Jetstream speed are depended on the sun. The variation in heat causes a variation in pressure, and Jetstream which cause winds. Given that there are a number of complex variables, and interactions we chose to simulate hurricane generation and track based off of sea surface temperature, and pressure. This limits the scope of our model, and allowed us to create a model in a short time frame. We chose these variables based off of the ease of acquiring the necessary data, and the fluid properties of water compared to air. We had initially acquired a net cdf file and developed code to read of winds but the data was formatted in satellite swathes which we were unable to use.

The general results of this model is that the randomly generated hurricane tracks follow realistic tracks. The randomly generated hurricanes tended to follow the lower latitudes and move into the Gulf of Mexico. This is a common track for hurricanes to take so that was a promising start to our model. The next step was to test the model at the time and location of its

2018 counterpart and see where the model tracked the hurricane. For the most part the model did really well considering the only factor that it took into account was sea surface temperature and the window patch. One of the main problems was proper strengthening and dissipation. The other glaring problem was turn radius and never dissipating over 3 months. Without additional information more rulesets had to be added to control the length of time a hurricane was active. One of the other concerns is in reference to the window patch set which uses the report function. The report function cannot report when there is no turtle present. When the first hurricane "dies" the report function generates an error. Besides this the model runs very well considering the time constrains and complexity of hurricane modeling.

The concepts of prediction and learning are not explicitly considered in our hurricane analysis. The general objective that drives the behavior is sea surface temperature. The storms look at the temperature within the neighborhood grid, and move to the highest temperatures. At this stage in our project we do not have other agents that interact with the primary turtle. The stochasticity for our model is in the initial generation of the turtle and can be adjusted for turtle movement. Within the movement function there is a piece that can be changed to manipulate the stochasticity of the turtle movement. This stochasticity helps to account for other factors in our model. No collectives are used in this model. Our model uses a reporter to display the windows, and this was used to verify the correct values for the window as the hurricane moved across the area of interest. This model uses one agency per run, and the sea surface temperature, as well as the pressure data can be modified for each month and ran accordingly. The initial model establishes the land features: Africa, Europe, North America, and South America, as well as the Atlantic Ocean.
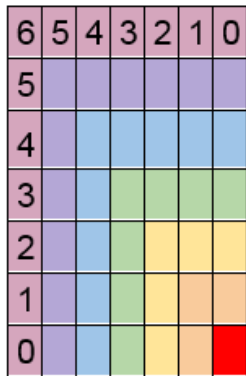
Input Data: Hurricane testing information

Hurricane Name	Start Date	End Date	Start Lat	Start Lon	Start Netlogo Xcord Lon	Start Netlogo Ycord Lat
Hurricane Florence	08/31	09/17	12.9 N	18.4 W	89	15
Tropical Storm Gordon	09/03	09/06	22.7 N	77.3 W	30	24
Hurricane Isaac	09/07	09/15	13.6 N	34.9 W	72	16
Hurricane Leslie	09/23	10/13	33.0 N	46.5 W	60	35
Hurricane Michael	10/07	10/11	18.0 N	86.6 W	20	20
Tropical Storm Nadine	10/09	10/12	10.3 N	29.7 W	77	12

Information from: https://www.wunderground.com/hurricane/atlantic/2018/

Window Patch

The 7 x 7 Window setup is a basic simulation of Prevailing winds and Coriolis Effect that help to assess the neighborhood in which the hurricane might move. This was done to establish an area around the turtle(hurricane) that would impact the strength and decay of the hurricane. Below are the two window types used for the model. The left window is for the Latitudes between 5N and 30N. The window on the right is for latitudes greater than 30N.
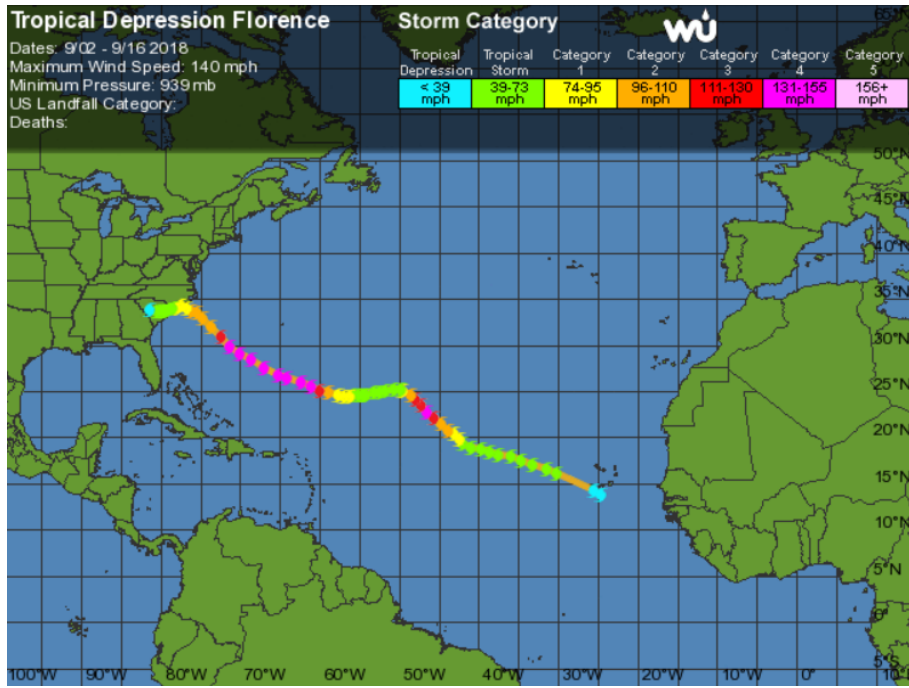
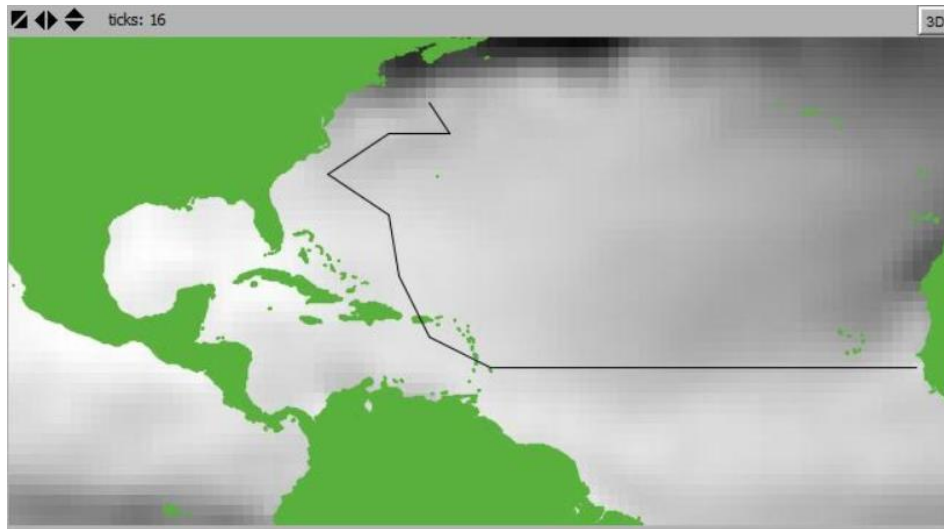Simulate NE Trade Winds   Simulate the Westerlies
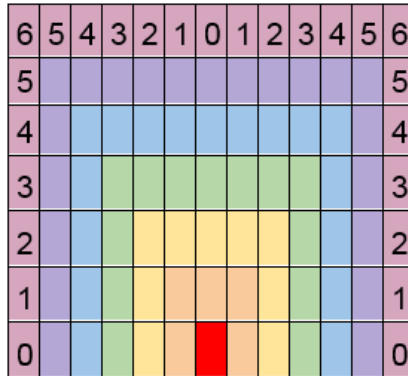
Red is the Hurricane's current location
Orange is searching at strength = 1
Yellow is searching at strength = 2
Green is searching at strength = 3
Blue is searching at strength = 4
Purple is searching at strength = 5
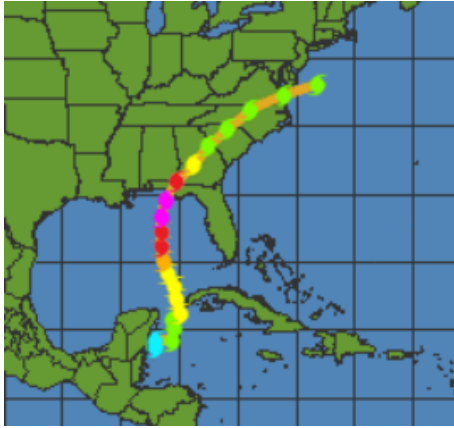Pink is searching at strength = 6
Results

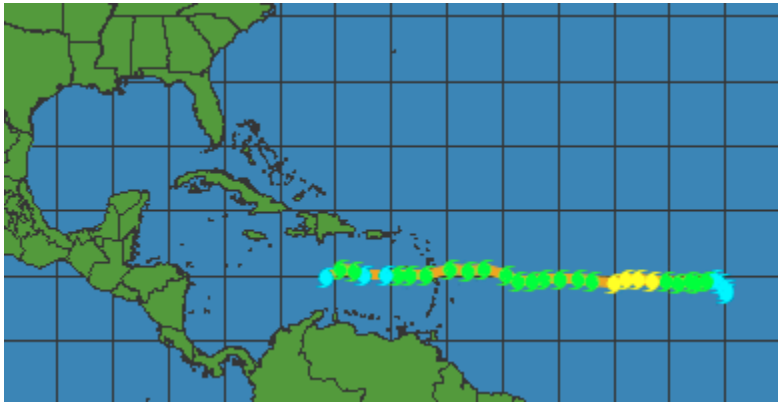Actual Florence track

Modeled Florence Track

Actual Michael Track

Modeled Michael Track

Actual Isaac Track

Modeled Isaac Track

Input Data Layers

Sea surface temperature is taken from the ascii delimited file from daily files for each

month in 2018 (08012018.asc would be for August 1st). The sea surface is established for the

day, and the model iterates through the values as it moves through the time ticks. Hsize is the

overall size of the storm ranging from 0-6. Size is what we used to determine overall strength of

the hurricane. Based on some recent changes the Hsize is no longer and integer but a float value.

Hurricane Sub-models
to setup establishes all the libraries being used for each run of this model, establishes the data sets, and applies the rasters to the area of interest (land, ocean, and land color)

to go begins the movement of the hurricane across the area of interest by calling the move function.

to move sets the turtle, or hurricane, in motion, reports the x and y values, and sets the pen down to draw the track.

to turn-at-most sets the maximum possible turn radius for the hurricane.

to strengthen creates a variable called dif which if the difference in sea surface temperature from one time step to the next.

to current_strength sets the size, and potential strength of the hurricane based on the dif variable from the strengthen function, current size, ycor, and sea surface temperature.

to land_check changes the color of the hurricane once it makes landfall in order to symbolize a lessening of strength or dying out.

to set_new_sst applies the sea surface temperature, sets the file path for the number of ticks to be used, it also applies the raster to our area of interest.

to set_new_pp sets the pressure for the area of interest for the storm to move about.

to-report window takes the x and y coordinates and hurricane size as parameters and establishes the custom neighborhood for the hurricane to look in to move to the local maximum sea surface temperature.

Discussion
        Some of the challenges we ran into during this project were: data compatibility, data

formats, website navigation, unit corrections, Netlogo compatibility, libraries, generate at

different times based off of layers. We spent a significant amount of time troubleshooting, and

trying different methods to accomplish the same goal. By the time we finished our model the

Netlogo file had over 470 lines. The code is comprised of functions that we developed

specifically for this project. We had to overcome a lot of difficult coding and function

difficulties. We ended up not using pressure in our model. This is because the neighborhood window that is set up is meant to allow the hurricane to jump patches, and not walk. We tried to incorporate a walk model, but at this point in our project we would be revamping the entire code. We decided that having a neighborhood to check for sea surface temperature was sufficient. Most of the data we had to convert between ascii, txt, excel, and shapefiles (or feature classes in a geodatabase). For such a large study area it was a challenge to find layers that covered the entire extent. That is where parsing out data, and making proper extent selections become key. Overall, there are a number of improvements that could be done with this project. Increasing the number of variables, adding more stochasticity, and improving data resolution to predict on smaller time scales. We could also use similar models to look at additional data from other years. Weather and climate models are constantly being adjusted, and improved to estimate track generation. This model is no different. We could improve this even more by adding code that would dissipate the strength of the hurricanes after reaching peak strength (Category 5). We could also improve the strengthen function to also look at the wind, and ocean currents. As sea level rises, and global temperatures rise the importance of predicting hurricane tracks will become more important. That combined with the ever increasing global population means that these storms will have a larger impact on coastal and near coastal regions.

Sources
Track generation: https://www.wunderground.com/hurricane/atlantic/2018/hurricane-michael
Bermuda Winds: https://weather.com/storms/hurricane/news/2018-07-14-africa-tropical-waves-hurricane-season
Sea Surface Temperature:
https://ftp.cpc.ncep.noaa.gov/GIS/sst_oiv2/
Pressure Data:
http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP-NCAR/.CDAS-1/.MONTHLY/.Intrinsic/.MSL/.pressure/%28mb%29unitconvert/DATA/2/STEP/dataselection.html

Experiment Report: Melissa Gfeller

When our group was deciding what the topic we choose from types of natural disasters. We talked about modeling volcanoes, tsunamis, earthquakes and hurricanes. In the end we decided to model hurricanes in the Atlantic Ocean. To model hurricanes I had to do research to decide which data layers we would need. The most important layers we would need are sea surface temperature, pressure and winds. Based on data availability we were able to find weekly sea surface temperature and monthly pressure. The wind layer we acquired was not in a format that we could use. Some other layers I looked for were humidity, bathymetry and coastal DEMs. It was difficult to find data layers that covered the Atlantic Ocean. The data layers that did cover the proper extent were sea surface temperature and pressure. I chose the study area based in the hurricane tracks for 2018. While our group was locating data I also wrote the proposal for the project with the initial research findings and basic description. I created the PowerPoint used for our presentation with some additions from Spencer.

One of the biggest challenges was formatting the data. As a group we worked to format the text files to ASCII. When the others group members were formatting the data I started writing the initial functions and procedures in Netlogo. Once we knew that one of the data layer was properly formatted I wrote the code that would load them and initialize the model setup. I wrote and tested the basic code that set the data layers and moved the turtle.

Later when the sea surface temperature function was written I helped Spencer to write the naming conventions for the 92 sea surface temperature layers. I did a similar thing when Spencer created the initial patch set function I helped write the rest of the iterations. We also choose which patches to include within the patch set based on the research I did into the prevailing winds at specific latitudes. I wrote the pressure function to iterate through the

different data layers each month depending on the number of ticks. Overall I help to keep the

group on track by setting up times to meet on the weekends. I also did a lot of the hurricane

research that was used to determine how the model would be developed.

The last piece that I did was to implement the "strengthen" and "dissipate" functions. I

had to add a number of rule sets that would prevent the hurricane from lasting forever. Some of

these included dissipation at high latitude, cooler temps and hitting land. The addition of a float

strength value helped to manage the extent of the dissipation influence on the hurricane.

Model Testing

The plan for our experiment was to test the model to see where the hurricane tracks

moved. Based on these runs we compared the results to the paths of the hurricanes that occurred

during those months in 2018. Within the months of August to October we chose six hurricanes

and tropical storms to test. The tropical storms we tested generally did not have as accurate a

path because are strengthen and dissipate function was developed foe stronger hurricanes. The

model had trouble dissipating tropical storms in the correct locations. The next thing to add

would be a category to rank dissipation based on whether the turtle is a hurricane or tropical

storm. The one storm that was not predicted well was Hurricane Leslie because of its location

father north.

Hurricane Florence and Isaac tested pretty accurately based on the unadjusted initial

conditions. The initial size started at 3 and the hurricane always chose the highest sea surface

temperature. The only condition changed when testing Tropical Storm Gordon was to adjust the

initial start size to 4 because it hits land multiple times before traveling into the gulf. This initial

increase in size allows Gordon to take a more accurate track.

More code adjustments were needed for Hurricane Michael and Tropical Storm Nadine. Both kept the initial size of 3 but were allowed far more variability when it came to where they could move. Hurricane Michael would only move to the highest sea surface temperature when the hsize was 6. This allowed any cell within the patch window to be chosen and allowed the hurricane to move more freely. For Tropical Storm Nadine only when the hsize is greater than 5.5 it would follow the highest sea surface temperature.

These variations allowed the model to generate more accurate tracks for each hurricane or tropical storm. Ideally the model would not have to be adjusted on a run by run basis but the general movement is correct given the limited factors used in the model. This simplistic model demonstrates the difficulties involved in modeling hurricanes.

Below is the code snippet mentioned above. The 2 was changed to 6 and 5.5(with a max strength of 6)

```
ifelse random-float 2 >= hsize
    [move-to max-one-of window_patch [psst]
    print max-one-of window_patch [psst]]
    [move-to one-of window_patch]
```

Hurricane Isaac: Modeled

Hurricane Isaac: Actual