Hilton Head Island Hurricanes and Climate Change
6.s898 Class Project

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1 Project motivation

Prior the 6.s898 course, I was naive to how climate change would impact my life, my family, and my community. After the first reading assignment, Kerry Emanuel's "What We Know About Climate Change", it became very clear that my home town was going to suffer greatly from carbon emissions and the warming of Earth's surface temperature. From the age twelve on-wards, I lived on Hilton Head Island, South Carolina, and my family still resides there today. Hilton Head Island (HHI) is twelve by four mile island at the southern most point of South Carolina, about an hour drive from Savannah Georgia. The island is a beautiful place with a great mix of culture from Gullah natives, Hispanics, southerners, and American transplants from mainly the east coast and Midwest. The island holds a special place in my heart and the hearts of many other; it would be terribly sad to see it face destruction or disappear.

After reading Professor Emanuel's book, I decided on my project: understanding how climate change would affect Hilton Head Island through investigating hurricanes under future climate scenarios. After the analysis I planned to write an opinion editorial article for my local newspaper "The Island Packet" (https://www.islandpacket.com/). I hope that by publishing this article, people of my community will think twice and adjust their daily actions that contribute to carbon emissions. There are many older and retired people in my community with the means to so. My article will be directed towards this audience.

2 Hurricane history of Hilton Head Island

For a southeastern coastal town, Hilton Head Island has a mild hurricane history. The island gets brushed or hit by a tropical cyclone on every 2.46 years [Hurricane City, 2016]. Of these cyclones, only 5% are major hurricanes, 66.1% are tropical storms and the rest (28.9%) are minor hurricanes. However, most of these cyclones are not direct hits. The island sees a direct

Figure 1: Hilton Head Island, SC

storm hit approximately once every 7.6 years. These direct hits are typically weak storms. Hilton Head Island has seen only two destructive hurricanes hit since 1851, the Sea Island Hurricane of 1893 and Hurricane Matthew of 2016 [Island Club of Hilton Head, 2017].

2.1 Hurricane Matthew

Hurricane Matthew formed on September 28, 2016. On October 1st, Matthew was classified as a category 5 storm. It made landfall on Cuba on October 4th. It continued through the Bahamas and up the eastern coast of Florida and lost wind speed, lowering it to a category 2 hurricane. On October 8th, Matthew directly hit Hilton Head Island, and despite it's greatly decreased wind speeds, it left a good deal of damage. Over 120,000 trees were downed on the island. More than 2 million cubic yards of debris were on the ground. Over 10% of the structures reviewed by the town were said to of received some damage. Over 700,000 cubic yards of sand was moved in 12 hours, a feat that would take a month to do mechanically. The storm surge was 6 feet high. The town spent over $51 million dollars in hurricane response and recovery. As of June 1, 2017, Hurricane Matthew was the 10th costliest storm the United States history, causing $10 billion dollars in damage nation-wide [Katherine Kokal, 2018, Island Club of Hilton Head, 2017].

3 Understanding the future of hurricanes and Hilton Head Island

My goal for this project was two-fold: 1) to understand how hurricanes in a warmed climate would change and how those changes would affect my home town of Hilton Head Island; 2) to

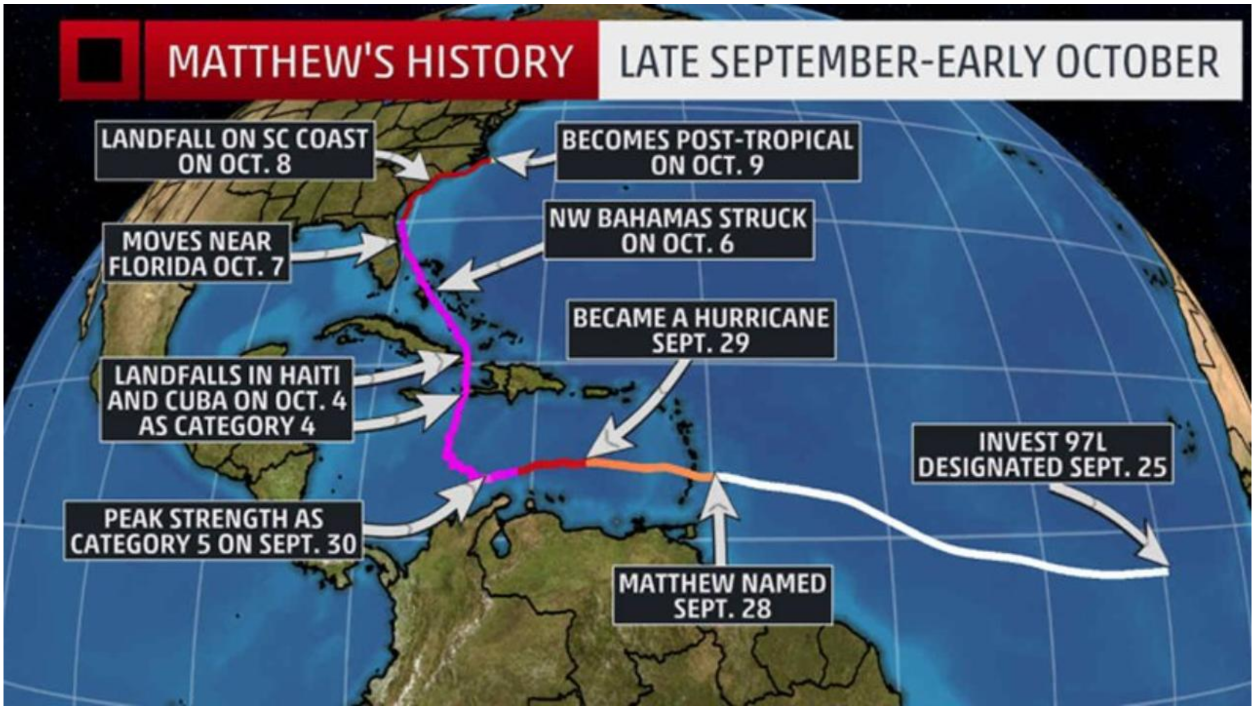

Figure 2: The path traveled by hurricane Matthew in 2016.

convey the potential changes to my community in an effort to get my community members to take action against climate change. In this section I will discuss the first goal of my project, understanding how climate change will affect hurricanes on Hilton Head Island.

3.1 The hurricane model

I began by reading Professor Emanuel's paper "Assessing the present and future probability of Hurricane Harvey's rainfall." [Emanuel, 2017]. The paper explained the application of Professor Emanuel's hurricane modeling to understand the devastation a hurricane like Hurricane Harvey would have under a future climate with no curtailing of carbon emissions. The hurricane model is dependent on an Earth systems model. The methods involve generating tropical cyclones (more than 3,000 tracks) in the Atlantic ocean and then simulating them at a fine scale (finer than Earth system's model grids). From there, tracks can be filtered by where they intersect points of interests (eg. a city), and sets of tracks can be compared to historical tracks (real hurricane tracks of past storms), called Best Tracks.

I contacted Professor Emanuel to request applying the model to my home town. Since the model would be too large and complex for me to run on my machine, professor Emanuel ran the model using multiple different Earth-systems models and provided me with the resulting data, a library of analysis functions, and setup and function documentation.

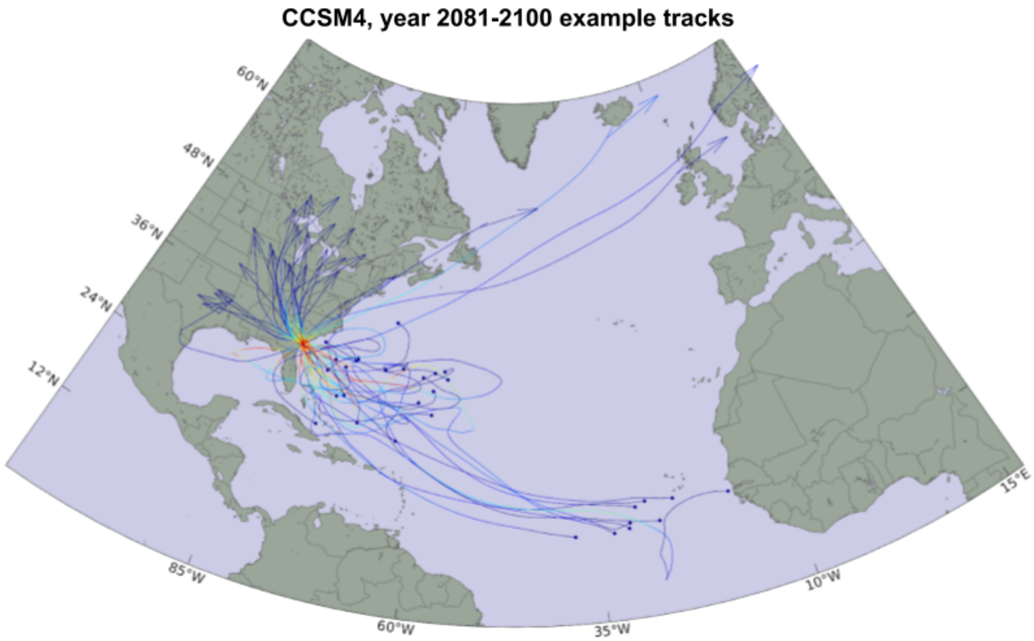

Figure 3: Set of example paths generated by Professor Emanuel's hurricane model.

3.2 Climate Models Used

The hurricane model was ran against six different Earth-systems models:

- CCSM4: The National Center for Atmospheric Research (USA)
- EC-Earth: A European community Earth-System Model
- HadGEM2-ES: United Kingdom Meteorological Office Hadley Center
- IPSL5: Institut Pierre-Simon Laplace (France)
- MIROC-5: Japan Agency for Marine-Earth Science and Technology
- MRI-CGM3: Japan Meteorological Institute

The six Earth system models were draw from the 5th Climate Model Inter-comparison Project (CMIP5). CMIP is a framework to study and understand the strengths and weakness of coupled atmosphere-ocean general circulation models. CMIP5 is the fifth iteration of this project. The goal of CMIP is to understand how well the models fit historical data, provide future projects of climate change, and understand the factors responsible for differences in model projects. From this project, modelers can better understand how their results fit into the modeling field and iterate and improve their models.

In my hurricane analysis, future climate predictions of these Earth-systems models were made based on RCP8.5. This means no limit in carbon emissions, and a warming predicted between 2.6 and 4.8 (mean 3.7) degrees Celsius [National Center for Atmospheric Research Staff, 2016].

3.3 Climate change could increase the number of storms

In my analysis of Professor Emanuel's hurricane model output with HHI as point of interest, I looked at the predictions for number of storms to come near Hilton Head Island over a calendar year. First, I began by comparing the historical Best Track data, from 1978-2018, to the model predictions for number of storms per month in the years 1981-2000 (Figure 4). Here I saw the models did a reasonable job at matching the observations; I didn't expect them to be great because the amount of historical data is small and therefore biased to the possible true hurricane distribution. Predictions were made by simulating $> 3,000$ tropical storm tracks and normalizing results to the historical Best Tracks (see Section 3.1) data.

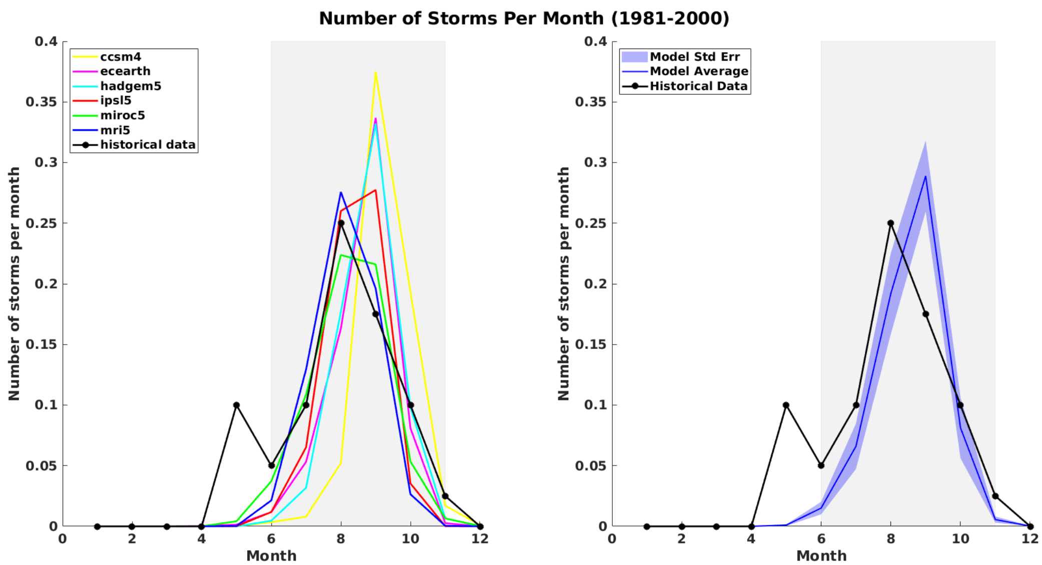

Figure 4: Hurricane Season: Model vs Historical Data

The plot depict the number of storms per month of the calendar year. Model results are plotted for the years 1981-2000. Best Track data is plotted for years 1978-2018. The left plot displays each individual model's predictions and the observed historical Best Track data. The right plot shows the average prediction across all models and the historical data. The shaded region represents the historical hurricane season for Hilton Head Island.

Satisfied with the model correctness, I compared the model predictions of the past to the predictions of the future (Figure 5). Simulations of $> 3,000$ tracks were done for both the past period (1981-2000) and the future period (2081-2100). The future projections assume RCP8.5, approximately 3.7 degrees Celsius increase (see Section 3.2). Here I found all models predicted an increase in total number of storms.

I was interested in looking at the average change between past and future over all models. In Figure 6, I compute the average change (future $-$ past). I then apply this delta to the historical, Best Tracks, data to generate Figure 7. The results show an increase from 0.8 total storms a year to 0.95 total storms a year. Note the historical data shows 0.8 storms

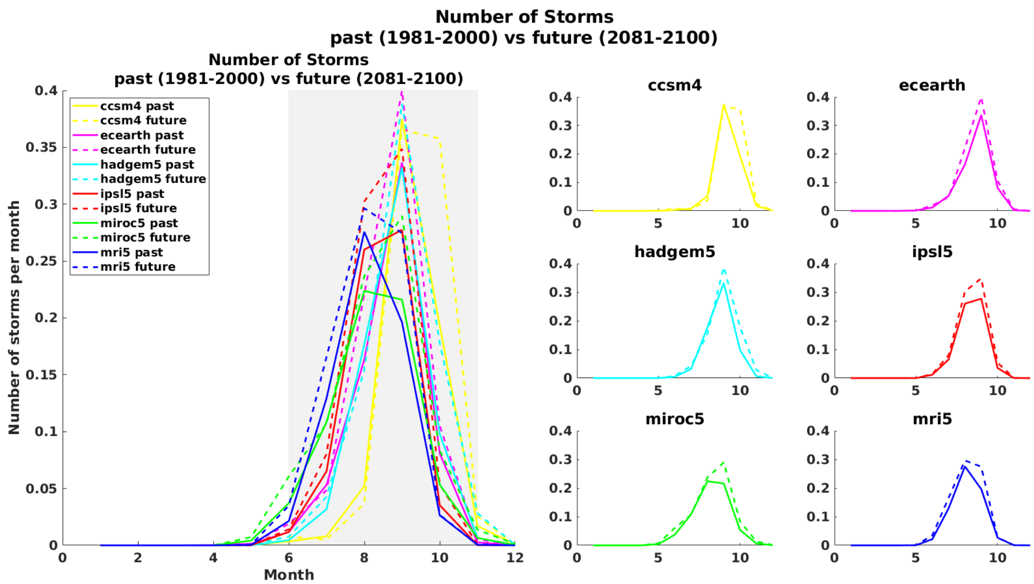

Figure 5: Hurricane Season: Model Projections Past vs Future

The plots display the model projects of the past (solid line) vs the model projections of the future (dashed line) of number of storms per month of the calendar year. The past are years 1981-2000 and the future are years 2081-2100 where an increase in temperature between 2.6 and 4.8 degrees is expected. The left-most plot is all models overlapping on the same figure; the right plots separate individual models. The shaded regions represents the historical hurricane season for Hilton Head Island.

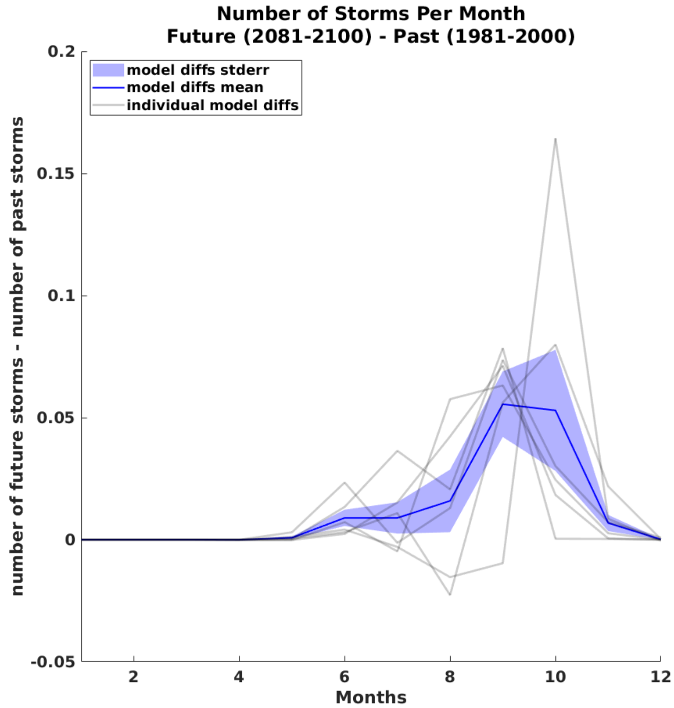

Figure 6: Hurricane Season: Model Average in Difference of Future vs Past Projections Gray lines represent the difference of future number of storm predictions vs past number of storm predictions for an individual model (where future is 2081-2100 and past is 1981-2000). The blue line represents the average difference between all models. The shaded region represents the standard error.

a year despite my discussion in Section 2 citing an expected 0.4 storms a year. The model tracks and Best Tracks are included in the analysis if they intersect a circular region of 250km from Hilton Head Island; a storm that in included in the analysis may not actually brush or hit Hilton Head Island. That is my best guess at why I see the discrepancy; however, a 2x increase between what is reported from external sources and my analysis does seem too large.

3.4 Return periods of storms decrease with climate change

I investigated the severity of hurricanes Hilton Head will see in a future with a high increase in Earth's surface temperature. I analyzed the return periods for storms based on their wind speeds. I compared the future projections and past projections of individual models, Figure 8. The results were scary. The EC-Earth model predicted storms of Hurricane Matthew wind speeds (90-110) would change from a once in forty year occurrence, to a once in eight year occurrence. Since 1851, Hilton Head Island has only been hit by a devastating hurricane ($\geq$ 100 wind speeds) twice; this is a once in eighty year occurrence. The island would not be able to handle a hurricane like Matthew once every decade.

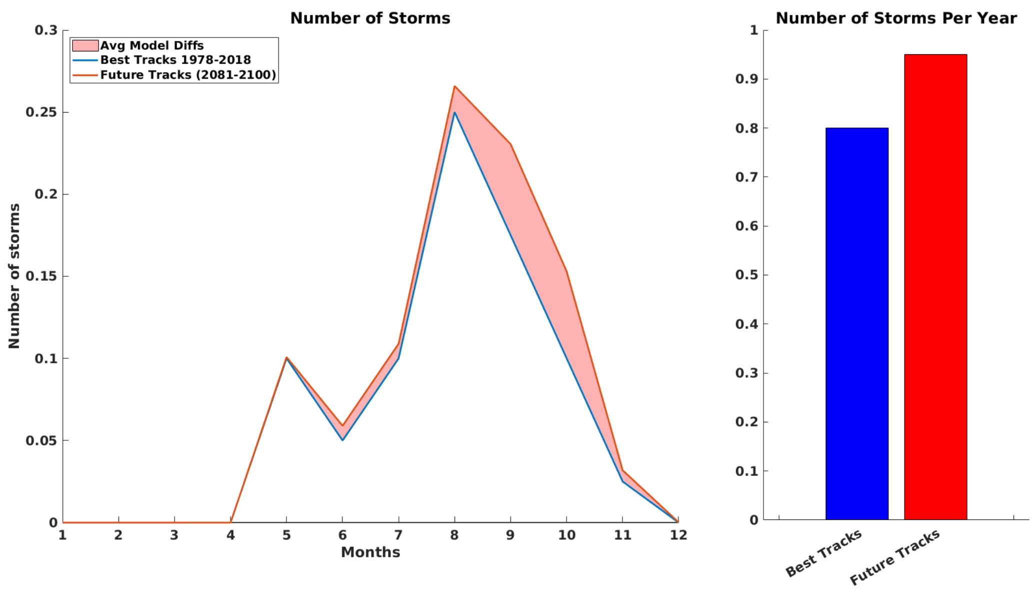

Figure 7: Hurricane Season: Historical Data Plus Average Model Projection Difference In the left plot, the average difference between the future and the past shown in Figure 6 is added on top of the Best Tracks (observed historical data) from 1978-2018. The blue line represents the Best Tracks data. The rend line represents the result of adding the model projected difference. The right figure shows the number of storms per year for the blue line and the red line in the left plot.

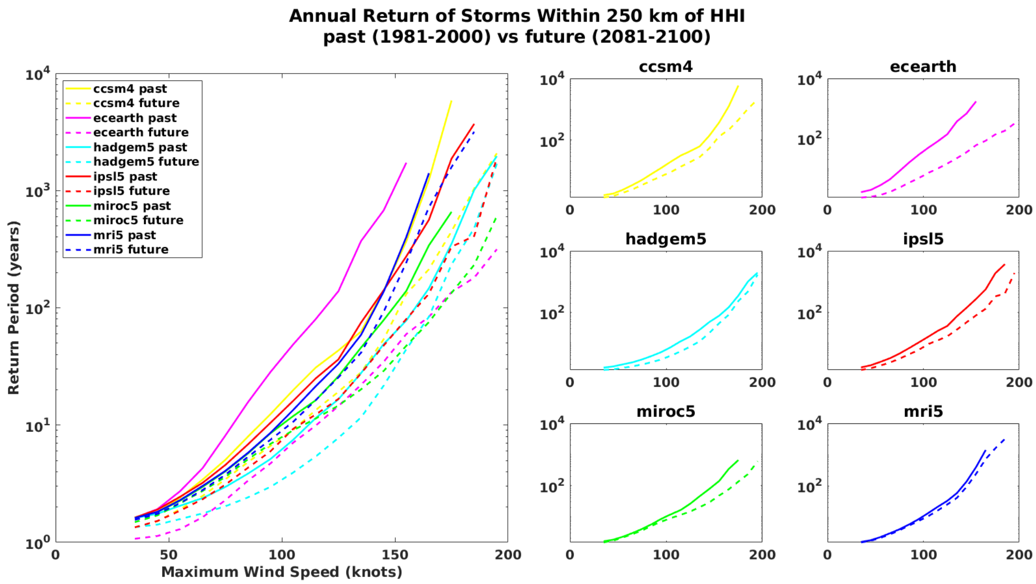

Figure 8: Wind Return: Individual Model Analysis

I plotted the model predictions of the past (solid line) vs the future (dashed line) under RCP8.5 emissions scenario. The past represents the years 1981-2000 and the future is the years 2081-2100. The left plot displays the climate models overlapping. The models are shown on individual plots on the right hand side. The future predictions show decreased annual return rates for storms of all wind speeds, especially high wind speeds.

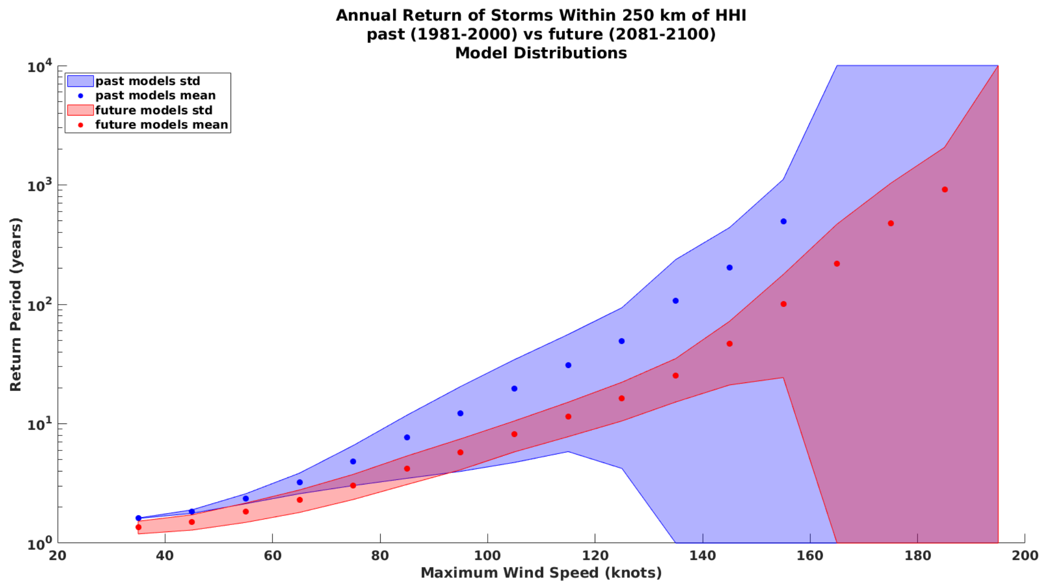

Figure 9: Wind Return: Models Average

I averaged the past (blue) and future (red) model predictions from Figure 8. The dots represent the averages of the models and the shaded region represents the standard deviation across models. On average, the models predict decreased annual return frequencies for all storms, especially those at high wind speeds.

In Figure 9, I average the results of all the models. The error bars going to 0 and infinity represent one of the six models having no predictions for those wind speeds. From the error bars alone, we see many models have more severe storms coming near Hilton Head Island under the future climate scenario.

The increase in frequency of big, devestating storms is saddening and frightening. Hopefully, I can compile and convey this information effectively to convince my community members to make changes in their lives to mitigate carbon emissions and warming.

4 Island Packet opinion editorial article outline

The second goal of my project was (and still is) to write an opinion editorial article for my local paper. Due to time constraints of the semester, I will continue this project into IAP. An outline for how I plan to approach the writing of the article is described in this section. Any suggestions or support in writing or publishing would be appreciated.

4.1 Grabbing the reader's attention

I want to immediately grab the reader's attention. I believe everyone in my area feels that tropical storms that hit, brush, and come near Hilton Head Island have become more frequent and more severe. Professor Emanuel wrote an article analyzing historical data showing that hurricane destruction has been increasing [Emanuel, 2005]. I plan to reference this work to back up the community's intuition. Next, I hope to convince my readers that scientists agree on climate change being real, being a caused by humans, and being a huge problem. I will draw from an article written by Professor Emanuel, Michael Mann, and others [Rahmstorf et al., 2018]; the article explains how strong tropical storms are becoming stronger from climate change. Finally, I plan to reference the work of James Kossin which explains that tropical storms are now moving more slowly due to anthropogenic warming of the climate, thus making them more destructive [Kossin, 2018].

4.2 Account of hurricane history in Hilton Head Island

After grabbing the readers attention, and hopefully convincing them that the effects of climate change are well based in science, I plan to bring up a still recent memory of the destruction of Hurricane Matthew. I will recall the destruction of Matthew and attempt to find evidence that the number of and intensity of hurricanes over the recent years, that have come close to Hilton Head, are in fact worse than the hurricanes of older history.

4.3 What the future holds with no carbon emission limits

I next plan to scare my audience by explain the results of Professor Emanuel's hurricane models (with the point of interest of Hilton Head). I will focus largely on return period of wind speeds. Although hurricane destruction is generally due to rainfall, for my town it seemed the wind was far more destructive. Most homes and buildings are built up a floor in case of flooding from hurricanes. However, the wind from Matthew caused over 120,000 trees to be downed on our 48 square mile island, many of which caused holes in homes.

4.4 There's hope

Finally, I want to leave the audience will a feeling of hope and ideas for immediate action. I will explain how there is no "silver bullet" for solving climate change and the policies required are complex. I am planning to reference the EnROADS model and encourage interested readers to play with the web application. I would like to briefly explain the simple science behind climate change (the atmosphere, ocean, and carbon emissions). Then I will explain new technologies for energy and energy storage. I am hesitant to discuss any carbon capture methods or geoengineering solutions since I want the readers to feel they must take action. Lastly, I will leave people with concrete actions they can take: having one fewer kid, being car free, avoiding travel by plane, buying green energy, moving to an electric car, eating a plant based diet (bonus points for buying produce from a no-till farm), and installing smart home energy systems [Institute of Physics, 2017]. Further, my town has many bike paths in place for tourists to take leisure bike rides. It would be ideal if the town could expand this infrastructure and promote biking as a primary form of transportation for locals and tourists alike; hopefully, I can plant the seed for this action in my article.

5 Contributions

The contributions from my project are:

- An analysis of future hurricanes with anthropogenic climate warming in the area of Hilton Head Island
- Increased awareness of future hurricane projections and human impact in Hilton Head Island
- A call to action for the members of Beaufort County
- An editorial article in "The Island Packet"

6 Analysis Code

6.1 Seasons Analysis

```
EVENT_SET = {
  'ccsm4', ...
  'ecearth', ...
  'hadgem5', ...
  'ipsl5', ...
  'miroc5', ...
  'mri5' ...
};

moth = [];
numEarly = [];
numLate = [];

for iEvent=1:length(EVENT_SET)
    prepf(['HiltonH_AL_' EVENT_SET{iEvent} '_20thcal'])
    load('temp.mat')
    annual()
    annualbesterr()
    if iEvent == 1
        month = x;
    end
    numEarly = [numEarly; y];
```

```
    prepf(['HiltonH_AL_' EVENT_SET{iEvent} '_rcp85cal'])
    load('temp.mat')
    annual()
    annualbesterr()
    if iEvent == 1
        bestTracks = y2;
    end
    numLate = [numLate; y];
end

%% Plot settings
set(0, 'DefaultLineLineWidth', 2);
set(groot, 'DefaultAxesTitleFontSizeMultiplier', 1.2);
set(groot, 'DefaultAxesFontWeight',  'bold');
set(groot, 'DefaultAxesFontSize', 15);

%% Individual Model Raw
COLORS = {'y', 'm', 'c', 'r', 'g', 'b'};
f1 = figure;
subplot(1,2,1);
rectangle('Position',[6,0,5,0.4], 'FaceColor', [0,0,0,0.05], 'EdgeColor', [0,0,0,0.05]);
hold on;
for iRow=1:size(numEarly,1)
    plot(month, numEarly(iRow,:), ['-' COLORS{iRow}]);
end
plot(month, bestTracks, 'k-o', 'MarkerFaceColor', [0 0 0]);
ylabel('Number of storms per month');
xlabel('Month');
legend([EVENT_SET, {'historical data'}], 'Location', 'northwest');
subplot(1,2,2);
rectangle('Position', [6,0,5,0.4], 'FaceColor', [0,0,0,0.05], 'EdgeColor', [0,0,0,0.05])
hold on;
stdshade(numEarly, 0.3, 'b');
plot(month, bestTracks, 'k-o', 'MarkerFaceColor', [0 0 0]);
legend({'Model Std Err', 'Model Average', 'Historical Data'}, 'Location', 'northwest');
sgt = sgtitle('Number of Storms Per Month (1981-2000)');
sgt.FontWeight = 'bold';
sgt.FontSize = 20;
ylabel('Number of storms per month');
xlabel('Month');

%% Model diffs raw
f2 = figure;
subplot(3,4,[1,2,5,6,9,10]);
```

```
rectangle('Position',[6,0,5,0.4], 'FaceColor', [0,0,0,0.05], 'EdgeColor', [0,0,0,0.05]);
hold on;
for iRow=1:size(numEarly,1)
    plot(month, numEarly(iRow,:), ['-' COLORS{iRow}]);
    plot(month, numLate(iRow,:), ['--' COLORS{iRow}]);
end
ylabel('Number of storms per month');
xlabel('Month');
title(['Number of Storms' newline 'past (1981-2000) vs future (2081-2100)']);
l1 = cellfun(@(s) [s ' past'], EVENT_SET, 'UniformOutput', false);
l2 = cellfun(@(s) [s ' future'], EVENT_SET, 'UniformOutput', false);
lzip = [l1(:),l2(:)].';
legend(lzip(:), 'Location', 'northwest');
subplot(3,4,3);
hold on;
plot(month, numEarly(1,:), ['-' COLORS{1}]);
plot(month, numLate(1,:), ['--' COLORS{1}]);
ylim([0,0.4]);
title(EVENT_SET{1});
subplot(3,4,4);
hold on;
plot(month, numEarly(2,:), ['-' COLORS{2}]);
plot(month, numLate(2,:), ['--' COLORS{2}]);
ylim([0,0.4]);
title(EVENT_SET{2});
subplot(3,4,7);
hold on;
plot(month, numEarly(3,:), ['-' COLORS{3}]);
plot(month, numLate(3,:), ['--' COLORS{3}]);
ylim([0,0.4]);
title(EVENT_SET{3});
subplot(3,4,8);
hold on;
plot(month, numEarly(4,:), ['-' COLORS{4}]);
plot(month, numLate(4,:), ['--' COLORS{4}]);
ylim([0,0.4]);
title(EVENT_SET{4});
subplot(3,4,11);
hold on;
plot(month, numEarly(5,:), ['-' COLORS{5}]);
plot(month, numLate(5,:), ['--' COLORS{5}]);
ylim([0,0.4]);
title(EVENT_SET{5});
subplot(3,4,12);
hold on;
```

```
plot(month, numEarly(6,:), ['-' COLORS{6}]);
plot(month, numLate(6,:), ['--' COLORS{6}]);
ylim([0,0.4]);
title(EVENT_SET{6});
sgt = sgtitle(['Number of Storms' newline 'past (1981-2000) vs future (2081-2100)']);
sgt.FontWeight = 'bold';
sgt.FontSize = 20;

%% Model diffs
diffMonths = numLate - numEarly;
f3 = figure;
hold on;
stdshade(diffMonths, 0.3, 'b');
plot(diffMonths', 'Color', [0 0 0 0.2]);
xlabel('Months');
ylabel('number of future storms - number of past storms');
xlim([1,12]);
legend({'model diffs stderr', 'model diffs mean', 'individual model diffs'}, 'location',
title(['Number of Storms Per Month' newline 'Future (2081-2100) - Past (1981-2000)']);

%% Expected future
diffMonths = numLate - numEarly;
future = bestTracks + mean(diffMonths);
f4 = figure;
subplot(1,3,[1,2]);
hold on;
f_ = fill([month month], [bestTracks future], 'r');
alpha(f_,.3);
plot(bestTracks);
plot(future)
legend({'Avg Model Diffs', 'Best Tracks 1978-2018', 'Future Tracks (2081-2100)'}, 'locat
xlim([1,12]);
ylim([0,0.3]);
xlabel('Months');
ylabel('Number of storms');
title('Number of Storms');
subplot(1,3,3);
hold on;
bar(1, sum(bestTracks), 'b');
bar(2, sum(future), 'r');
xticklabels({'', 'Best Tracks', 'Future Tracks'});
xtickangle(30);
title('Number of Storms Per Year');
```

6.2 Wind Return Analysis

```
%% Data prep
EVENT_SET = {
  'ccsm4', ...
  'ecearth', ...
  'hadgem5', ...
  'ipsl5', ...
  'miroc5', ...
  'mri5' ...
};

speed = [];
returnEarly = [];
returnLate = [];

for iEvent=1:length(EVENT_SET)
    prepf(['HiltonH_AL_' EVENT_SET{iEvent} '_20thcal'])
    load('temp.mat')
    return_period()
    if iEvent == 1
        speed = x;
    end
    returnEarly = [returnEarly; 1./(1-exp(-y))];


    prepf(['HiltonH_AL_' EVENT_SET{iEvent} '_rcp85cal'])
    load('temp.mat')
    return_period()
    returnLate = [returnLate; 1./(1-exp(-y))];
end

%% Plot settings
set(0, 'DefaultLineLineWidth', 2);
set(groot, 'DefaultAxesTitleFontSizeMultiplier', 1.2);
set(groot, 'DefaultAxesFontWeight',  'bold');
set(groot, 'DefaultAxesFontSize', 15);

%% Model diffs raw
f1 = figure;
subplot(3,4,[1,2,5,6,9,10]);
for iRow=1:size(returnEarly,1)
    semilogy(speed, returnEarly(iRow,:), ['-' COLORS{iRow}]);
    hold on;
```

```
    semilogy(speed, returnLate(iRow,:), ['--' COLORS{iRow}]);
end
ylabel('Return Period (years)');
xlabel('Maximum Wind Speed (knots)');
l1 = cellfun(@(s) [s ' past'], EVENT_SET, 'UniformOutput', false);
l2 = cellfun(@(s) [s ' future'], EVENT_SET, 'UniformOutput', false);
lzip = [l1(:),l2(:)].';
legend(lzip(:), 'Location', 'northwest');
subplot(3,4,3);
semilogy(speed, returnEarly(1,:), ['-' COLORS{1}]);
hold on;
semilogy(speed, returnLate(1,:), ['--' COLORS{1}]);
ylim([0 10^4]);
title(EVENT_SET{1});
subplot(3,4,4);
semilogy(speed, returnEarly(2,:), ['-' COLORS{2}]);
hold on;
semilogy(speed, returnLate(2,:), ['--' COLORS{2}]);
ylim([0 10^4]);
title(EVENT_SET{2});
subplot(3,4,7);
semilogy(speed, returnEarly(3,:), ['-' COLORS{3}]);
hold on;
semilogy(speed, returnLate(3,:), ['--' COLORS{3}]);
ylim([0 10^4]);
title(EVENT_SET{3});
subplot(3,4,8);
semilogy(speed, returnEarly(4,:), ['-' COLORS{4}]);
hold on;
semilogy(speed, returnLate(4,:), ['--' COLORS{4}]);
ylim([0 10^4]);
title(EVENT_SET{4});
subplot(3,4,11);
semilogy(speed, returnEarly(5,:), ['-' COLORS{5}]);
hold on;
semilogy(speed, returnLate(5,:), ['--' COLORS{5}]);
ylim([0 10^4]);
title(EVENT_SET{5});
subplot(3,4,12);
semilogy(speed, returnEarly(6,:), ['-' COLORS{6}]);
hold on;
semilogy(speed, returnLate(6,:), ['--' COLORS{6}]);
ylim([0 10^4]);
title(EVENT_SET{6});
sgt = sgtitle(['Annual Return of Storms Within 250 km of HHI' newline 'past (1981-2000)
```

```
sgt.FontWeight = 'bold';
sgt.FontSize = 20;

%% Model diff avgs
returnEarlyAvg = mean(returnEarly);
returnEarlyStd = std(returnEarly);
returnLateAvg = mean(returnLate);
returnLateStd = std(returnLate);

lowerEarly = (returnEarlyAvg - returnEarlyStd);
lowerEarly(lowerEarly < 0 | lowerEarly == Inf | isnan(lowerEarly)) = 1;
upperEarly = returnEarlyAvg + returnEarlyStd;
upperEarly(upperEarly == Inf | isnan(upperEarly)) = 10^4;
lowerLate = (returnLateAvg - returnLateStd);
lowerLate(lowerLate < 0 | lowerLate == Inf | isnan(lowerLate)) = 1;
upperLate = returnLateAvg + returnLateStd;
upperLate(upperLate == Inf | isnan(upperLate)) = 10^4;

f2 = figure;
hold on;
fe_ = fill([fliplr(speed) speed], [fliplr(upperEarly) (lowerEarly)], 'b');
fe_.EdgeColor = [0 0 1];
alpha(fe_,.3);
scatter(speed, returnEarlyAvg, 50, 'b', 'filled');
fl_ = fill([fliplr(speed) speed], [fliplr(upperLate) (lowerLate)], 'r');
fl_.EdgeColor = [1 0 0];
alpha(fl_,.3);
scatter(speed, returnLateAvg, 50, 'r', 'filled');
set(gca, 'YScale', 'log');
ylabel('Return Period (years)');
xlabel('Maximum Wind Speed (knots)');
title(['Annual Return of Storms Within 250 km of HHI' newline 'past (1981-2000) vs futur
legend({'past models std', 'past models mean', 'future models std', 'future models mean'
```

References

[Emanuel, 2005] Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436(7051):686.

[Emanuel, 2017] Emanuel, K. (2017). Assessing the present and future probability of hurricane harveys rainfall. *Proceedings of the National Academy of Sciences*, 114(48):12681–12684.

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