Ensemble vs. Deterministic Simulations for Predicting Storm Surge

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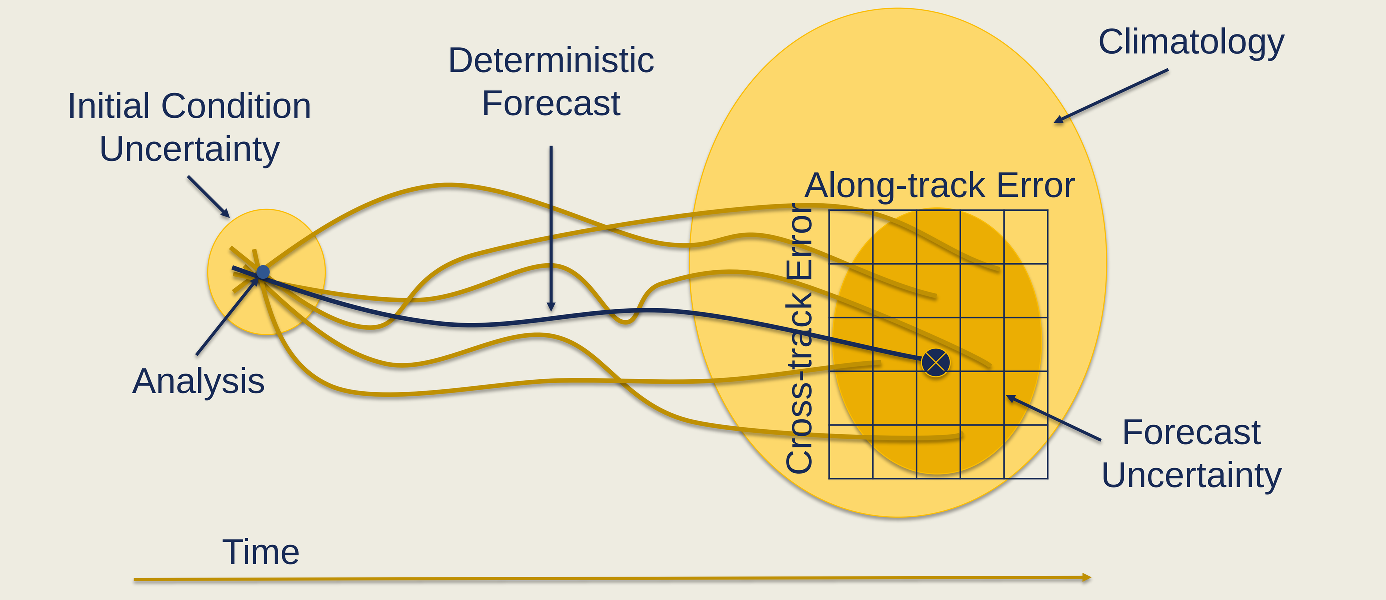
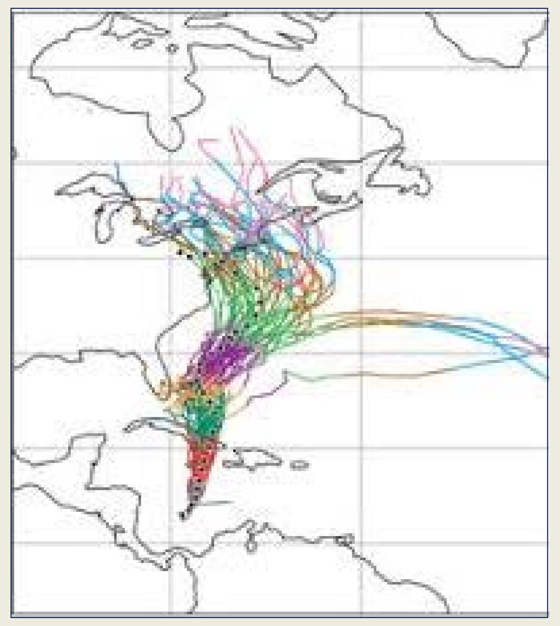
Abstract
A deterministic model for Hurricane Sandy is created using the "Best Track" wind data, from which the winds are perturbed to create ensemble forecasts with varying numbers of members. The modeling system "Delft3D" is used to generate water levels and currents using these wind fields. To ensure statistical accuracy, these members are pulled from a number of input possibilities, which can also be modified. This project gives insight into the statistical advantage of ensembles and aims to determine the balance between ensemble members, cost, and accuracy.

Background
In a deterministic model of a hurricane, only the forecast track is used to generate the winds, and the results are run in a model at a given resolution, yielding a single forecast. An ensemble, or probabilistic forecast, takes this set of data and perturbs individual conditions, such as wind speed, cross-track errors and along-track errors, in order to produce a number of members that follow different routes. The model is run with each individual wind field and the results are collated to generate the probabilistic forecast.

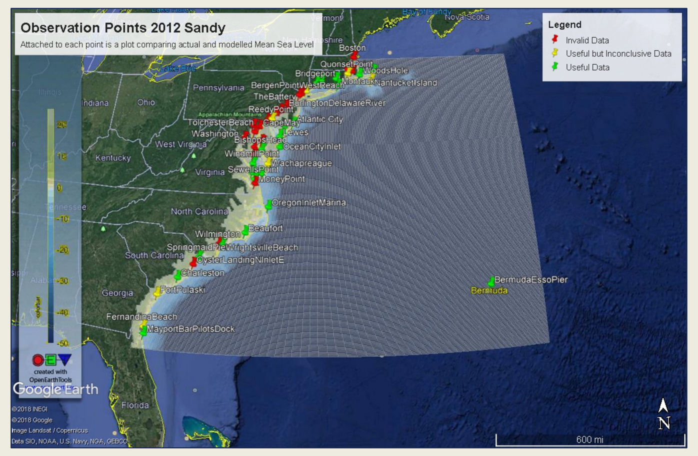


Objectives
An ensemble forecast can be run at lower resolutions than its deterministic counterpart, allowing for more reliable model output and minimizing cost and computing time. This project seeks to optimize the number of members in an ensemble to keep resources low while maintaining a high degree of accuracy. This will also help improve the speed at which a valuable forecast can be produced in response to the formation of a hurricane.

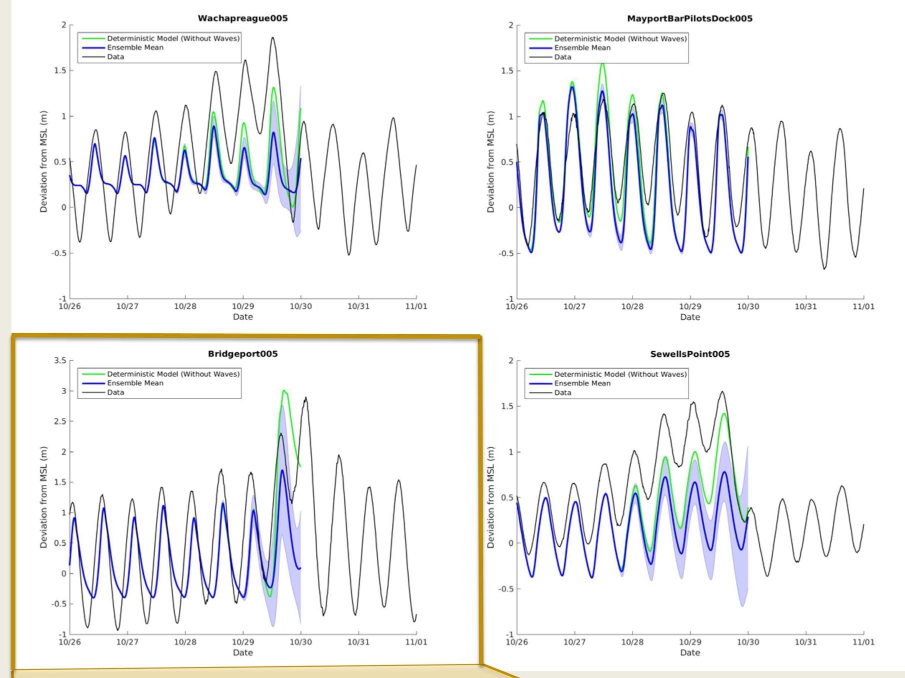
Why Sandy?
Hurricane Sandy has an abundance of valuable data collection on the coastline and took an interesting path. On October 29, scientists believed it could have continued its track north or veered east, based on conventional knowledge of global wind patterns. Some forecasts (ECMWF, HFIP GFS, etc.) have more members taking an eastward path, although this did not occur in our model[1].

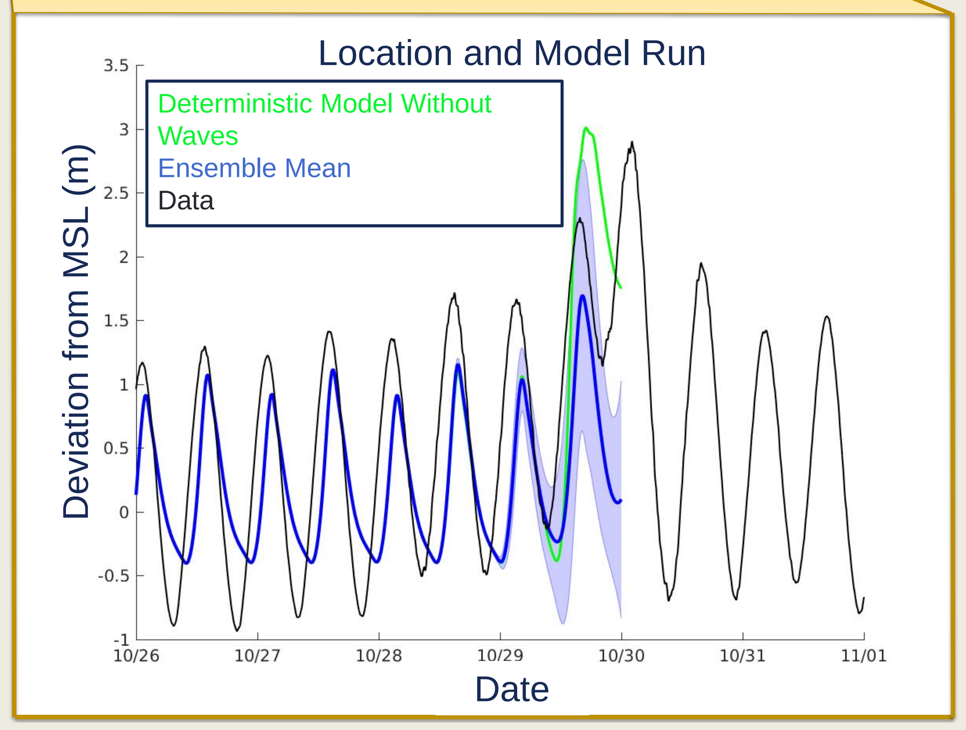


Methodology and Models
Mean sea level data was gathered from 63 of NOAA's onshore CO-OP stations on the East coast and plotted in a KML file, overlaid with a model grid that contains cells at a resolution of 5 square km. I collected these data points from NOAA's website and excluded the ones that resolution cut off. With the domain laid out, a deterministic model was built from the ground up, considering mean sea level, winds, and tides/currents. I used MATLAB to plot comparisons of each draft of the model and historical mean sea level and attached them to each station in the KML.



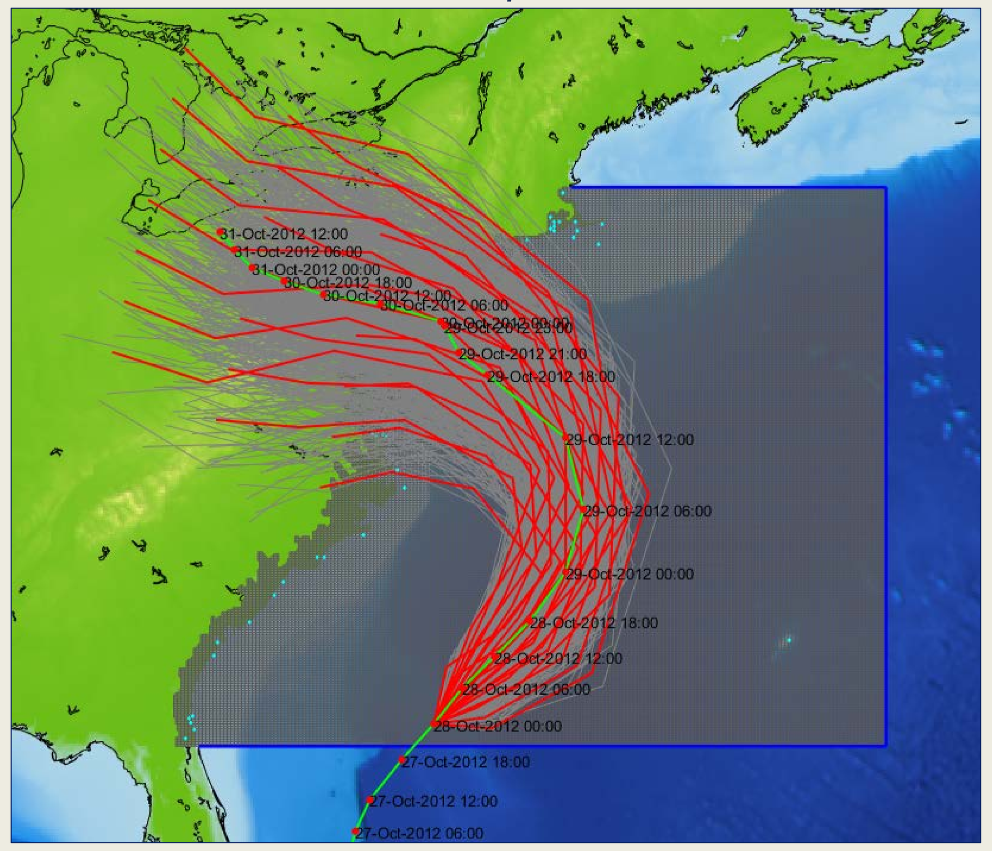
Creating the Ensembles
The Monte Carlo method was used to perturb the best track winds. With the wind files altered, 1000 ensembles (pictured in thin grey lines below) were created, from which 63 (pictured in red below) and 30 (not shown) representative members were used for the ensemble runs[2]. The mean and its standard deviation of the member runs were calculated and plotted next to the historical data, as well as the deterministic model that considered water level and the original best track winds (right). I assigned each observation point with the respective plot. (These were also generated with the deterministic model, including waves/tides, although it is not shown for clarity reasons)



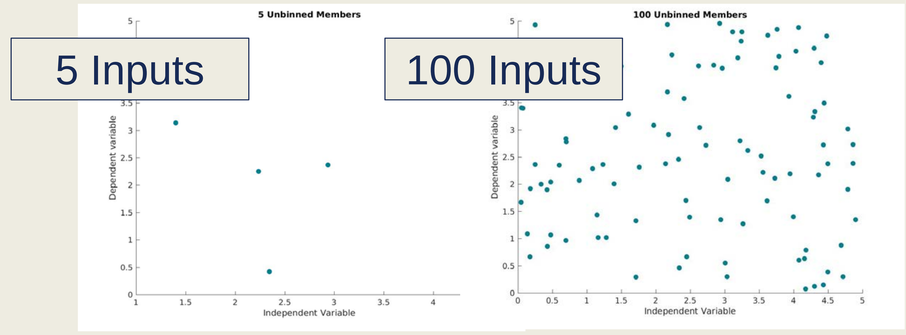


Ensemble Run	Characteristics
1	63 binned members of 1000
2	30 binned members of 1000

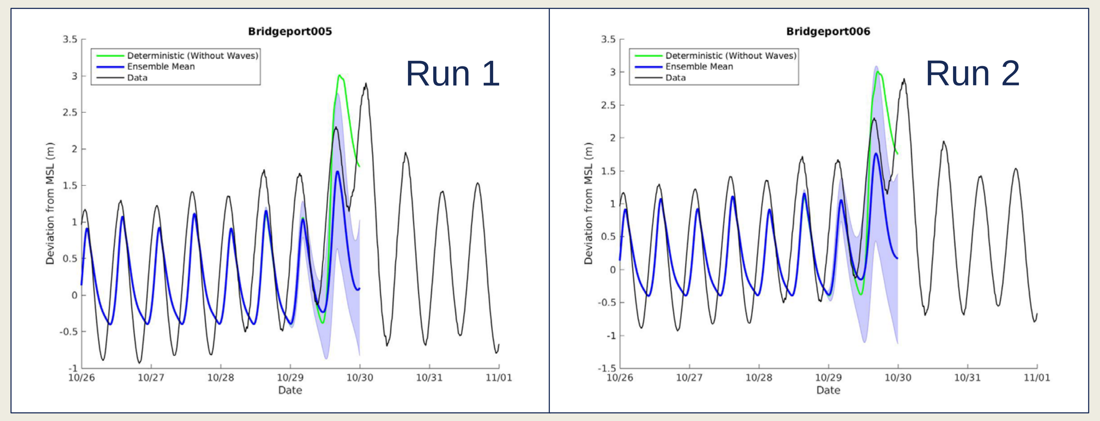
Run 1: 63 binned of 1000 possibilities



The scatterplots below serve to explain the binning process. They show axes representing Cross-track and Along-track Error with random points. At each range, or bin, the points are averaged. With more input possibilities, it is more likely one will fall within every range.



Results
The runs with 63 and 30 representative member showed the same mean value, although the standard deviation was significantly larger at most observation points in the 30 member run.



Looking at the hurricane track from above, this would mean that the path it takes in the model fans out more over time.

The mean value is less than the deterministic model value in most cases, which is expected because it is the average of all representative members. These members may not pass directly over the observation point, meaning many make landfall farther away, so the averaged value is typically less than the deterministic.

Conclusion
- The relatively low resolution posed issues for many observation points, drawing them too far inland or not being fine enough for stations in narrow rivers; we saw better results with the points directly on the coastline.
- The 30 member ensemble has a larger margin of error because it pulls fewer representatives. The more representatives there are, the more accurate the forecast will be.

Further Work
The project has numerous paths it can take from this point. The same ensemble process can be used for any other hurricanes, and factors other than wind can be perturbed to observe the effect of different inputs. Next year, I plan to continue this work for another hurricane and gather a more complete set of data.

Furthermore, I could improve grid resolution by confining the grid file to not include Bermuda.

References
1. Apectyphoon.org. June 2013. Vol. 3 No. 2. APEC Research Center for Typhoon and Society. [6/13, 7/10/18]
2. Knaff, John. DeMaria, Mark. Knabb, Richard. Lauer, Chris. Sampson, Charles. DeMaria, Rober. 2009. A New Method for Estimating Tropical Cyclone Wind Speed Probabilities
3. noaa.gov. https://tidesandcurrent.noaa.gov. [6/7/18]

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