A Numerical Study on the Landfall of Hurricane Maria in Puerto Rico

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Introduction

Tropical cyclone's (TC) structure, behavior and variables such as wind and rainfall are influenced by the topography when the system makes landfall in a region characterized by complex terrain and multiple mountain ranges. This implies that the atmospheric processes involved in a TC depend on the interaction with landmass. However, computer models cannot resolve the topographical factors that affect surface weather.

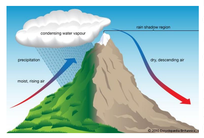

FIG 1: Graphic representation of the orographic precipitation process (Encyclopedia Britannica, 2010)

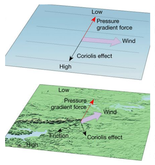

FIG 2: Diagram of the forces that influence wind speed and wind direction (The Atmosphere, 8th edition, Lutgens and Tarbuck, 8th edition, 2001)

Researches have shown that incorporating the surface roughness, or a high-resolution terrain data in models has an impact on the representation of the atmospheric variables and landfall of a TC that goes with what is theoretically expected.

Methodology

The basis for the study is the set of simulations produced by version 4.1 of the Advance Research version of the Weather Research and Forecasting Model (WRF). The model employs three domains with a "nested grid refinement method" where the outer domain is stationary and the inner domains move following the hurricane.

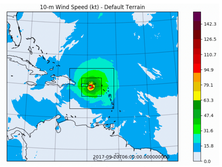

FIG 3: 10m wind speed of Hurricane Maria before making landfall in Puerto Rico. The outermost box represents the domain 1, and the inner boxes represent domain 2 and 3.

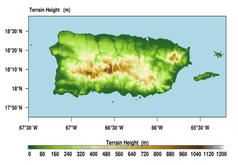

FIG 4: Representation of Puerto Rico using high-resolution terrain data

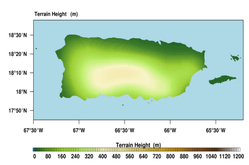

FIG 5: Representation of Puerto Rico using the default resolution terrain data

One of the simulations used a default land surface data, and the other a data set with high-resolution terrain. To study the impact of terrain resolution in simulations of tropical cyclones an ensemble of 5 members was generated by stochastically perturbing QVAR

Results

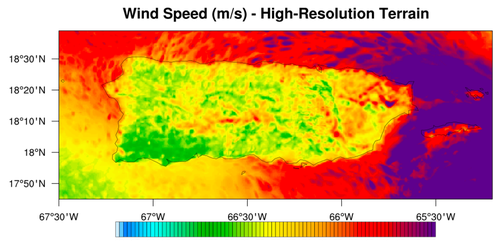

FIG 6: Highest magnitude of wind speed over Puerto Rico on September 20, 2017 for the high-resolution terrain simulation

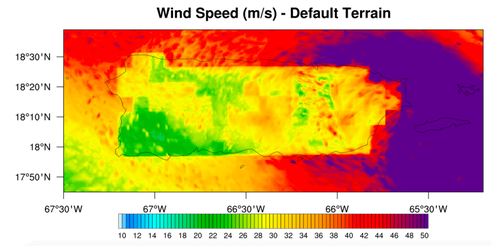

FIG 7: Highest magnitude of wind speed over Puerto Rico on September 20,2017 for the default terrain simulation

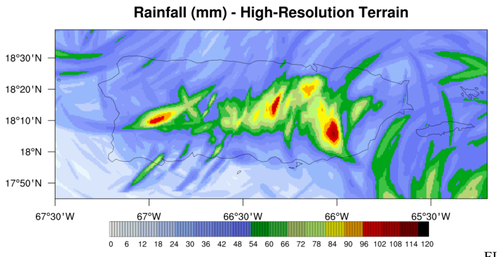

FIG 8: Highest 1-hour accumulated rainfall over Puerto Rico using the high-resolution terrain data

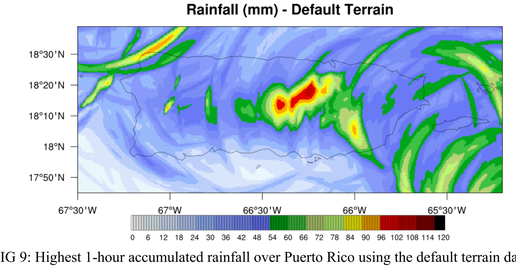

FIG 9: Highest 1-hour accumulated rainfall over Puerto Rico using the default terrain data

----------High-Resolution Terrain----------

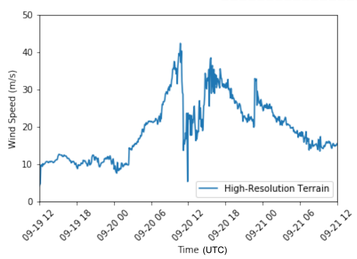

FIG 10: 10-m wind speed for one location of Puerto using high-resolution terrain data

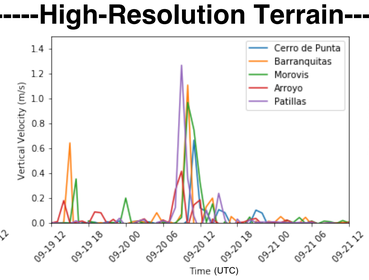

FIG 11: 40-m vertical velocity of winds for five locations of Puerto Rico using high-resolution terrain data

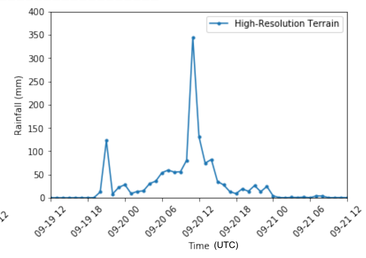

FIG 12: Accumulated rainfall for one location of Puerto using high-resolution terrain data

----------Default Terrain ----------

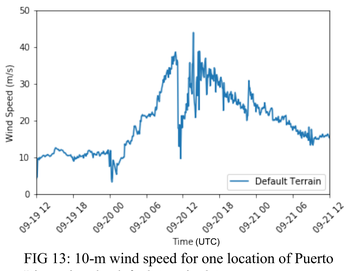

FIG 13: 10-m wind speed for one location of Puerto Rico using the default terrain data

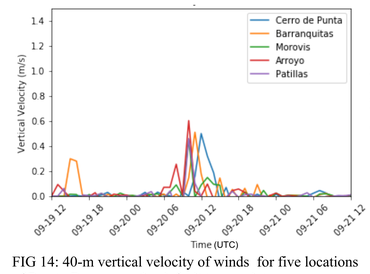

FIG 14: 40-m vertical velocity of winds for five locations of Puerto Rico using the default terrain data

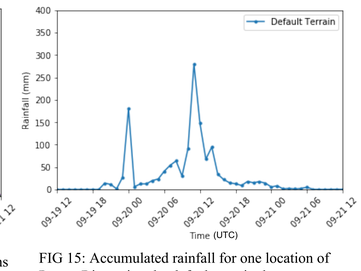

FIG 15: Accumulated rainfall for one location of Puerto Rico using the default terrain data

Discussion

When the hurricane made landfall its wind field experimented a higher decrease on the intensity due to the interaction with landmass when incorporating the high-resolution terrain data on the simulations. In addition, the strongest winds were located in the most elevated points of the island. On the other hand, for the high-resolution terrain simulation the magnitude of the vertical movement of the air was higher in contrast to the default terrain simulation, resulting in an increase of the accumulated rainfall.

Conclusions

When using the high-resolution terrain data we found stronger winds, the highest accumulation of rainfall and vertical movement of the air in the mountainous interior of the island.

High-resolution land data has the potential to lead to more accurate forecasts of wind and rain in cases when a TC interacts with a landmass.

Future Work

Study the variables of interest using a stochastic ensemble with 5 members for each topography setting

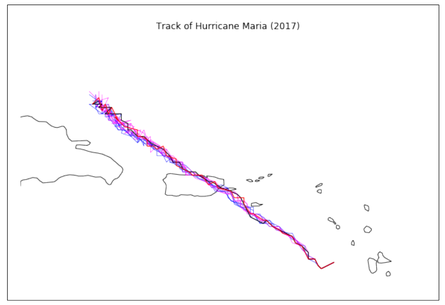

FIG 16: Track of Hurricane Maria from September 19 at 12 UTC to September 21 at 12 UTC. The red line shows the trajectory of the hurricane for the high-resolution terrain simulation and the black line for the default terrain simulation. The pink lines show the trajectory for the 5-members of the stochastic ensemble with high-resolution terrain data, and the blue lines for the 5-members of the ensemble with default terrain data.

Acknowledgments

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