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Simulating Hurricane Katrina with WRF: Assessing the Impact of Sea Surface Warming

Introduction

Climate change, a consequence of the anthropogenic release of excess greenhouse gases into the atmosphere, has led to increasing concerns regarding the future of tropical cyclones. With warming global temperatures, scientists expect to see more intense and frequent tropical cyclones, which could bring about devastating impacts for vulnerable communities. This assumption is based on the notion that climate change is expected to increase sea surface temperatures (SSTs), and the fact that warmer SSTs are essential to the formation and intensification of tropical cyclones. This reality prompts the question that serves as the driving force behind this research assignment: "What would Hurricane Katrina look like if there were a 2°C increase in sea surface temperatures?"

To answer this question, I decided to use the Weather Research and Forecasting (WRF) model to compare a control simulation of Hurricane Katrina using observed sea surface temperatures to a warming simulation with a 2°C increase in sea surface temperatures. By analyzing the differences between them, I hope to have a better understanding of just how impactful warmer SSTs are in the formation of tropical cyclones. I hypothesize that the warming simulation will show a lower central pressure, stronger winds, and increased amounts of precipitation for Hurricane Katrina, due to the warmer atmosphere's increased ability to contain moisture.

Data and Methods

For this project, I utilized the WRF model with 30 km horizontal resolution over the Gulf of Mexico. Firstly, I ran the control simulation, which uses the observed surface temperatures from late August 2005. Secondly, I modified the wrflowinp_d01 file provided within Darwin to account for a +2°C SST increase, and ran this new modified file to generate the warming simulation. After running both simulations and obtaining the output files from both, I tried to use the Climate Data Operators' (CDO) "cdo sub" tool to subtract the results of the control simulation from the warming simulation, per the assignment instructions, but ran into an issue that made the resulting difference file unusable. Although this was a minor setback, I was able to move forward with this portion of my data analysis in Python using Google Colab. I processed these files by adding the control (wrfout_control) and warming (wrfout_run) simulation output files into my Google Drive, where I then linked my Drive to the Colab Notebook.

For the actual analysis portion of the assignment, I focused on the final time slice in the model (index 8), which corresponds to the end of the 24-hour simulation period. Using the WRF-python package, I was able to extract the following key variables to generate various plots:

- Sea Level Pressure (SLP)
- Precipitation (which is a sum of RAINC and RAINNC)
- Zonal and meridional wind speeds
- Surface wind speeds
- Wind speed at 500mb heights

I was able to compute the difference between each variable within my warming and control runs by using the NumPy array subtraction. I was able to use Cartopy for geographic projection, and I added coastlines to provide visual context for the location of the storm. Lastly, I ensured that each plot was titled based on the variable being analyzed.

Results

By way of the aforementioned data analysis methods, I was able to generate various difference plots, which show Hurricane Katrina as being much more intense in the +2°C warming simulation. *Figure 2*, which depicts the difference in precipitation between the warming and control simulations, shows an increase in precipitation near the center of the storm. The plot shows up to a 240mm increase in total precipitation, in comparison to the control run, as a result of the warmer SSTs. *Figure 3* does a great job of displaying the difference in sea level pressure. Hurricane Katrina is recorded as having a "minimum central pressure of 902 mb", which is the eighth lowest central pressure on record (Beven et al., 1109). By looking at the figure, we can see that Katrina's central pressure dropped by roughly 20 millibars in our warming simulation, which is a known indicator of an intensifying hurricane. As central pressure drops, the isobars pack together more tightly than before, which indicates that there has been an increase in wind speed as well. *Figure 4* confirms this, as wind speeds near the surface saw an increase of up to 30 m/s, especially near the center of the storm, as predicted by *Figure 3*. Lastly, *Figure 5* confirms that there is an enhanced upper-level divergence, as windspeeds at the 500mb heights were up to 50 knots stronger in the warming simulation than in the control simulation.

Discussion

Overall, I was able to determine that there is a significant intensification of Hurricane Katrina in our warming simulation. While I am happy with these results, as they align with my initial hypothesis, there are some aspects of it that I would like to change if I were to run it again. I would begin by changing the horizontal grid spacing of the simulation, as the current resolution is far too coarse to resolve fine-scale details like the eye of the storm and the eye wall, which are two very important features to analyze in a warming simulation. Will there be a strengthening of the eye wall? Will the eye wall be more organised? Will the eye of the hurricane become larger or smaller as sea surface temperatures continue to increase? To combat this issue, I would look for datasets that have a grid spacing of 4 km or less; that way, I could better analyze my results. I also must take into consideration that this is a single case study, and because of that, we are unable to generalize every single tropical cyclone's response to warming SSTs based on Katrina's. However, this experiment serves as a great illustration of the trend that the majority of tropical cyclones will follow, given that the consequences of climate change are upon us.

Conclusion

This project also allowed me to take a step back and look into the real-world implications of climate change. If I were to continue looking into this research topic, I would also focus on how the intensification of tropical cyclones due to climate change impacts marginalized communities, such as my own, and the socioeconomic impacts it may have on those affected. Stroms enhanced by warming SSTs may most likely lead to an increase in precipitation, which could lead to more frequent flooding, and stronger winds, which could lead to severe damage to infrastructure and loss of life. After Hurricane Katrina made its way through New Orleans, the housing market saw a sharp decline, as "Hurricane Katrina…rendered two-thirds of the city's housing stock uninhabitable" (Vigdor, 146). While the physical/economic consequences of climate change are important, we must also take a step back and consider the emotional and psychological effects severe weather events may have on people within the communities most impacted by natural disasters. After Hurricane Katrina made landfall on the Gulf Coast, many residents of the region experienced feelings of "fear, loss, anger, support, spirituality, and resilience" as a result of the trauma they endured at the hands of the devastating circumstances (Powers, 89). In a warming world, how much worse could these consequences be? Would homelessness be on the rise, unlike ever before? Would people migrate to areas that are less frequently impacted by tropical cyclones? This assignment has re-piqued my interest in this topic, and I hope to look into the socioeconomic impacts of tropical cyclone frequency and intensity during my tenure at graduate school.

Figures and Descriptions

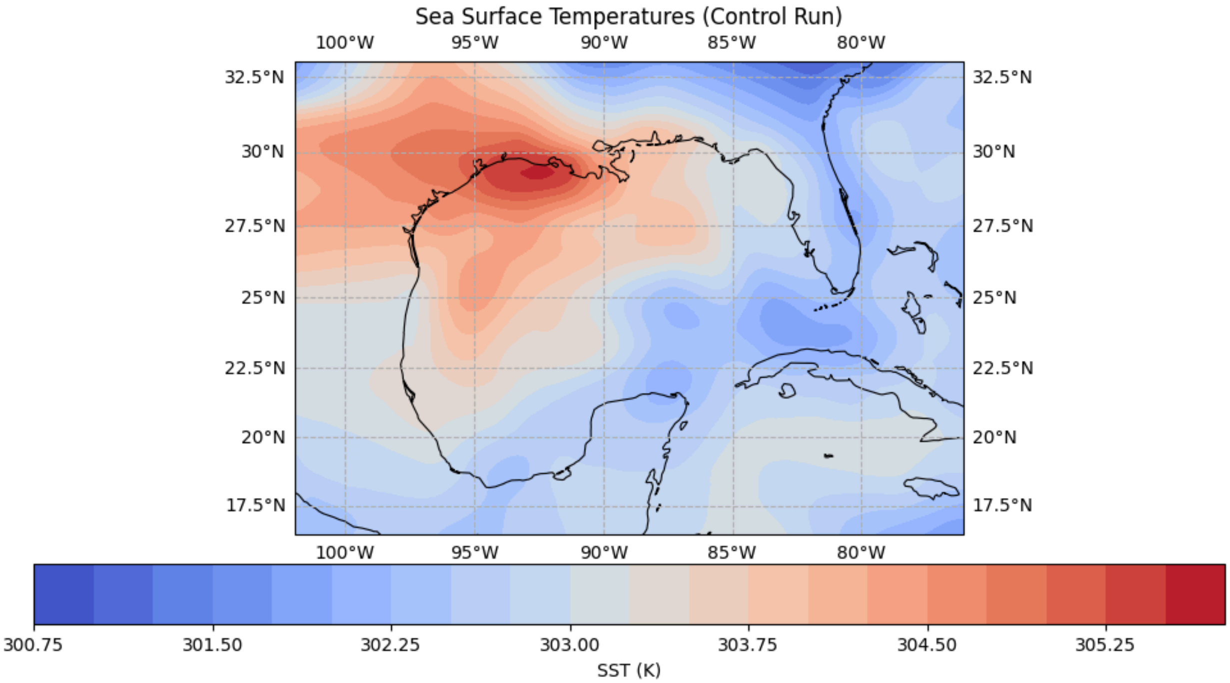

Figure 1 (not mentioned in the paper): *Sea Surface Temperatures (SST) used in the Control Simulation (K).* This figure shows the spatial distribution of sea surface temperatures from the control run of the WRF model, initialized before the +2°C warming sensitivity experiment. Warmer SSTs are concentrated in the northern Gulf of Mexico, particularly along the Louisiana coast, with values exceeding 305 K (~32°C). These elevated SSTs provided a substantial energy source for Hurricane Katrina's intensification in the baseline simulation. Cooler SSTs are present in the southern Gulf and Caribbean regions.

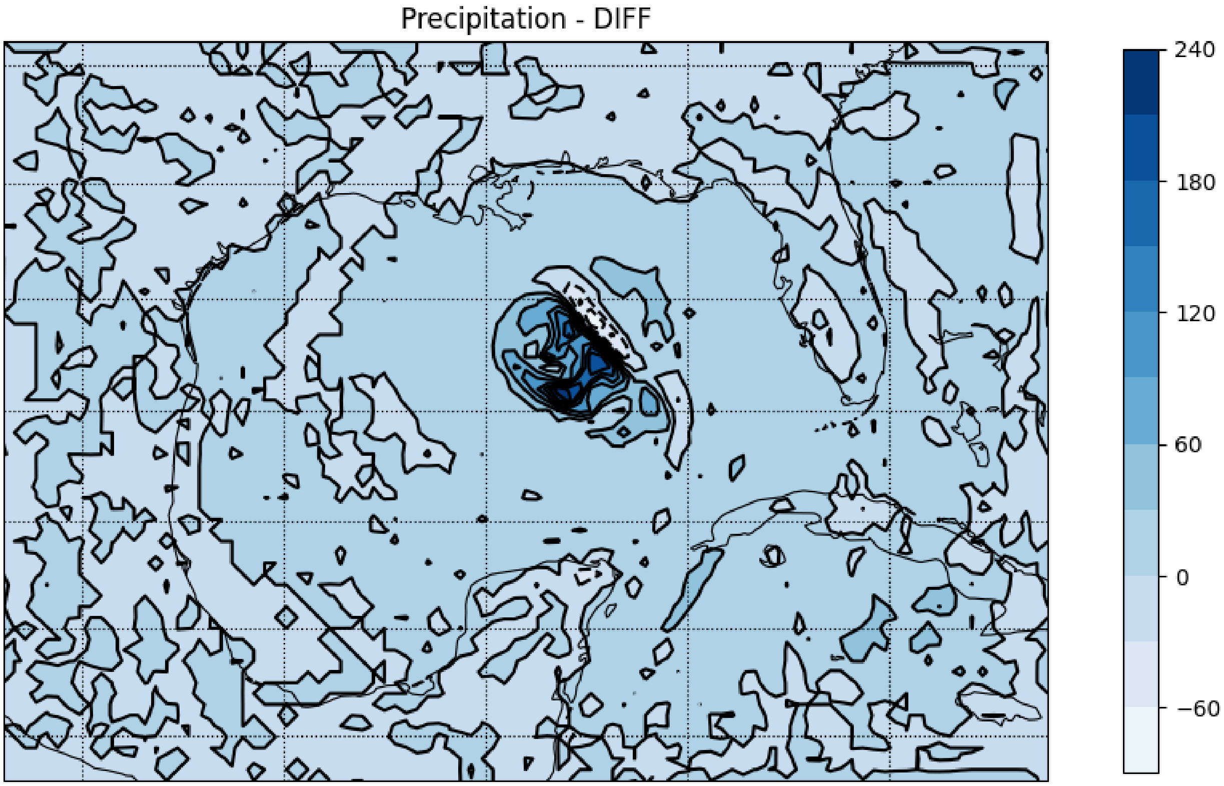

Figure 2: *Difference in Precipitation, in mm.* Shaded contours show the spatial distribution of precipitation change at the final time step of the simulation (24 hours after initialization). The greatest increases in rainfall are concentrated around the storm core and adjacent spiral rainbands, with local differences exceeding 200 mm.

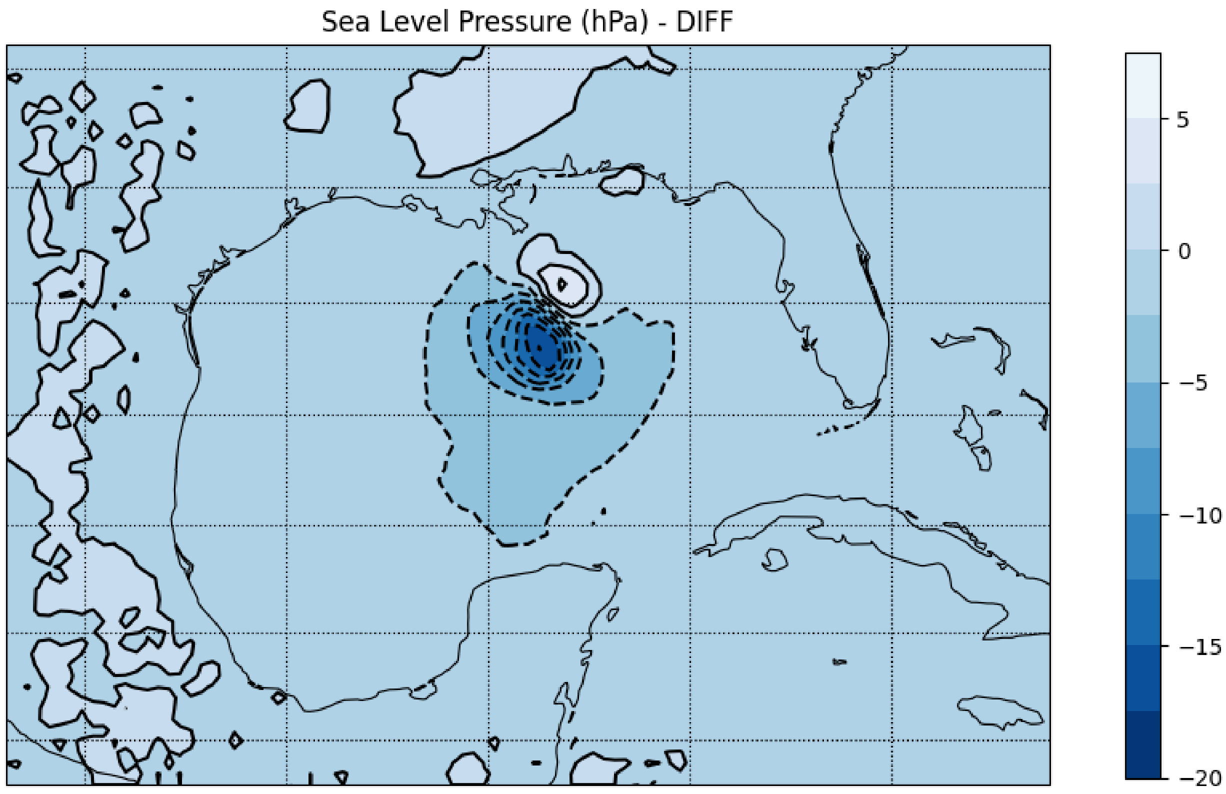

Figure 3: *Difference in Sea Level Pressure (hPa).* Contours indicate the change in sea level pressure between the warming and control runs. Negative differences of up to −20 hPa are centered over the Gulf of Mexico, corresponding to a deeper low-pressure core in the warming run.

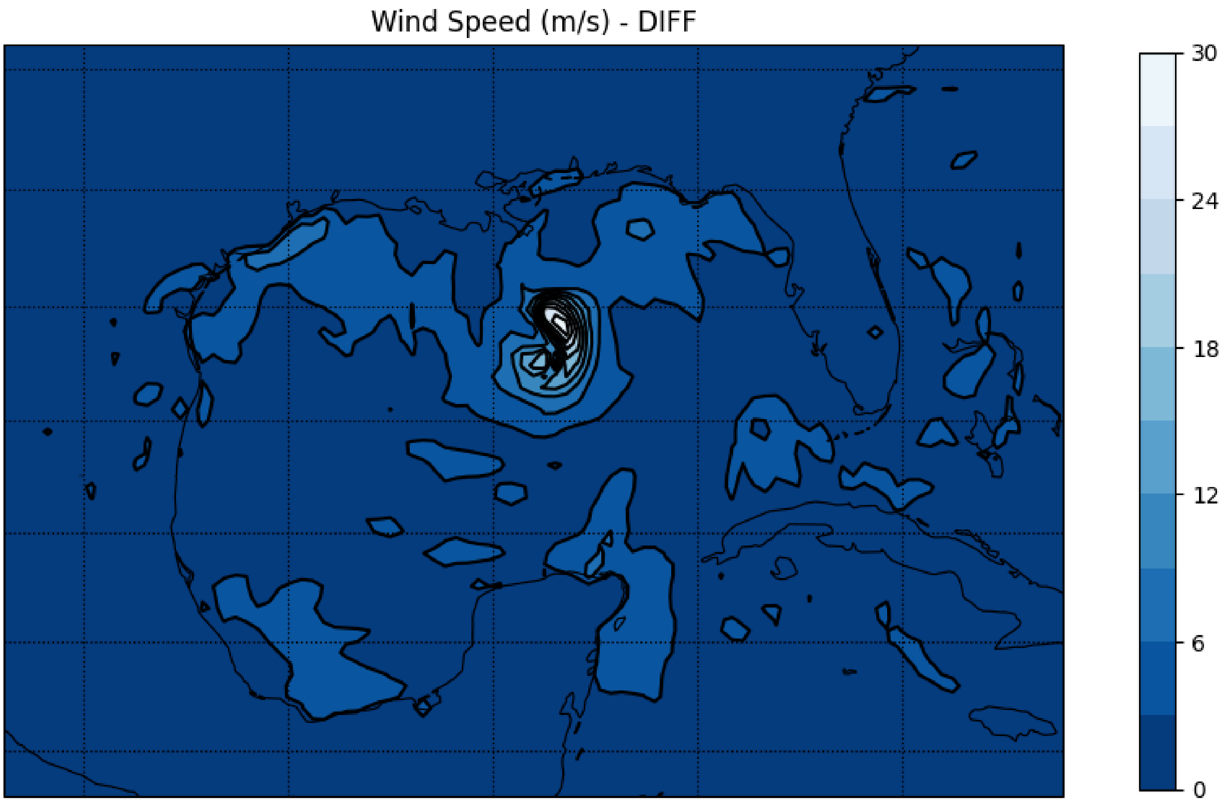

Figure 4: *Difference in 10 m Wind Speed (m/s).* Near-surface wind speed differences indicate significant strengthening of low-level winds in the warming scenario, with maximum increases up to 30 m/s around the eyewall region.

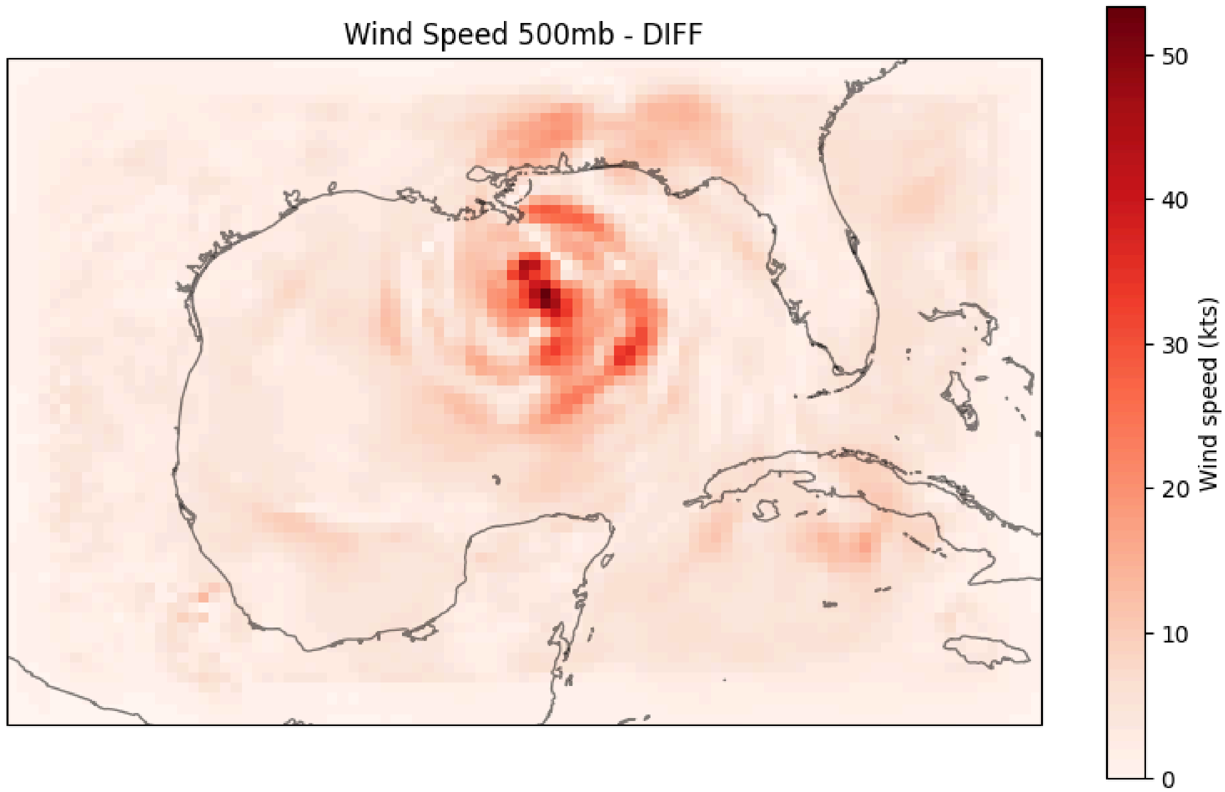

Figure 5: *Difference in Wind Speed at 500 mb (kts).* Shaded contours represent changes in mid-tropospheric wind magnitude. Increases of 30–50 knots are found near the storm center, forming a well-defined spiral pattern. The enhanced wind speeds aloft imply stronger upper-level divergence, which aids in the vertical development and intensification of the cyclone.

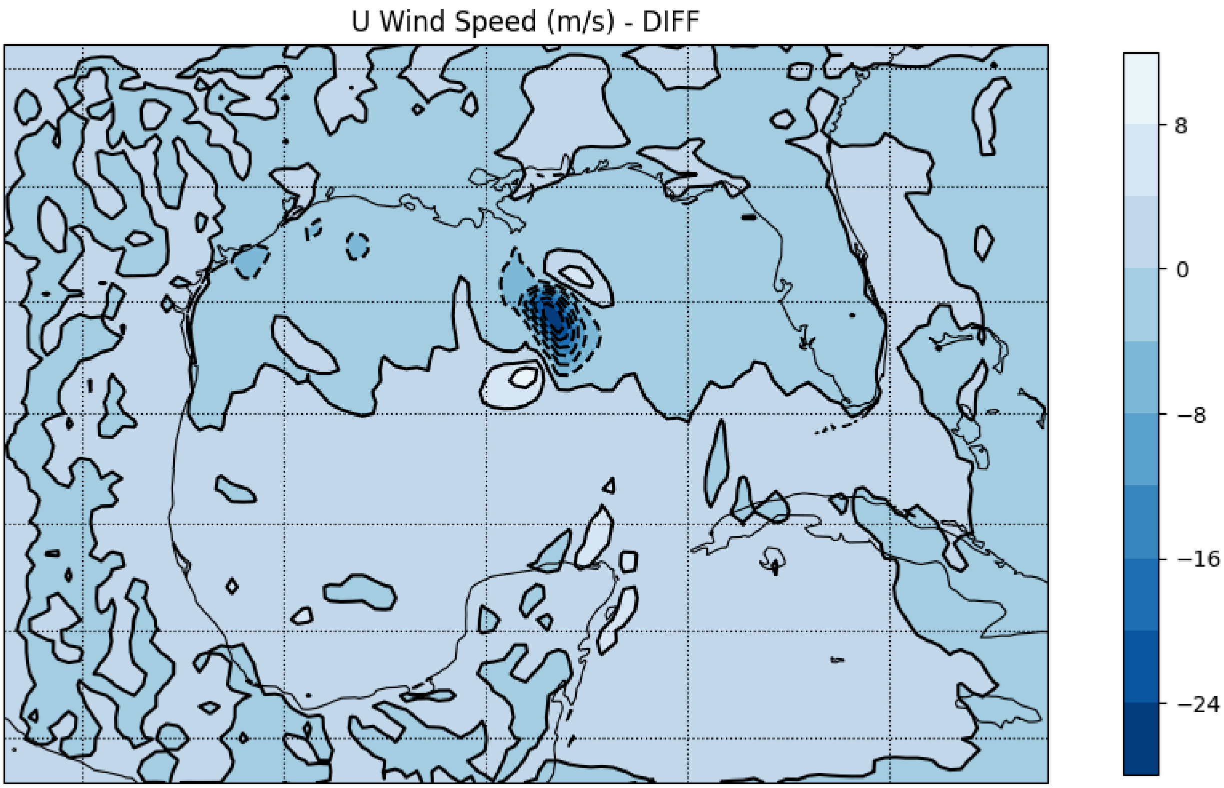

Figure 6 (not mentioned in the paper): *Difference in 10 m U-Component Wind Speed (m/s).* Zonal (east-west) wind speed differences reveal localized intensification of horizontal wind flow near the storm center, particularly along the storm's eastern flank.

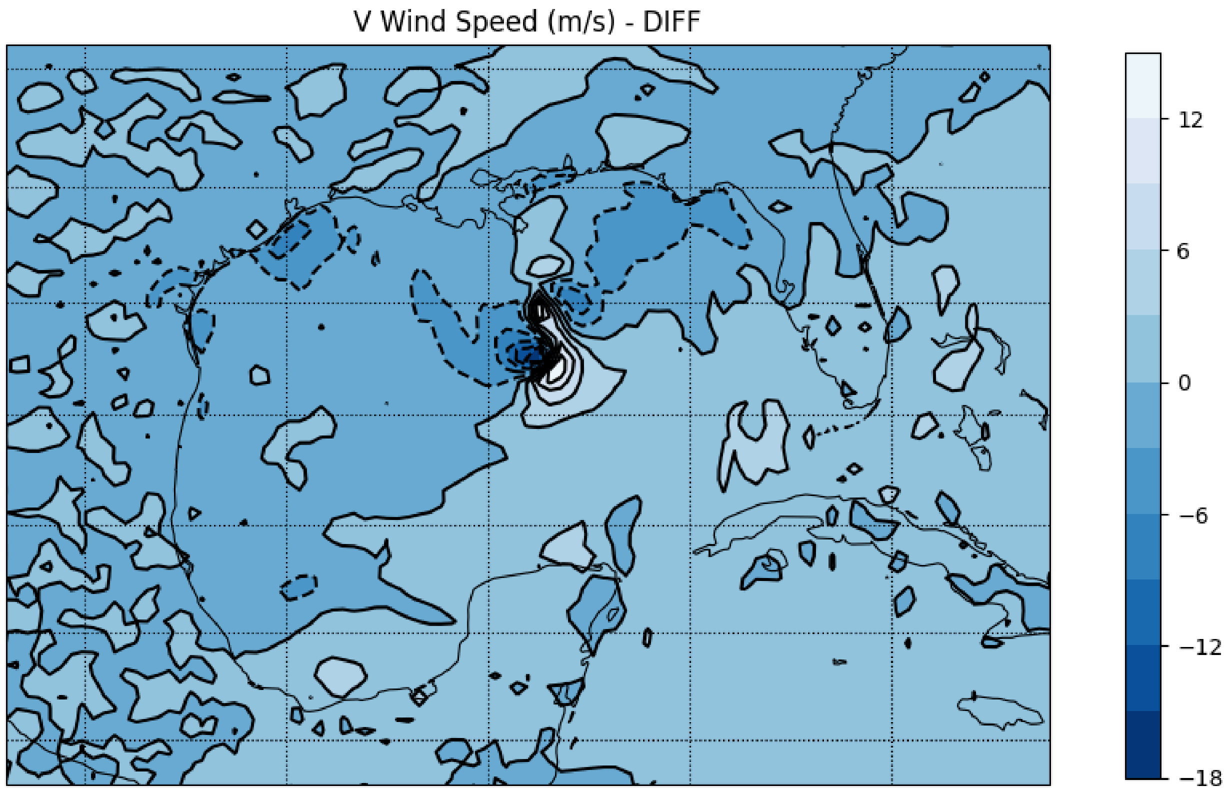

Figure 7 (not mentioned in the paper): *Difference in 10 m V-Component Wind Speed (m/s).* Meridional (north-south) wind differences show strengthened inflow and outflow across the Gulf of Mexico, especially along the southern and northern sectors of the storm. These changes indicate improved low-level convergence and vertical circulation dynamics in the warmer environment.

Works Cited

Beven et al. “Annual Summary Atlantic Hurricane Season of 2005.” *National Oceanic and Atmospheric Administration*, www.aoml.noaa.gov/hrd/hurdat/mwr_pdf/2005.pdf. Accessed 13 May 2025.

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Vigdor, Jacob. “The Economic Aftermath of Hurricane Katrina.” *Journal of Economic Perspectives*, www.aeaweb.org/articles?id=10.1257%2Fjep.22.4.135. Accessed 12 May 2025.