Evaluation of Over-Land Surface Winds in WRF Simulations of the Landfall of Hurricane Laura

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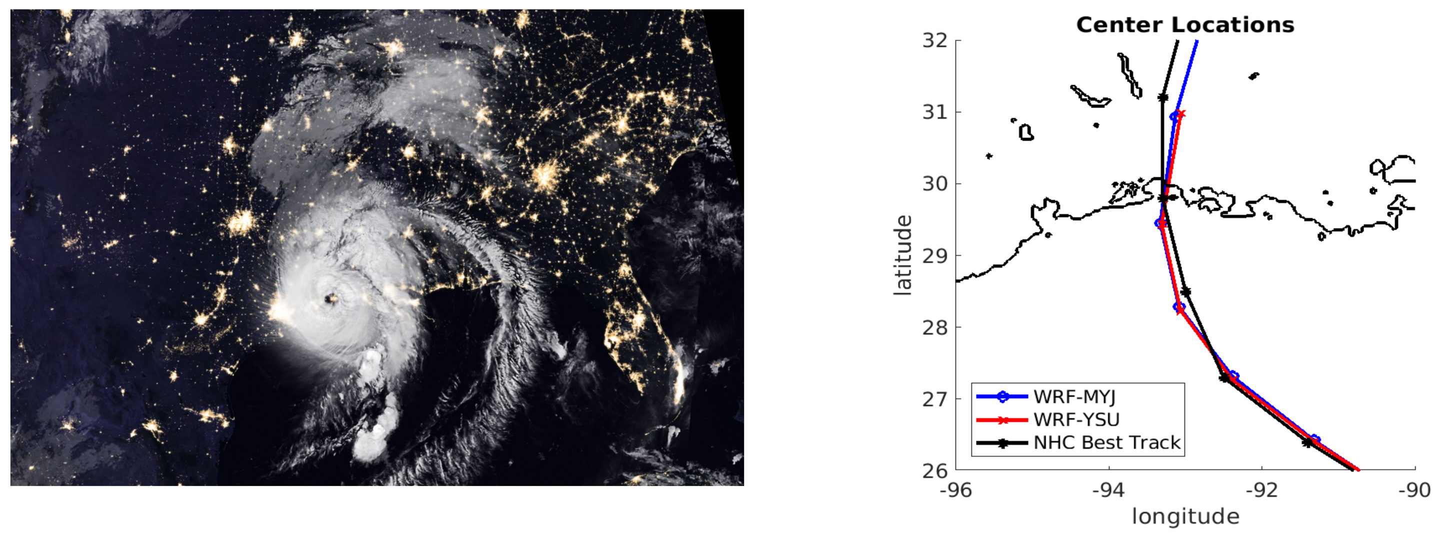
BACKGROUND & MOTIVATION

- In 2020, Hurricane Laura was one of nine tropical cyclones that underwent rapid intensification, culminating in its transformation into a fierce category-4 hurricane. Just before landfall in Cameron, Louisiana, it reached a maximum intensity of 130 kt (150 mph), rendering it the most powerful tropical cyclone to hit the United States that year. Tragically, the storm resulted in 81 fatalities and an estimated $23 billion in damages. Given the extensive destruction wrought by Hurricane Laura, there is a pressing need for improved accuracy in simulating intricate tropical cyclone wind fields.

- Computer models are essential for forecasting tropical cyclones and analyzing their physical processes. However, the accuracy of simulated hurricane wind fields over land has yet to be extensively validated, and numerical models are not used to predict over-land wind fields and damages. The main objective of this work is to legitimize the simulation's physics by comparing it to observational data.

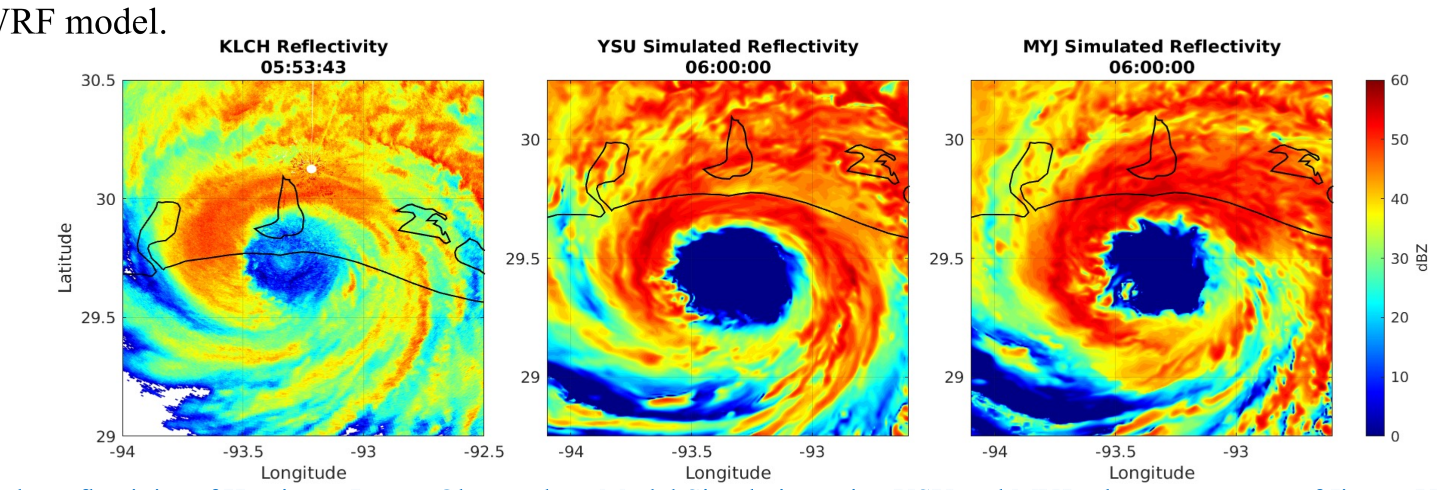


Hurricane Laura (2020) over Louisiana. Left: Infrared imagery of Hurricane Laura acquired by NOAA-20 at 2:50 a.m. CDT on August 27, 2020. Right: Both observed best track and WRF simulation center locations for Hurricane Laura.

The simulated tracks of Hurricane Laura by the WRF parameterized YSU and MYJ schemes deviate considerably to the right of the best track after landfall, leading to potential downstream effects on the intensity and gust factor estimates owing to differences in location.

OBSERVATIONAL DATA & WRF SIMULATIONS

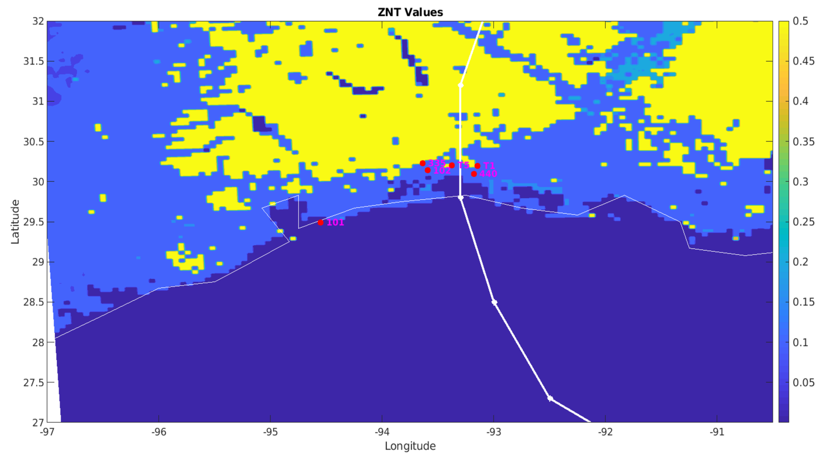
We use the Weather Research and Forecast Model (WRF) with two different boundary layer parameterization schemes (MYJ and YSU) to simulate Hurricane Laura. The MYJ and YSU schemes account for the effects of turbulence on momentum and heat transfer using very different methods. The choice of parameterization scheme can impact the simulation of surface-level wind fields of TCs in the WRF model.



Radar reflectivity of Hurricane Laura: Observed vs. Model Simulation using YSU and MYJ schemes courtesy of Jimmy Yunge

Our observations come from two sources; the University of Florida College of Engineering deployed the first set of towers (T1 and T5). These towers recorded wind speed and wind direction every 0.1 seconds at a measurement height of 10 meters. Additionally, Texas Tech University researchers distributed 48 StickNet sites that recorded wind speed at 2.25 meters, providing valuable observational data. The StickNets recorded at a frequency of 1 and 0.1 seconds. Some of the site locations are provided in the figure below.

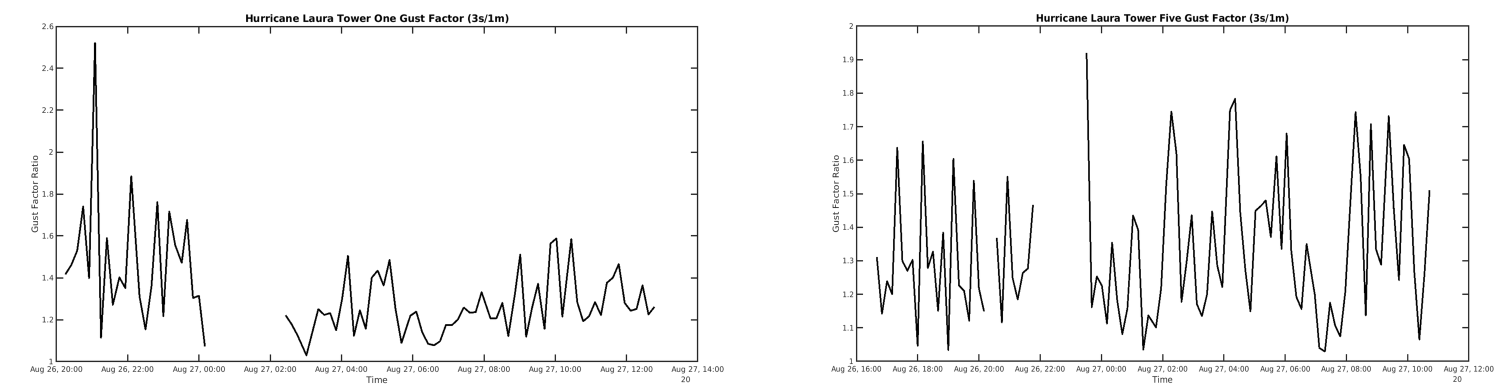
UF5 (Left) and StickNet Instruments (Right) installed in advance of tropical cyclone landfall



The best track of Hurricane Laura, depicted in white, is considered as ZNT contours and surface wind data locations are analyzed to explore the correlation between surface roughness and the wind field of the TC

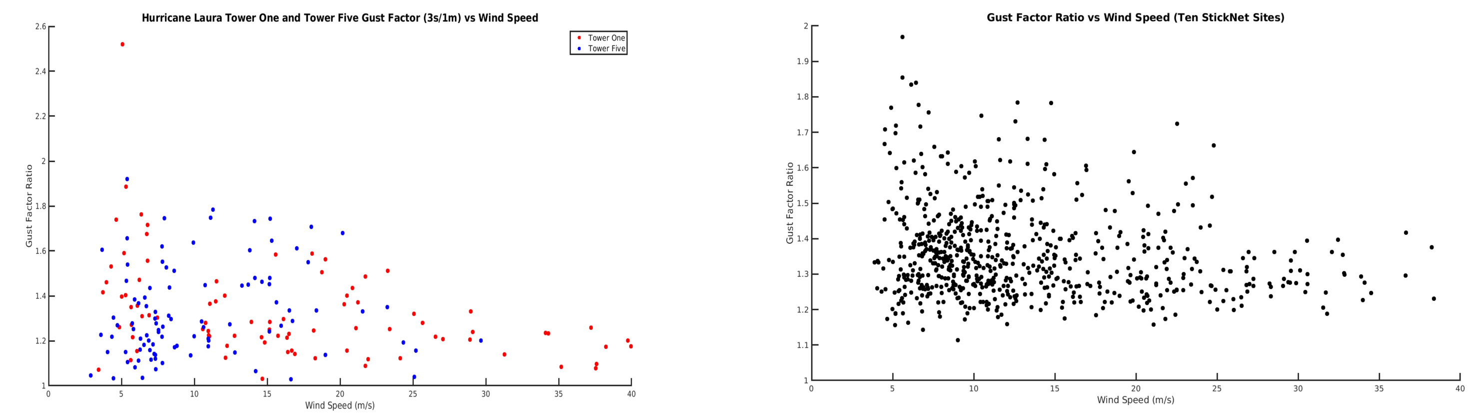
GUST FACTOR VARIABILITY

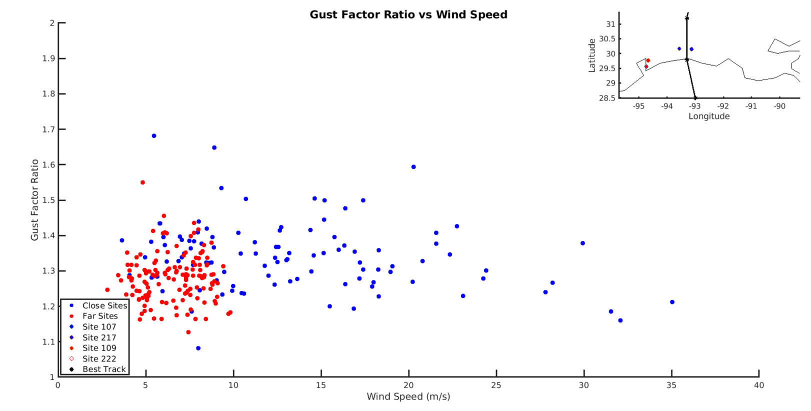
The ratio of the 3-second wind speed to the 1-minute wind speed, also known as the gust factor, is an important tool for analyzing Hurricane Laura's over-land surface winds:



- Gust factors provide information about the variability and intensity of wind gusts during a particular period. By analyzing gust factors, researchers and engineers can better predict the potential impact of wind gusts on structures and infrastructure and develop more accurate wind hazard models. Additionally, gust factor data can validate and improve numerical models, leading to more accurate predictions of over-land surface winds during TC events.

Gust Factor Ratio as a function of mean 1-minute wind speed scatter plots are shown below for both the UF tower sites as well as the StickNet sites:

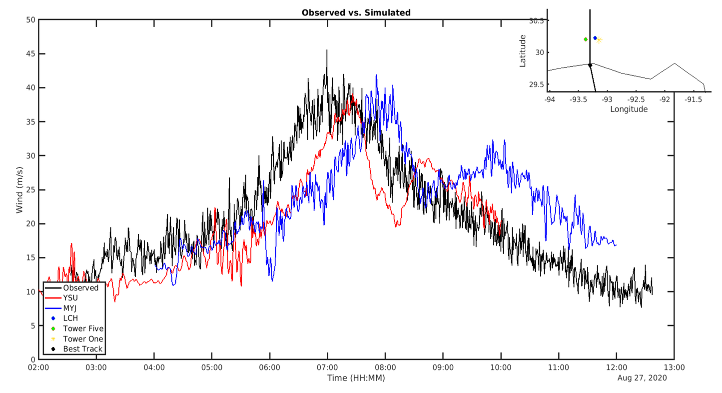




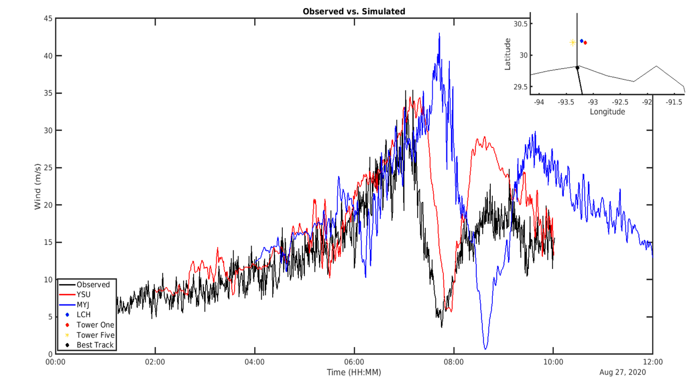
At a location inland with approximately open terrain, the anticipated gust factor values at a height of 10 meters are 1.49, while off the coast, the corresponding values are 1.36.

- In general, rougher surfaces lower wind speeds but produce higher gust factor ratios, as the wind flow has more turbulence and variability. This is because the roughness elements cause the wind to break into smaller eddies, which can cause gusts. Furthermore, the relationship between the gust factor ratio and mean wind speed is not constant and depends on the roughness characteristics of an area. As a common observation from these figures, gust factors exhibit significant variability at lower wind speeds but stabilize and gain consistency in gust factor values at high wind speeds, in agreement with prior research.

SURFACE WIND COMPARISONS

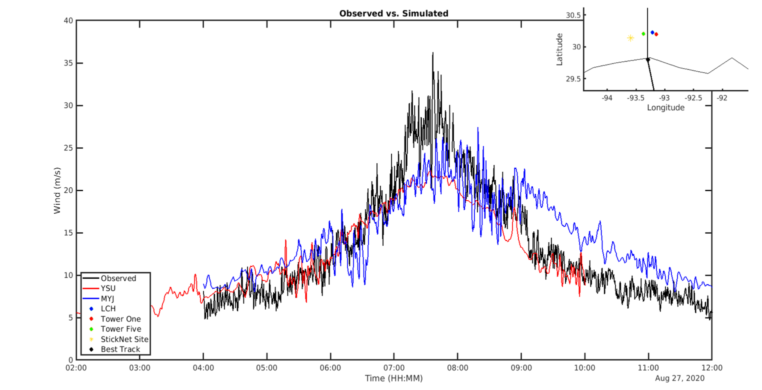


Tower 1 Surface Wind Comparison: Time Series of observed and simulated 1-min mean wind speeds. The simulations share both a slight negative wind speed bias and time delay.



Tower 5 Surface Wind Comparison: Time Series of observed and simulated 1-min mean wind speeds. Laura's center of circulation roughly passed over Tower 5, allowing for "classic" time histories of wind speed indicative of the passage of the hurricane eye.

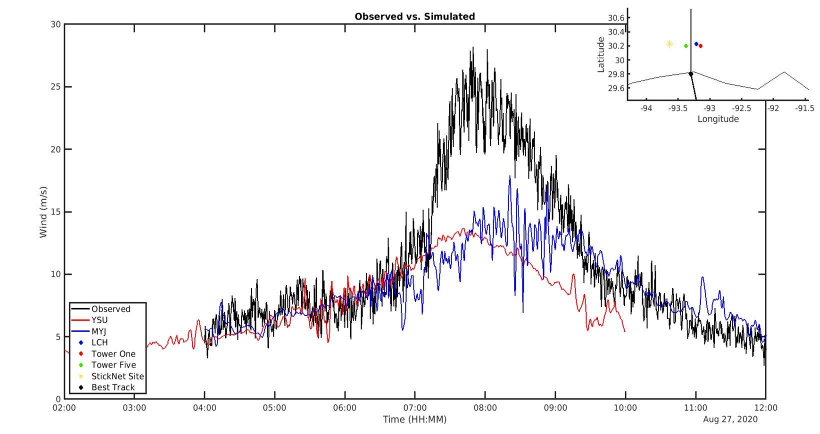
SURFACE WIND COMPARISONS

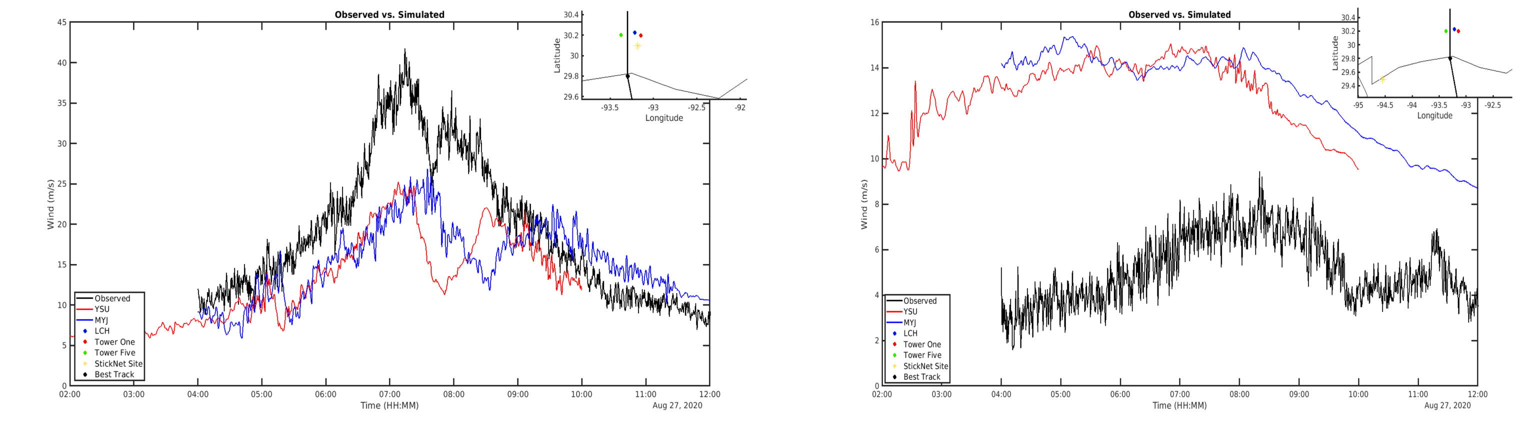


StickNet 102 Surface Wind Comparison: Time Series of observed and simulated 1-min mean wind speeds. The discrepancy between the observed and simulated wind speed at the event's peak is around ~ 10 m/s. In contrast, the similarities before and after the peak suggest that the boundary layer may have been relatively consistent.

Surface roughness plays a significant role in the atmospheric boundary layer, and its representation in models can significantly impact wind speed simulations. Surface roughness is affected by land cover, topography, and other factors, and it can vary considerably over short distances. If the model parameterization scheme does not accurately represent surface roughness, it can lead to errors in the simulation of wind speeds.

StickNet 335 Surface Wind Comparison: Time Series of observed and simulated 1-min mean wind speeds. The sudden shift in wind speeds during the peak of Hurricane Laura in the time series could be attributed to a combination of mesoscale and land surface effects. The StickNet observational data may have been influenced by local land surface effects that were not accounted for in the YSU and MYJ simulations.





StickNet 440 (left) and StickNet 101 (right) surface wind data with the corresponding simulations show good temporal agreement. Still, differences in land roughness values may contribute to differences in wind speed intensities. StickNet site 101, situated along the southwestern Louisiana coast, exhibits extremely low ZNT (surface roughness) values. An underestimation of the roughness level in the model may lead to an overestimation of the 1-minute wind speeds, as observed in the data. StickNet site 440, located near the best track for Hurricane Laura, experienced shifting wind directions over varying ZNT values that could result in lower simulated wind speeds before and during the storm's peak. These findings suggest the importance of accurately representing land roughness in numerical models for simulating wind speeds during extreme weather events.

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