Simulations of Near-Ground Hurricane Winds Influenced by Built Structures

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Introduction

- Accurate hurricane near-ground wind forecasts are important, but difficult due to uncertainties in how the wind interacts with structures onshore.
- This study examines winds in four separate structural environments by using 4 km Weather Research and Forecasting (WRF) model hurricane wind forecasts as input in the Fluent computational fluid dynamics solver.
- Resulting velocity magnitudes are normalized to the predicted WRF model 10-meter wind and to the ambient "undisturbed" winds at all elevations to assist forecasters in issuing guidance.

Methodology

- Hurricanes Rita, Katrina, and Wilma were simulated using GFS analyses in WRF, with 4 km grid spacing and 35 vertical levels.
- Upon making landfall, vertical wind profiles were extracted from the region of highest predicted 10-meter winds, and were used to initialize wind tunnels in Fluent.
- Four domains, including a single story house, a two story house, a suburban array, and an urban environment were constructed in Gambit for flow simulation (Fig. 1).
- Domains were run in Reynolds-averaged Navier-Stokes (RANS) mode using the k-ε turbulence model, providing time averaged 3-D variability to the results (Hanna et al., 2006).
- Horizontal grids of spatial uniformity were generated in close proximity to the structure(s) upon which two types of normalization were applied (Fig. 2 and 3).

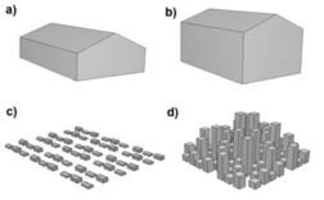

Figure 1. Visual display for the a) single story house, b) two story house, c) suburban array, and d) urban environment domains.

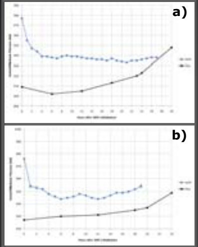

Figure 2. Time series of central minimum pressure near landfall for a) Hurricane Katrina and b) Hurricane Rita.

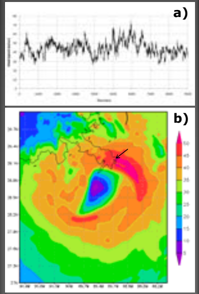

Figure 3. a) Time series of the observed 10-meter wind from an instrument tower deployed in Hurricane Katrina at Belle Chase, LA and b) WRF 10-meter winds forecast for Hurricane Katrina. Arrow denotes location of wind profile extracted for Fluent simulations.

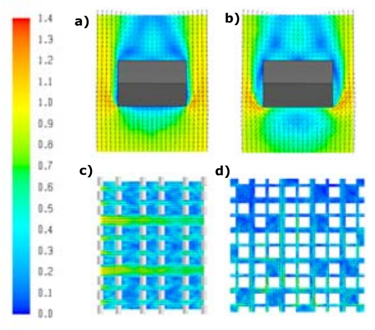

Figure 4. Horizontal grids of normalized 2-meter winds for the a) single story house, b) two story house, c) suburban, and d) urban domains.

WRF

- In our best simulations, the central minimum pressure was 10 to 15 mb weaker at landfall than that observed (Figs. 2a and 2b), likely due to the coarseness of the model's initialization data (Kimball and Dougherty, 2006).
- Barker et al. (2004) show that assimilating observations into model initialization can greatly improve a hurricane forecast using WRF-3DVAR. Thus, future efforts will focus on data assimilation to improve our WRF simulations.
- While the central minimum pressure is underpredicted, WRF's predicted 10-meter winds near landfall (Fig. 3b) compare well with observations from instruments placed in Katrina's path (Fig. 3a).
- We determined that a profile extracted from the region of maximum predicted landfalling winds would be sufficient for flow simulations in Fluent.

WRF Profile Normalization

- The suburban and urban environments reduced a larger percentage of the wind speeds near the ground than the single story and two story houses, corresponding to a 10% to 40% reduction from the original value (Fig. 5). This corresponds to the blue contoured regions of Figure 4.
- The single story and two story house environments increased a portion of the winds near the ground (Figs. 5a and 5b) above their original value. This corresponds to the orange contoured regions of Figure 4a and 4b.
- The suburban environment decreased virtually the entire profile from the expected values in the lowest 20 meters (Figs. 4c and 5c).
- The urban environment had the most substantial impact on the profile (Figs. 4d and 5d). The winds are substantially decreased or increased from their original value, depending upon height.

WRF 10-Meter Wind Normalization

- Figure 6 reveals how well the WRF 10-meter forecasted winds (black line) compare to Fluent's depiction of flow in the structural environments (contours).
- Forecasts using the WRF 10-meter wind may be reasonable for the single story and two story house environments (Figs. 6a and 6b), but would not work well for suburban and urban environments (Figs. 6c and 6d).
- Height dependent scaled adjustments relative to the WRF 10 meter wind are recommended.

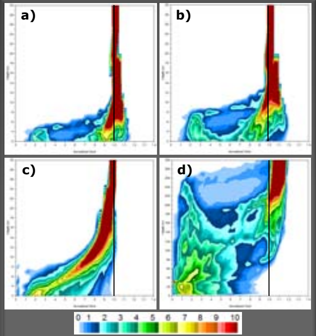

Figure 5. Distribution contour plots (0-10%) normalized to the initializing WRF profile for the a) single story house, b) two story house, c) suburban, and d) urban domains.

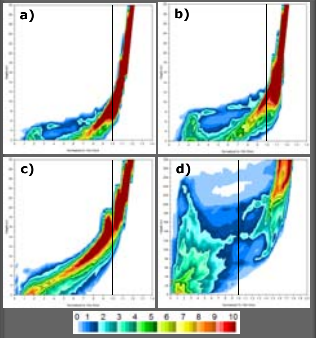

Figure 6. Distribution contour plots (0-10%) normalized to the WRF forecasted 10 meter wind for the a) single story house, b) two story house, c) suburban, and d) urban domains.

Conclusions

- The WRF forecasted 10-meter winds from our Hurricane Katrina simulations compare well with winds measured by instruments placed in Katrina's path. While these results appeared reasonable for subsequent Fluent simulations, our goal remains to improve our hurricane simulations by utilizing WRF-3DVAR.
- In general, the structural environments act to decrease the magnitude of the incoming profile in regions at or below the elevation of the structure(s), and act to slightly increase winds at higher elevations.
- Height dependent scaled adjustments are recommended when forecasting winds for each structural environment, based on the implications of Figure 6.

References

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