1.4 THE USE OF MESOSCALE MODELS FOR ANALYSIS OF HIGH IMPACT WEATHER EVENTS

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1.0 Introduction

With the increased populations within urban areas and along coastlines severe weather events such as tropical cyclones, winter storms, and severe convective storms can have an increased impact on infrastructure and industrial operations. The Penn State/NCAR Mesoscale Model (Grell et al, 1995) and more recently the Weather Research and Forecast (WRF) models have been used simulate severe storm events worldwide both for storm analysis as well as operational prediction. Numerous modeling studies of hurricanes have been conducted using both MM5 and WRF which suggests that mesoscale models are capable of realistically simulating the complex structure of hurricanes. In recent years, multiscale modeling studies have shown that the inner core structure of hurricanes can be well simulated using fine enough grid resolution.

In most events, there are typically only limited observational data available. During intense hurricanes, the extreme surface conditions often lead to loss of some data or complete destruction of the meteorological measurement systems during the event. Also, the typically sparse resolution of meteorological monitoring networks will not in most cases facilitate a detailed analysis of the surface wind structure and significant high wind events can be missed. Additionally, detailed information on the vertical boundary layer wind profile in most situations is not available. This information is valuable in assessing the peak wind gust potential in the hurricanes inner core region. High-resolution numerical modeling can allow for a realistic assessment of horizontal and vertical structure of wind fields as well as other meteorological parameters during these extreme weather events.

This paper will discuss a real application using the Penn State/NCAR Mesoscale Model (MM5) to assess the likely peak surface wind speeds over New Orleans during the passage of Hurricane Katrina and the use of this data to assess damage to industrial buildings. This paper will discuss how mesoscale models can be used as a valuable analysis tool to assess the impact of severe weather events by developing realistic high-resolution data sets of meteorological fields for the time period of the event. Specifically, fine-scale numerical simulations of Hurricane Katrina were conducted in an effort to provide a reasonable estimate of wind speeds that impacted the New Orleans urban center during landfall and passage of the hurricane. The wind speed estimates were then used to determine the likely cause of damage to industrial buildings in New Orleans using the FLUENT Computational Fluid Dynamics model.

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2.0 Modeling Configuration

The Penn State/NCAR Mesoscale Model MM5 Version 3.74 was used to conduct simulations of Hurricane Katrina prior to and during landfall and passage across the New Orleans area. Since the objective was to realistically estimate surface wind speeds it was important to reasonably capture the inner-core structure of the hurricane prior to and during landfall. Multiple nested grids were used to achieve the required resolution sufficient to reasonably reproduce the inner core structure. Previous modeling studies (Liu et al, 1997) have shown that using a grid resolution of 2 km is sufficient to provide a realistic simulation of the hurricane inner core structure. Figure 1 shows the arrangement of the nested grids used for the simulations. Following (Liu et al, 1997), four modeling grids with horizontal resolutions of 54, 18, 6, and 2 km resolution were used along with 32 vertical levels from the surface to 100 mb. The nested grids were all two-way interactive to allow for full feedback between the fine scale nested grid and its parent domain. The inner 2 km grid is a movable nest configured to follow Hurricane Katrina on its path across the coast. Early test simulations with MM5 showed that starting the model closer to the time of land fall didn't allow for adequate spin-up of the model simulated hurricane. The MM5 was initialized on August 27, 2005 at 1200 UTC and was run out to 60 hours. The 2 km movable nested grid was initialized 36 hours into the simulation once the hurricane was fully developed by MM5.

Initial and lateral boundary conditions were provided by the National Centers for Environmental Prediction (NCEP) Final Analysis Global data at a resolution 1 x 1 degree, while sea surface temperature data was provided by the NCEP Real Time Global (RTG) 0.5 degree resolution data.

Several test simulations were conducted to determine the planetary boundary layer (PBL) scheme that would yield the best overall results. It was found that both the storm intensity and track were significantly impacted by the selection of the PBL scheme. After some test simulations with different schemes, the Blackadar PBL scheme was selected for the primary simulations of Hurricane Katrina. The Betts-Miller cumulus parameterization scheme was chosen following on both the 54 and 18 km grids while convection was explicitly simulated on the 6 and 2 km grids. Cloud microphysics was simulated using the Tao-Simpson scheme. The

Betts-Miller scheme and the Tao-Simpson have been shown to yield good results when simulating hurricanes.

Since Hurricane Katrina was a well developed hurricane within the Gulf of Mexico the NCAR Tropical Cyclone Bogussing Scheme (Davis and Low-Nam, 2001) was implemented to help improve the initialization of the storm in the MM5 model. The storm position and intensity were taken from the NCEP-Tropical Prediction Center (TPC) best track data. The radius of maximum wind was estimated to be approximately 60 km using visual inspection of both enhanced infra-red and available microwave satellite images of the storm at or near the initialization time.

The MM5 simulations were conducted with Four Dimensional Data Assimilation implemented on the coarse modeling grid only. This was done primarily to help with track corrections within the MM5 simulations. Initial MM5 simulations showed that a slight deviation of the track by about 30 km westward occurred during landfall of the Hurricane from the best-track data. Only three-dimensional analysis nudging was used during these simulations. Sensitivity simulations showed the MM5 track too far west without the use of FDDA and too far east with full FDDA using the default nudging parameters for wind, temperature, and moisture. For the primary simulation nudging parameters of about 50 percent of the default value were found to minimize the track errors and this yielded a track that matched the NCEP-TPC best track data.

3.0 Results of the MM5 Simulations

Figure 2 shows the wind field on the 2 km movable nested grid at 0600, 1200, 1300, and 1400 UTC on August 29, 2005. This was the period when the hurricane eye crossed the coast and passed just east of the New Orleans urban area. During this period, New Orleans was within the western eyewall of Katrina. This is shown by Figure 3 which shows 1 km resolution GOES visible satellite picture at 1200 UTC. A comparison with best-track data shows that the longitudinal position of the storm was well simulated by MM5, but the MM5 simulation was too fast bringing the storm northward. The maximum wind speeds from the MM5 simulation compared well with the best track-data winds. For example at 0600 UTC (not shown) the maximum surface wind speed from MM5 was 66 m/s (128 knots) while the best track data showed maximum sustained winds of 64 m/s (125 knots). At 1200 UTC the maximum winds from MM5 were 63 m/s (122 knots) while the best track data showed maximum sustained winds of 57 m/s (110 knots). However, as shown in Figure 2b, the peak wind from MM5 was confined to a small pocket which was likely a highly transient feature. The band of maximum winds on the east side of the hurricane was on the order of 57 m/s which is in agreement with the maximum winds shown in the best-track data. Thus the MM5 simulated storm showed a realistic inner core wind field and maximum winds were comparable to the best-track data winds just prior to and during landfall. The hurricane was in a weakening phase just prior to landfall due internal structural changes such as the beginning of an eyewall replacement cycle, the entrainment of dry air into the circulation and lower sea surface temperatures as the storm moved into the northern Gulf of Mexico. The weakening storm intensity was depicted reasonably well in the MM5 simulations. As the hurricane moved northward and interacted with land the reduction in the core winds was enhanced and this was shown in the MM5 simulations (See Figure 2a-d).

Recent studies (Henning, 2006) have suggested that the wind gust potential is very high in the hurricanes inner core and have provided evidence of peak wind gust events coupled to deep eyewall convection. Vertical wind profiles in hurricanes typically show very strong vertical gradients in wind speed within the first 500 meters of the surface. Deep convection can facilitate strong momentum transfer to the surface resulting in large peak gusts of wind.

Figure 4 shows a vertical profile of the wind speed at New Orleans from the MM5 simulations at 1300 UTC on August 29, 2005. The MM5 vertical wind profile is consistent with what is typically observed in hurricanes and suggests that MM5 captured the core wind structure of the storm reasonably well. This profile is also consistent with an observed inner core profile from dropsonde data at Pass Christian, MS during land fall of Hurricane Katrina (Henning, 2006). The wind speed profile in Figure 4 shows wind speeds increasing from about 36 m/s at 10 meters above the ground to greater than 60 m/s at a height of 300 meters. The vertical wind speed profile suggests that convective wind gusts likely occurred leading to much higher wind gusts at the surface than may have been indicated by examining the 2-d surface wind speed plots alone. The model simulations support sustained surface winds across New Orleans of near 35-40 m/s. But convective wind gusts of near 60 m/s are supported by the vertical wind speed profile.

Figure 5 shows MM5 wind speed profiles at Pass Christian, MS at 1300, 1400, and 1500 UTC on August 29, 2005 compared to the dropsonde data. The dropsonde data was taken at 1422 UTC. Examination of Figure 5 shows that the dropsonde profile fits the MM5 profiles best at 1300 and 1400 UTC. This is because the MM5 simulated hurricane was approximately 90 minutes too fast as it moved northward. As a result the 1500 UTC profile from MM5 reflects both a small error in position and a somewhat weaker hurricane since it has traversed more land than the actual storm did at this time. Overall the MM5 profiles are smoother than the dropsonde profile and the MM5 peak winds occur near 600 meters versus 300 meters from the dropsonde data. However, MM5 profiles show a reasonable fit with the dropsonde profile. This suggests that the vertical wind structure from MM5 provides a reasonable estimate of the actual vertical wind profile in the hurricane.

4.0 Application of the MM5 Data

One of the objectives of this analysis was to estimate peak winds and show that this was the cause of structural damage to industrial buildings in the New Orleans area. This was done by using the FLUENT Computational Fluid Dynamics (CFD) Model with the MM5 model peak wind speed as input and then simulating the wind-induced pressure forces affecting building structures. As an example, Figure 5 shows the calculated pressure contours around the building structure both with building doors closed and open. The winds were from the upper left and the figure shows strong negative (outward) pressures (blue shaded areas) on rear of the building. This correlated highly with areas of heavy wall damage.

5.0 Conclusion

This study showed that mesoscale models such as MM5 can be useful analysis tools in reproducing meteorological fields that occurred during extreme weather events such as hurricanes. The MM5 simulations realistically simulated the core wind structure, the intensity and intensity trends during landfall of the storm. The result was a high-resolution meteorological data set with a spatial resolution of 2 km that allowed reasonable estimates of peak winds within the New Orleans area, in the absence of observational data.

The estimated peak winds were then used in the FLUENT CFD model to show that wind was the cause of damage to industrial buildings in the New Orleans area.

6.0 References

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Grell, G., J. Dudhia, D.R. Stauffer, 1995: A Description of the Fifth-Generation Penn State/NCAR Mesoscale Model (MM5), *NCAR Technical Note*, NCAR/TN-398+STR, June 1995.

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Liu, Y., D. Zhang, M.K. Yau, 1997: A Multiscale Numerical Study of Hurricane Andrew (1992). Part I: Explicit Simulation and Verification. *Monthly Weather Review,* 125, 3073-3093.

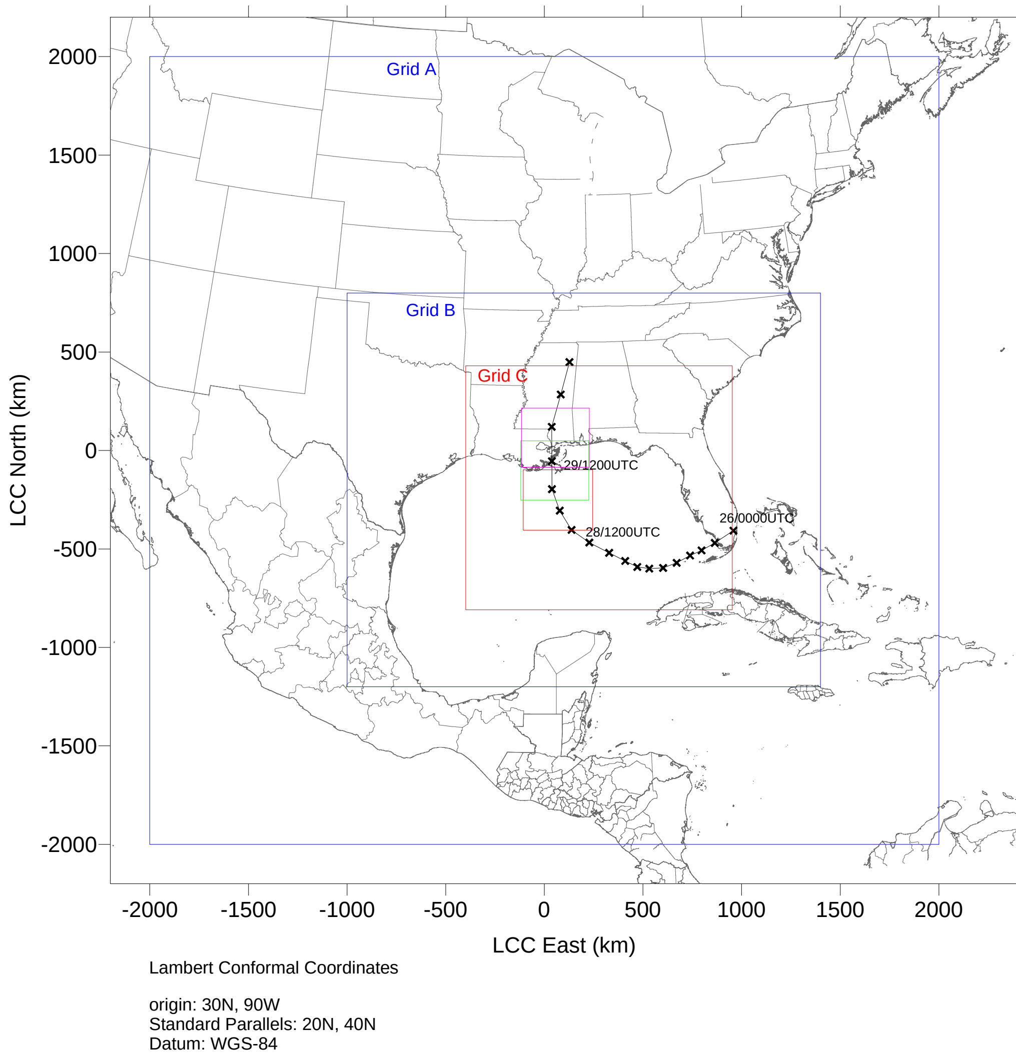


Figure 1. Plot of MM5 modeling domains. The x's plotted show the observed track of Hurricane Katrina and was taken from the Tropical Prediction Center Best Track Data.

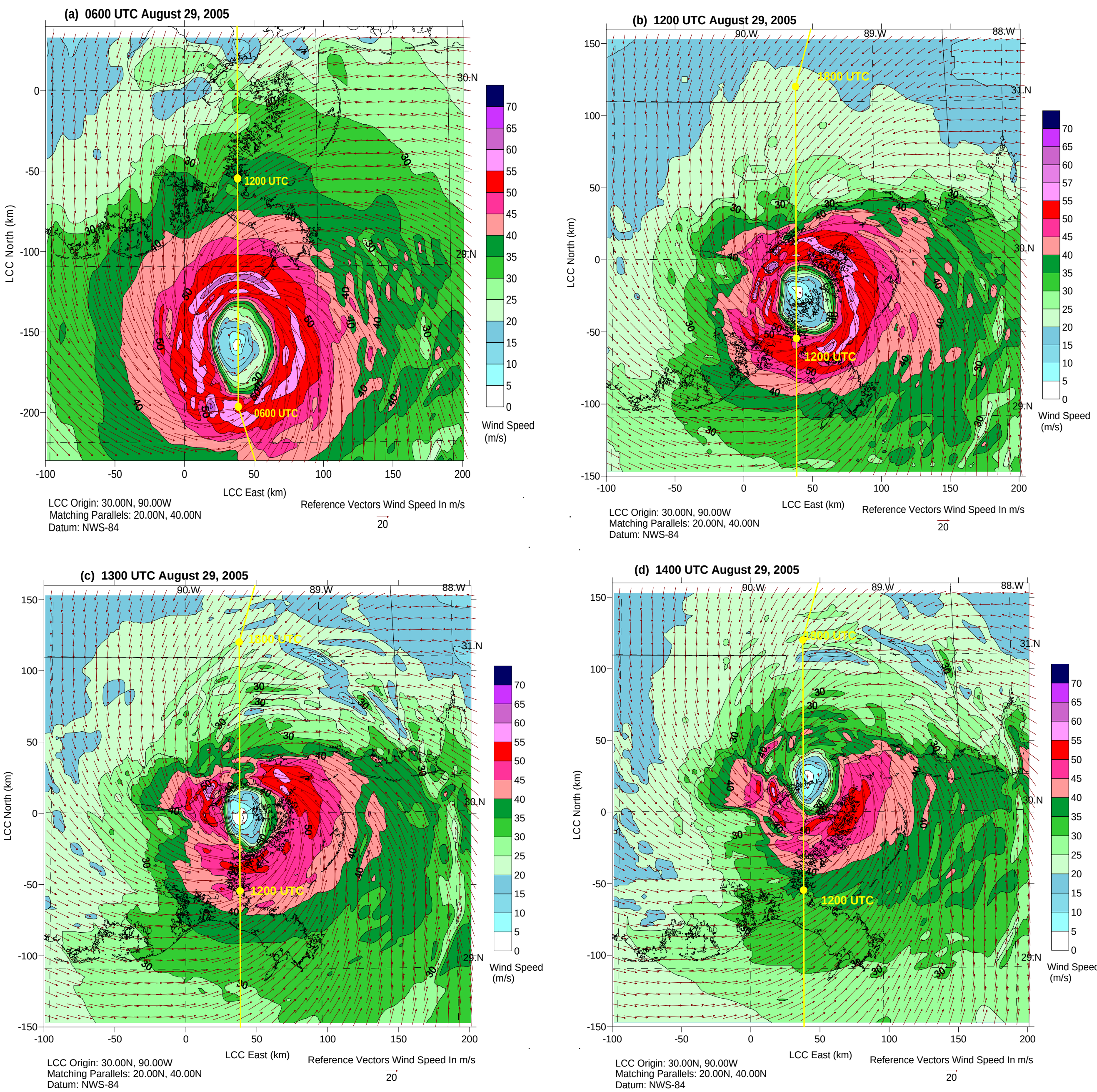


Figure 2. MM5 simulated wind vectors and surface isotachs at 0600 UTC(upper left), 1200 UTC(upper right), 1300 UTC (lower left), and 1400 UTC (lower right) on August 29, 2005. The yellow line and circles show the storm position from the NCEP-TPC Best Track Data at 0600 UTC (upper left plot only), 1200 UTC, and 1800 UTC. Wind vectors are every fourth vector.

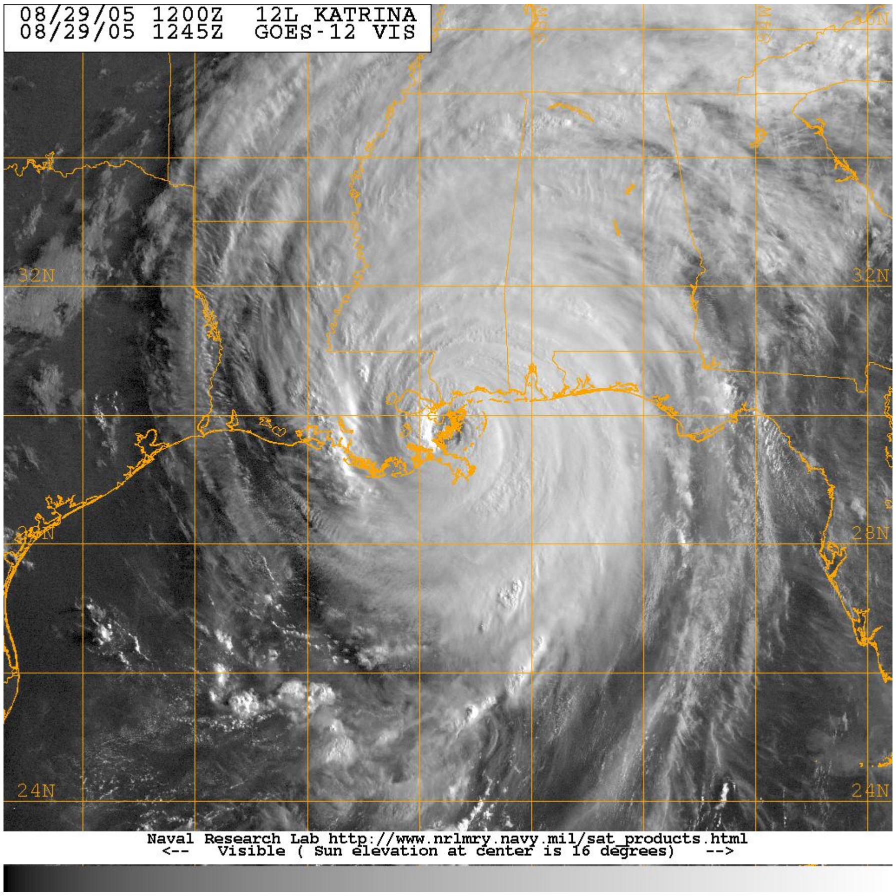


Figure 3. GOES visible image at 1245 UTC, August 29, 2005. Image resolution is 1 km. Imagery provided by the Naval Research Laboratory http://www.nrlmry.navy.mil/sat_products.html.

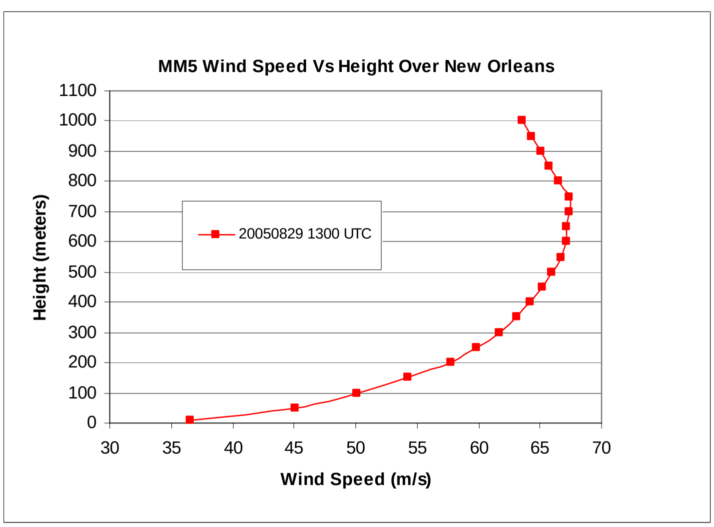


Figure 4. Vertical profile of MM5 simulated wind speed versus height at New Orleans at 1300 UTC, August 29, 2005

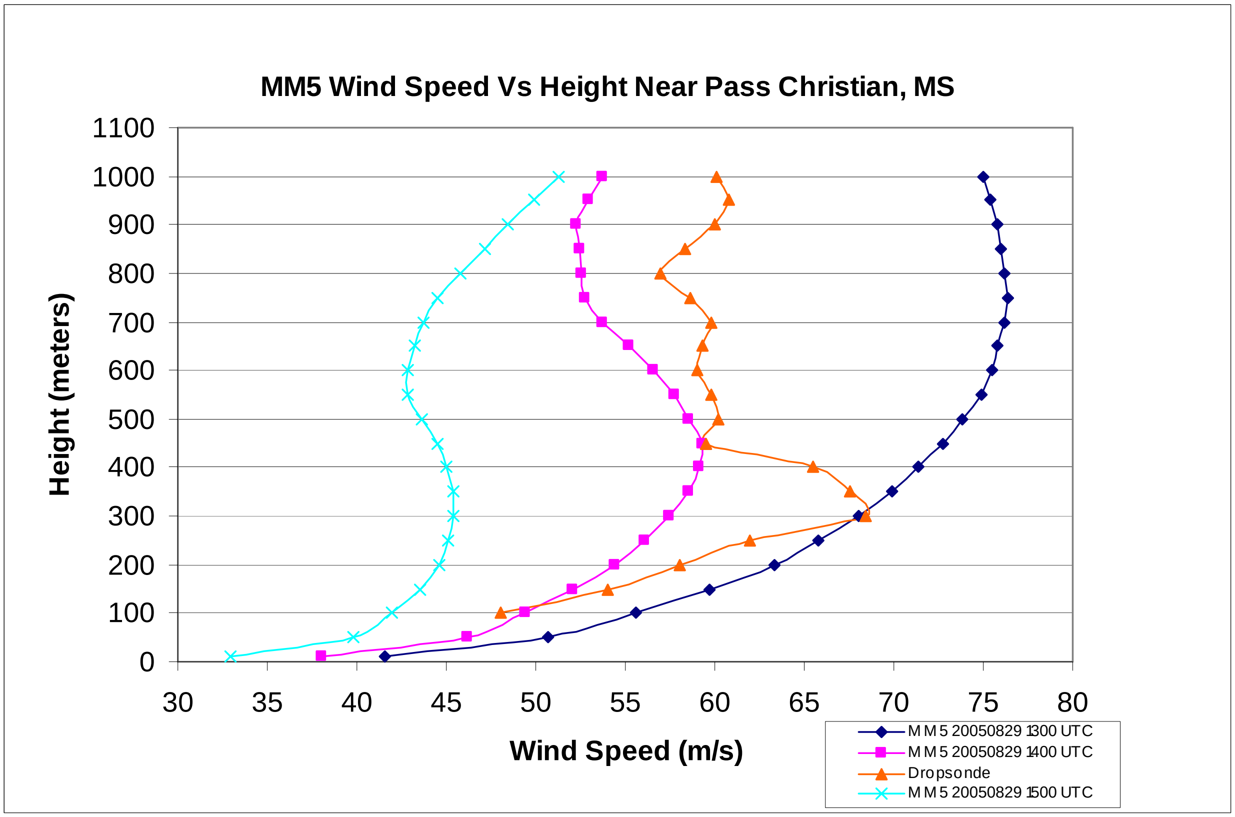
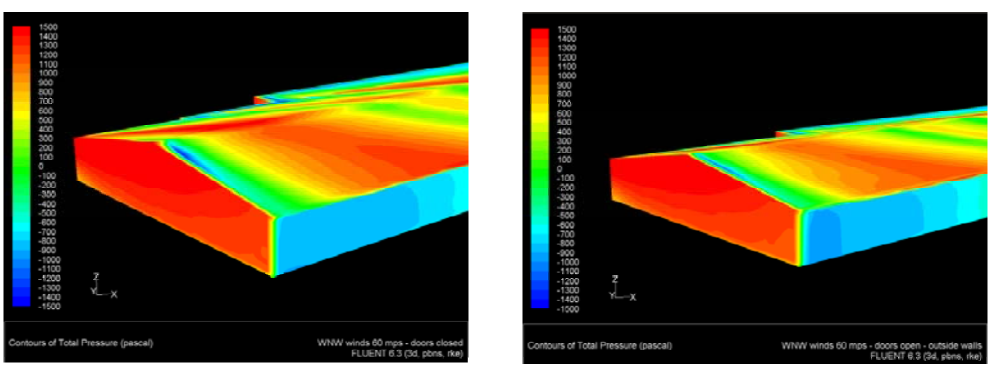


Figure 5: Vertical wind speed profiles from MM5 at 1300, 1400, and 1500 UTC on August 29, 2005 at Pass Christian, MS compared to Dropsonde data (see Henning, 2006).

Pressure Contours - 60 m/s WNW



Doors Closed   Doors Open

Figure 6 Plots of wind-induced pressure contours from the FLUENT model. Plot shown are based on a west-Northwest wind gust of 60 m/s.