A COMPARATIVE WIND INVESTIGATION USING MESOSCALE NUMERICAL PREDICTIONS AND EXPERIMENTAL DATA AT AUBREY CLIFFS, ARIZONA

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Abstract

- Aubrey Cliffs is a wind power research site in Arizona equipped with five 30-meter and one 50-meter meteorological towers that record 10 minute average wind data. Data collected over a one year period has been analyzed to determine the wind characteristics at the site.
- The aim of this work was to reproduce these characteristics using a numerical simulation, and to determine the domain size influence and grid resolution on the model's performance. A six month MM5 (Mesoscale Modeling v5) simulation was completed for the proposed site, with a grid resolution of 1-km in the proximity of the cliffs. Three different gridding scenarios were used to investigate the accuracy of the numerical results, necessary grid refinement, and extent of atmospheric influence outside of the nested grid.
- The first domain scenario uses a course vertical grid resolution bounding the state of Arizona. The second scenario increases the vertical resolution using the same horizontal scheme. The third scenario implements a large horizontal domain with the same fine vertical resolution.
- Output from the simulation was compared to field data using an interpolation scheme within FIELDVIEW®. Results showed that increasing the vertical resolution from 23 to 34 non-dimensional pressure levels produces more accurate results. Supporting figures and animations show how a larger radius of influence (i.e. extent of outermost grid) around the cliffs, influences the accuracy of the results.

Introduction

- Adequate knowledge of long term wind characteristics is of concern to wind power plant developers.
- The proposed research site is located near Seligman, AZ, is owned in part by the state of Arizona and by the Navajo Nation, and has five 30-meter meteorological towers and one 50-meter tower.
- MM5 has been used extensively by meteorologists, atmospheric scientists, and engineers to simulate the atmosphere for a number of different purposes.
- Aubrey Cliffs, Arizona was used as the center of the numerical domain for a series of MM5 simulations and was the focus of this investigation.
- Two grid scenarios were developed with similar dimensions and resolutions to allow for direct comparison. Figure 1 shows the small area scenario. Figure 2 shows the large area scenario, which uses the same two nested grid as shown in Figure 1.
- Figure 3 shows the topography of the Aubrey Cliffs area. As can be seen, a large escarpment is present, rising about 400-m above the valley floor to its west.
- The prevailing wind direction is from the southwest at this location, so one would expect flow acceleration as the wind ascends up and over the cliff, and a turbulent separation pocket sometimes present near the edge of the cliff.
- Questions of interest:
  - Does increasing the vertical resolution generate more accurate wind speed data?
  - Is a large area outer domain required to produce accurate wind speed data?

Figure 1: Representation of grid scheme A. Domain 1 corresponds to the outermost coarse domain with horizontal resolution of 3.0km and Domain 2 is the first nest domain with resolution of 1.0km.

Figure 2: Representation of grid scheme B. Domain 1 corresponds to the outermost coarse domain with horizontal resolution of 9.0km, D02 is the first nest domain with resolution of 3.0km, and D03 is the second nested domain with resolution of 1.0km.

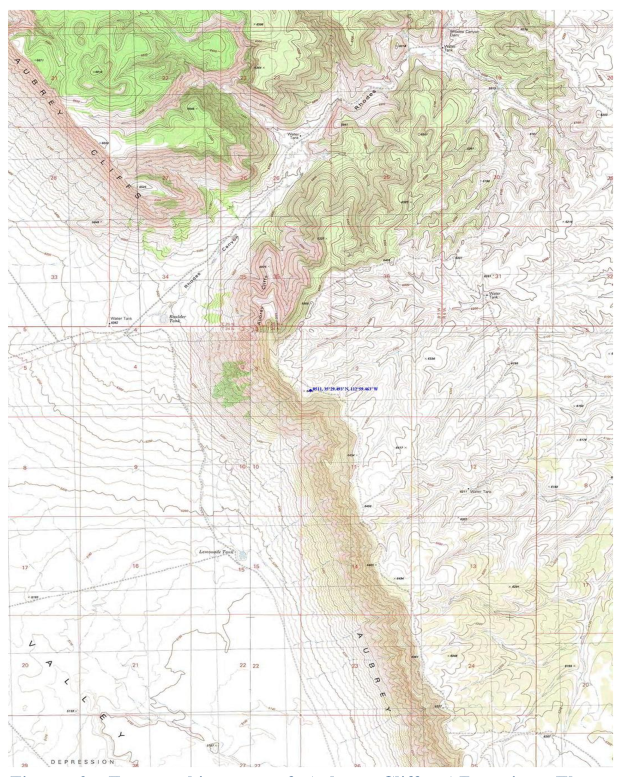

Figure 3: Topographic map of Aubrey Cliffs, AZ region. The meteorological station (marked in blue text) is approximately 100 m west of the nearest grid point. The area depicted in this map is entirely contained within the innermost modeling domain of both scenarios.

Mesoscale Modeling 5 (MM5)

- MM5 is the latest Numerical Weather Prediction (NWP) in a series of models developed in unison with the model used by Anthes from PSU to simulate hurricanes and storm propagation.
- MM5 has played an important role in mesoscale meteorological research and the advancement of mesoscale NWP.
- The data used for this model was obtained from the NCEP FNL model in a six hour temporal resolution and 1.0° x 1.0° horizontal resolution.
- This data is then prepared for the model simulation by using the module in MM5, INTERPF to vertically interpolate data onto levels of constant reference state sigma, given as: $\sigma_k = \frac{p_{ijk} - p_{top}}{p^*_{ij}}$
- The initial and boundary condition data are read into MM5 which then solves for the unknown atmospheric variables (wind speed, temperature, pressure, etc.) using a non-linear mathematical model based upon the governing physics as explained by (Grell and Dudhia, 1994)
- MM5 uses second-order, centered, finite difference and the second-order leap frog technique to solve the time variant atmospheric pressure equation, three dimensional momentum equations, and thermodynamic equation.

Scenario Name	Coarse Grid (N/S x E/W)	1st Nested Grid	2nd Nested Grid	Horizontal Resolution (Coarse – Fine)	Vertical Resolution
Scheme A	246km x 219km	52km x 52km		3.0km – 1.0km	23 sigma levels
Scheme A	246km x 219km	52km x 52km		3.0km – 1.0km	29 sigma levels
Scheme A	246km x 219km	52km x 52km		3.0km – 1.0km	34 sigma levels
Scheme B	1116km x 1521km	246km x 219km	52km x 52km	9.0km – 3.0km – 1.0km	34 sigma levels
Scheme C	83.7 km x 67.5 km	49.5km x 33.3km		2.7km – 0.9km	23 sigma levels

Table 1: Summary of simulations completed for study. All scenarios were run for six months during the year of 2006 with the exception of grid scheme A with 34 sigma levels which run for one full year, and grid scheme B which was run for 5 months.

Overall Results from MM5

- Scheme A was used to compute several important wind resource characteristics that will assist in the site study.
- Several wind characteristics were used for comparison, including; predominant numerical wind speed and direction, terrain induced flow observations, Weibull statistics, and turbulence intensity.

Wind Speed, Direction and Wind Power Density Comparison

Table 2: Summary of outputs from MM5 using domain scheme A at two height above ground level. The table shows a comparison between the experimental data measured at Aubrey Cliffs and the nearest computational point to the met tower.

Variable	Numerical 6m AGL	Experimental 10m AGL	Numerical 33m AGL	Experimental 30m AGL
Mean wind speed	4.6 m/s	5.1 m/s	6.3 m/s	6.7 m/s
Mean wind direction	145.8°	177.9°	135.3°	184.1°
Mean air density	Not predicted	Not measured	0.9806 kg/m³	0.9681 kg/m³
Mean WPD	101.8 W/m²	148.2 W/m²	238.8 W/m²	327.2 W/m²

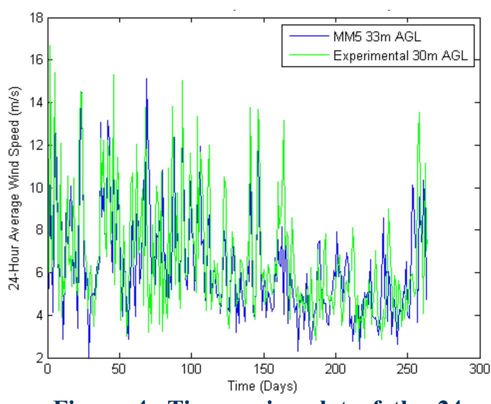

Figure 4: Time series plot of the 24-hour average wind speed for the MM5 and experimental data at 33m and 30m AGL, respectively.

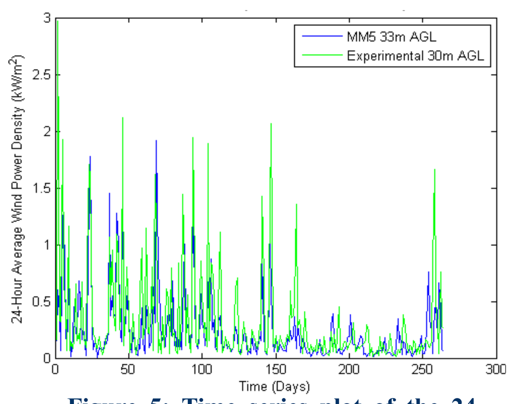

Figure 5: Time series plot of the 24-hour average wind power density for the MM5 and experimental data at 33m and 30m AGL, respectively.

Wind Flow Observations

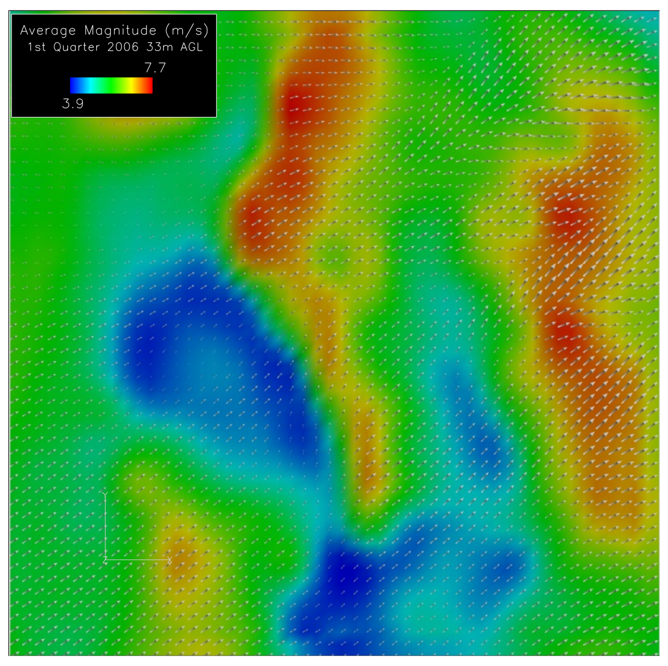

Figure 5: Horizontal cross section of region near Aubrey Cliffs showing the average magnitude of the wind speed and direction for the first three months of 2006 at 33m AGL.

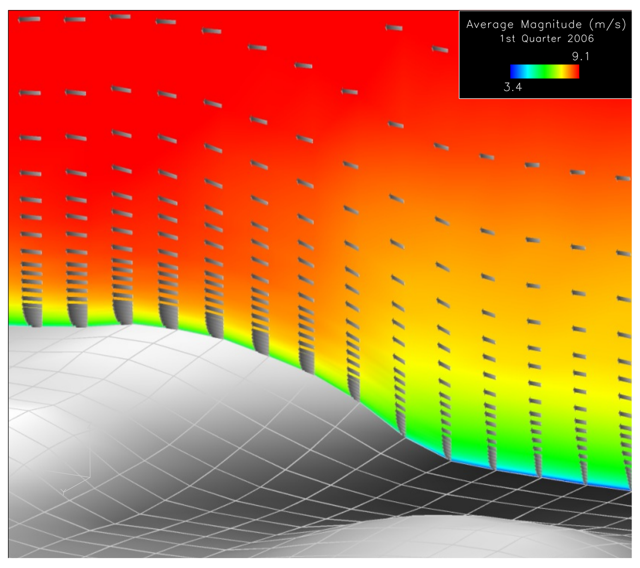

Figure 6: Vertical cross section of numerical domain showing the magnitude of the wind velocity and the projected velocity vectors for a 3 month average of wind speed values. The region is plotted looking from the northeast and shows approximately 15km of the domain. Note that the vertical scale is 5 times the horizontal scale, 5:1.

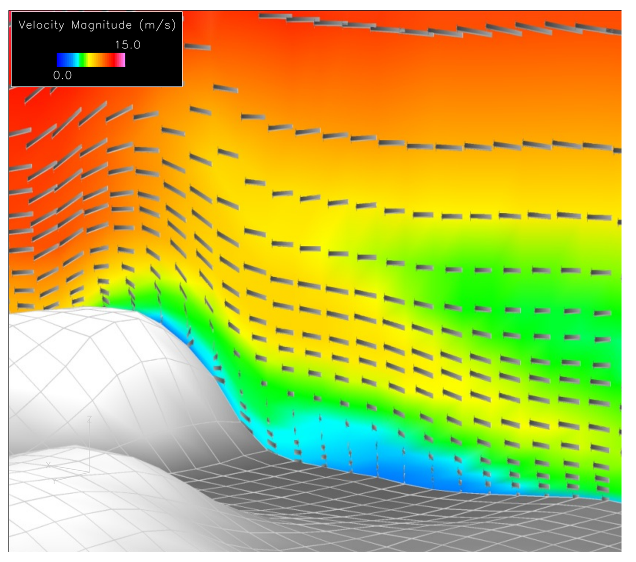

Figure 7: Vertical cross section of numerical domain showing the magnitude of the wind velocity and the projected velocity vectors for a 10-minute average dataset. The region is plotted looking from the Northwest and shows approximately 25km of the domain. Note that the vertical scale is 10 times the horizontal scale, 10:1.

Weibull Parameters

- The numerical predictions fluctuate more frequently than the experimental values.
- The numerical approximation was found to be consistently less than the experimental values for each wind direction and time frame.
- The Weibull parameters were found to be 6-7% lower than the actual experimental values.

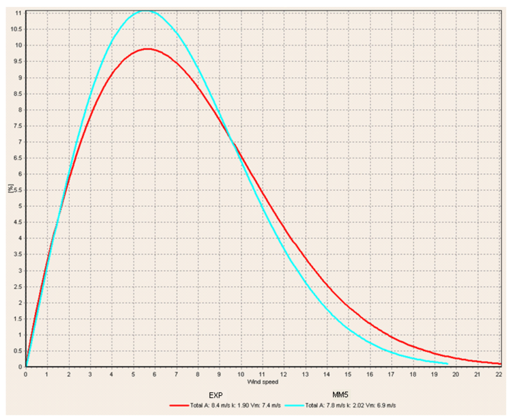

Figure 8: Weibull distribution of wind speed values during the first six months of 2006. The plot shows that the numerical data predicts slightly lower values of wind speed with greater variability.

Turbulence Intensity

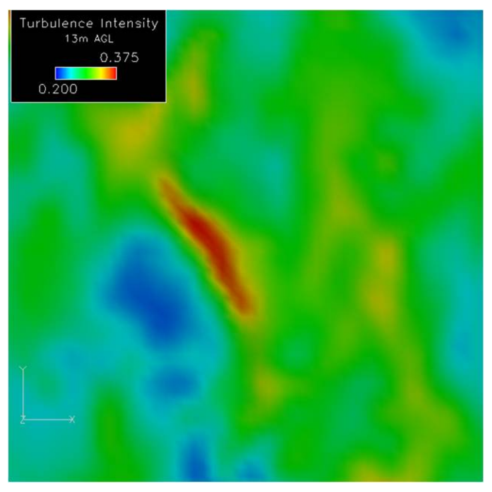

Figure 9: Contour plot of instantaneous turbulence intensity at 13m AGL for March 10, 2006 at 1:10pm. The TI was computed using 10-minute average time steps, which may not correctly interpret small scale wind fluctuations.

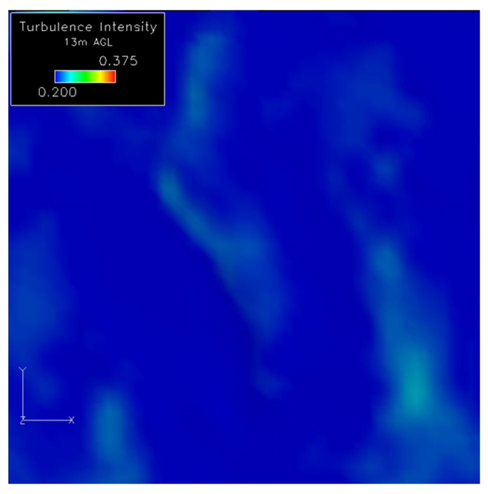

Figure 10: Contour plot of instantaneous turbulence intensity at 13m AGL for March 10, 2006 at 10:10pm.

Simulation Comparison

For the cases and resolution scenarios tested:

- It was found that the outer domain is not necessary to produce similar wind speed results.
- Increasing the vertical resolution produces more accurate wind flow patterns and better approximates the wind speed.
- 23 sigma levels does a poor job of characterizing the wind at low levels in the boundary layer.
- Minimal difference between 29 sigma and 34 sigma level cases

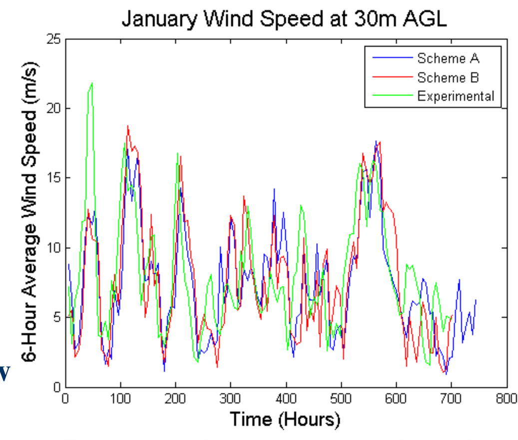

Figure 11: 6-hour average wind speed for grid scheme A, B, and the experimental data, plotted for January 2006.

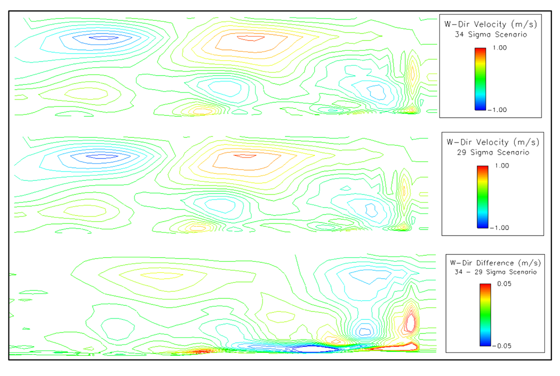

Figure 12: Vertical velocity contour plots for grid scheme A domain 2 with 34 (top) and 29 (center) sigma levels. The bottom plot shows the difference between the two scenarios.

Conclusion

- MM5 can be used to simulate the wind speed in complex terrain to understand large scale wind flow patterns and approximate magnitude of high wind speed events.
- The solver has difficulty in correctly predicting the wind direction within a moderate range of error.
- Turbulence intensity plays a significant role when assessing the feasibility of a wind power plant.
- MM5 should be implemented to operate with an adequate vertical resolution using a designed number of non-dimensional pressure levels.
- Using a large outer domain may not be required when solely predicting wind speed, but may be needed for other weather parameters.

References

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