Comparison and Analysis of Turbine Wake Interaction

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Introduction

As air moves through wind turbines, wakes form, impacting wind speed and power generated throughout the wind farm. Wakes decay with distance, but also interact to reinforce or cancel each other. Atmospheric conditions can compound these interacting wakes, resulting in more or less power obtained at the farm. Previous research in this area are limited, and generally focused on offshore farms.

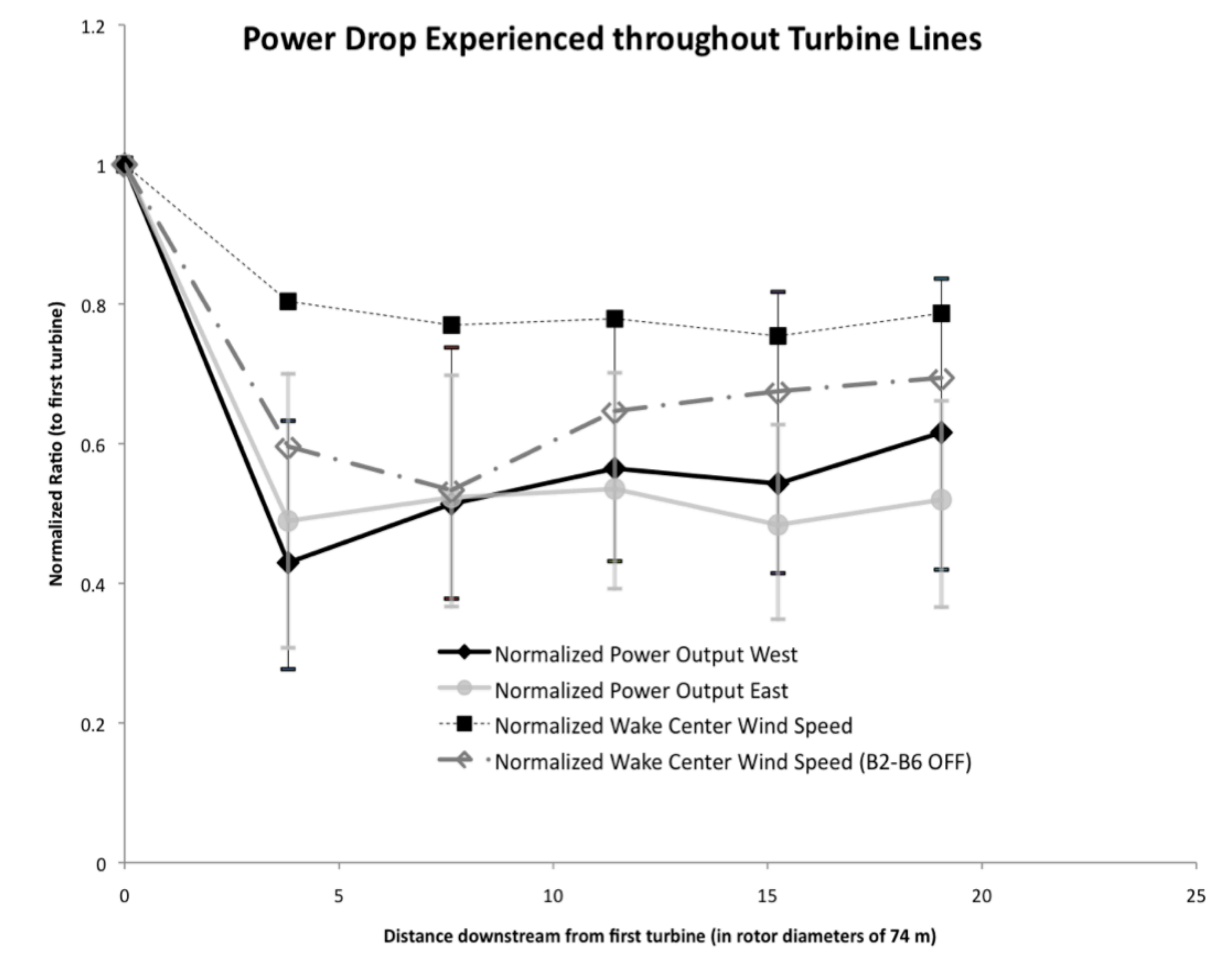

Figure 1. Comparison of wake impacts on power at an Iowa wind farm with those from an offshore study (Barthelmie, 2010).

Methods

Ratios of the power and wind speed at each down wind turbine compared to the lead turbine compare wake impacts. These ratios were compared throughout the line of turbines, and to various atmospheric conditions, such as wind speed and direction, pressure, temperature, and the concurrent surface-level stability and net radiation in the surrounding agricultural field.

Site Data

Data were collected during two summers from a wind farm in central Iowa. Turbine hub heights measure 80m, with a rotor diameter (D) of 77m. Within one line, turbines are spaced about 3.6 D apart. Line A (5 turbines) is north of line B (6 turbines). The B-line also includes two more turbines (B7 and B8) to the northeast of the main line but south of the A-line. The two lines under consideration are spaced about 23 D from each other.

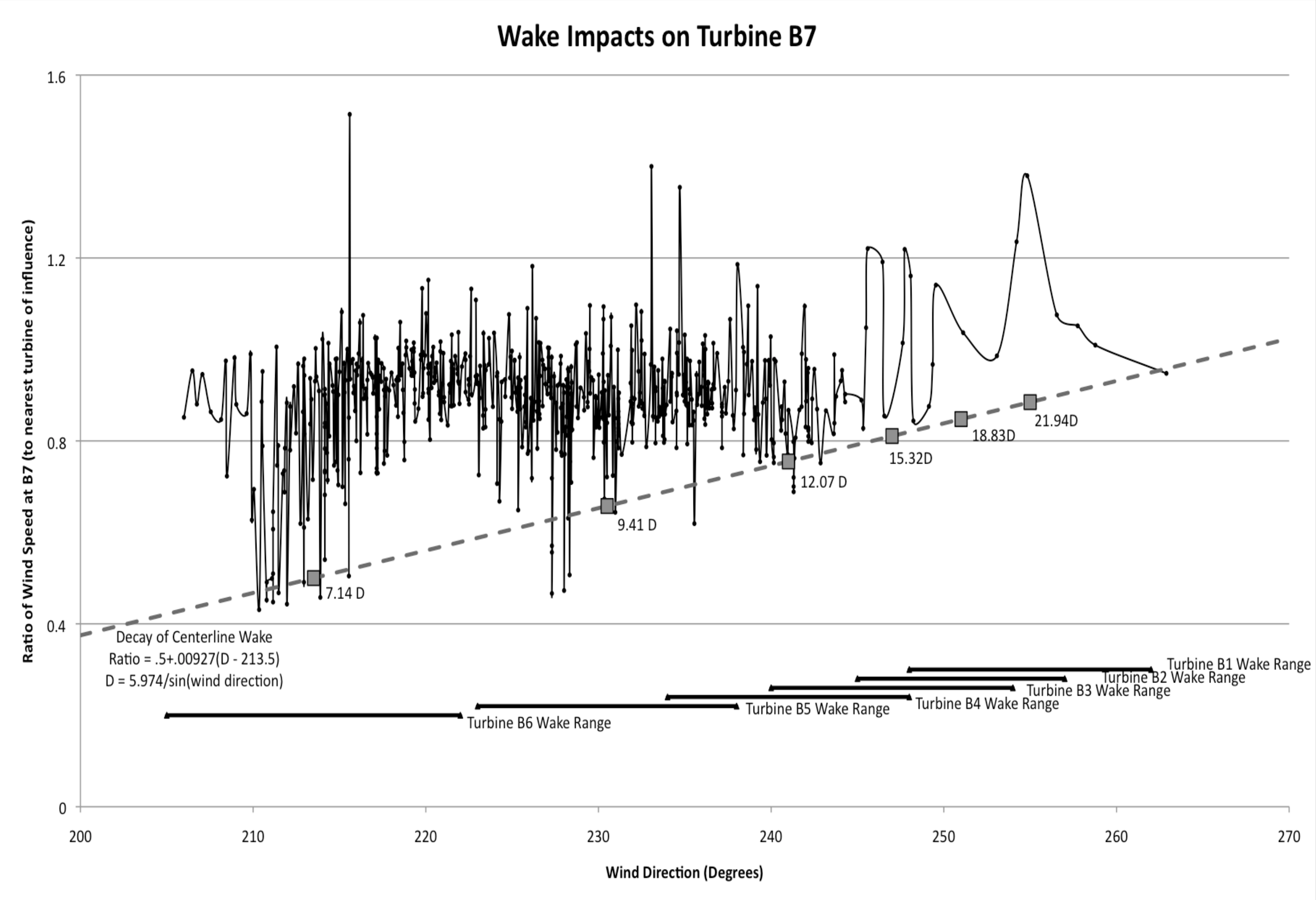

Figure 2. B-line turbine wakes impacting B7. The wake center wind speed is lower than other regions of the wake. Closer wakes have stronger influences.

Results

Power generated at these turbines drops most significantly in the due east and due west wind direction. Figure 1 shows that after moving through the initial turbine, power drops to 40-50% of its initial value, and then gradually recovers to about 50-60% by the final turbine. This trend parallels that of wind speed, which drops initially and then levels off.

In Figure 2, Power drop is less severe when the second turbine is farther away. The decay of the wake appears to be logarithmic with distance, approaching a power ratio of one around 30 D. It is unclear when wakes can be considered dissipated completely, but they are certainly less significant after 15 D. It can also be seen that wake impacts are most significant in the center of the wake, as confirmed in Figure 3.

Numerical analysis revealed that horizontal wind speed is the strongest indicator of how heavily wakes will impact downwind conditions (Figure 4). Net radiation, turbulence, and other factors can also have impact.

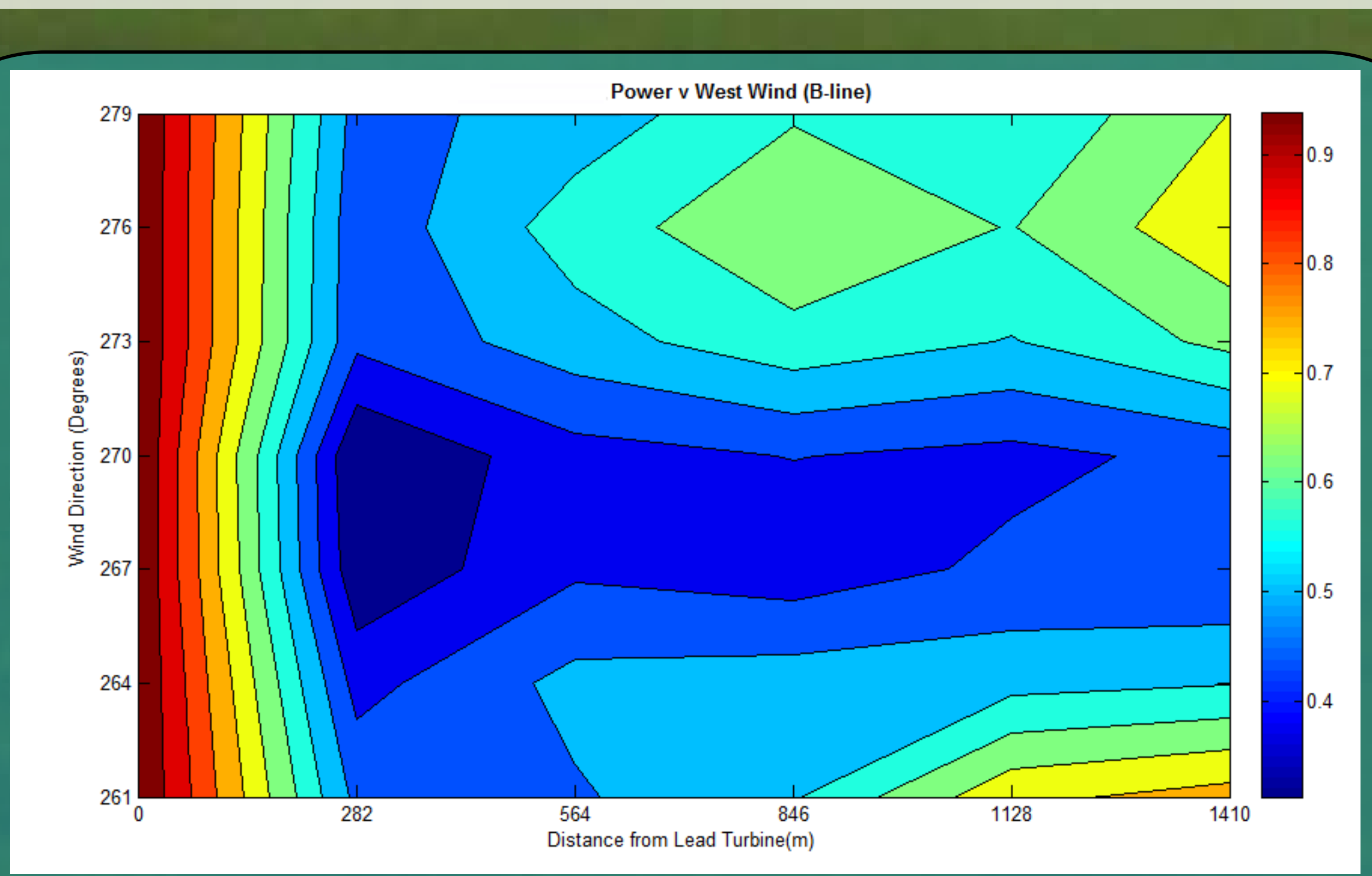

Figure 3. Wake effects on power generation are most severe in the center of the wake. Wake impacts lessen over distance.

Conclusions

Power drop and wind speed deficit experienced through a line of turbines is most severe after the first turbine. After the initial drop, both appear to recover down the line. High variability in the extent to which power and wind speed change through the line may be due to variations in atmospheric conditions, particularly horizontal wind speed.

The wake impacts study are strongest in the middle of the wake line, with weaker impacts noted at the edge of the waked area. These data also show clear logarithmic decay of wakes with downwind distance. It appears that the impacts of wakes on downwind turbines may decay almost completely within 20D.

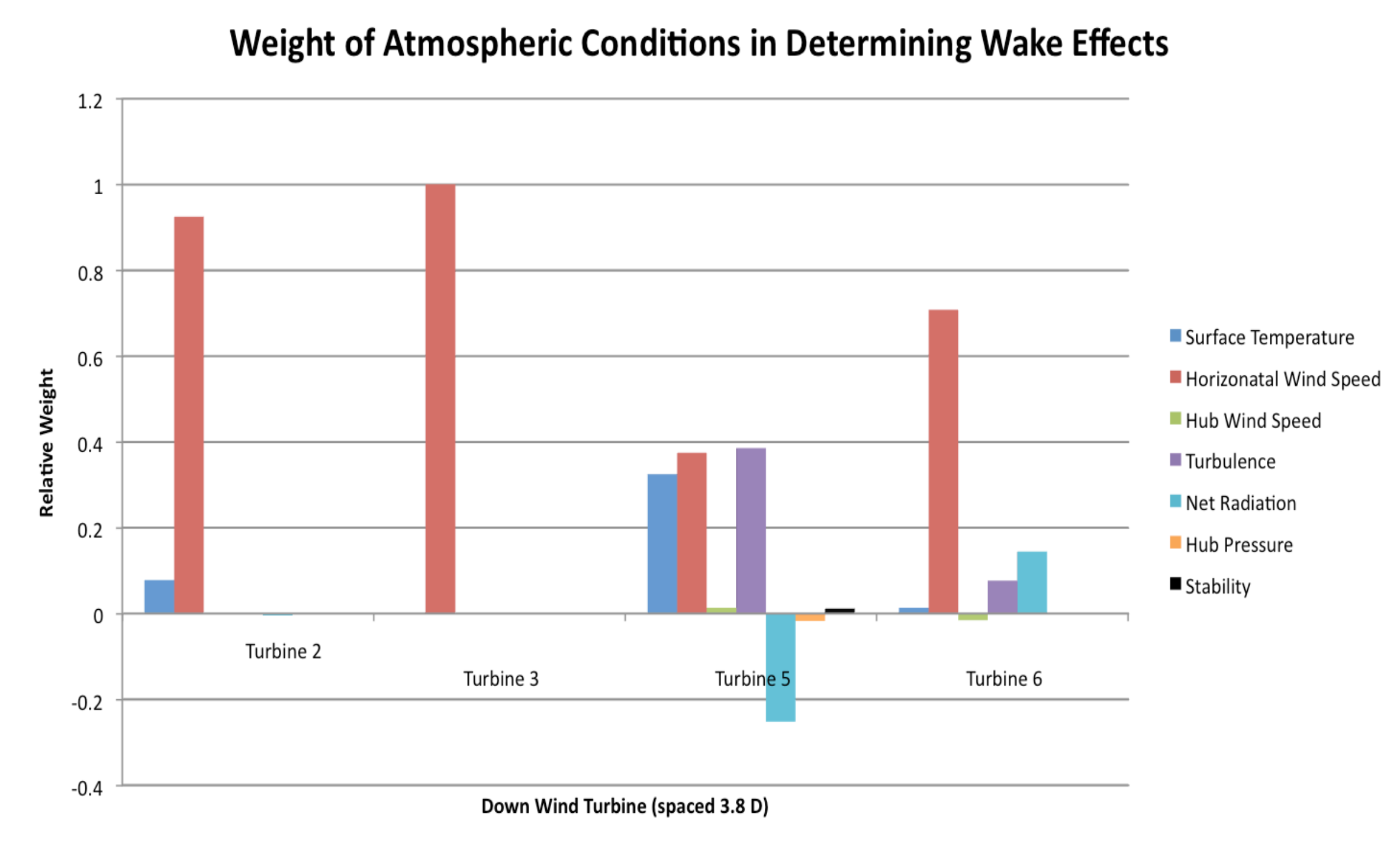

Figure 4. Summary of numerical techniques applied to wake data. Relative weights of atmospheric conditions as contributing factors in wake effects.

Discussion

These results agree with and expand upon previous research in wind turbine wake studies. These results show a higher power and wind speed recovery rate than a similar study of offshore turbines.

It would be useful to continue this study in a number of capacities. Similar analysis on some of the longer lines of turbines would help confirm observed trends and expand upon them. It would also be interesting to compare these results from the periphery of the wind farm with similar data taken in the heart of the farm. The use of LIDAR data to better determine free stream wind conditions, or the use of a wind tunnel to better isolate changes in atmospheric conditions would also be beneficial to our understanding of wake science.

References

Barthelmie, R.J. and Jensen, L.E. 2010: *Wind Energy*, **13**, 573–586, DOI: 10.1002/we.408.

Background adapted from:

Alex Bruns, “Wind Farm,” 12 May 2009 via Flickr, Creative Commons License.

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