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Dynamic Line Ratings Predicted with Computational Fluid Dynamics Simulations in Complex Terrain

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Abstract

The maximum capacity of transmissions lines is traditionally calculated used static ratings of the conductor using predetermined environmental conditions assuming very little wind. The use of computational fluid dynamics (CFD) simulations coupled with local weather station data can potentially be used to give more accurate predictions of maximum line capacities, which are typically underestimated. Here, the region of investigation is a complex area of study named Hell's Canyon, the deepest river gorge in North America, located along the border of Idaho and Oregon. The Snake River flows 1600 meters below the west rim, and 2300 meters below mountain peaks to the east. This area is of interest due to the hydroelectric dams in the region.

Method

The process for developing an accurate CFD model relies on first constructing the appropriate mesh and boundary conditions. The terrain elevation is constructed from data that is transformed from a latitude-longitude space into a linear projection (UTM 11 here) to allow for the easy use of a Cartesian grid in the CFD. The spatial resolution used here consists of 30 meter increments in the horizontal directions, over an area approximately 30 by 60 kilometers. To account for the sub-grid effects near the surface, a roughness factor is determined which accounts for trees, shrubs, buildings and so forth. A three-dimensional map highlighting the complexity of the terrain is shown in Figure 1.

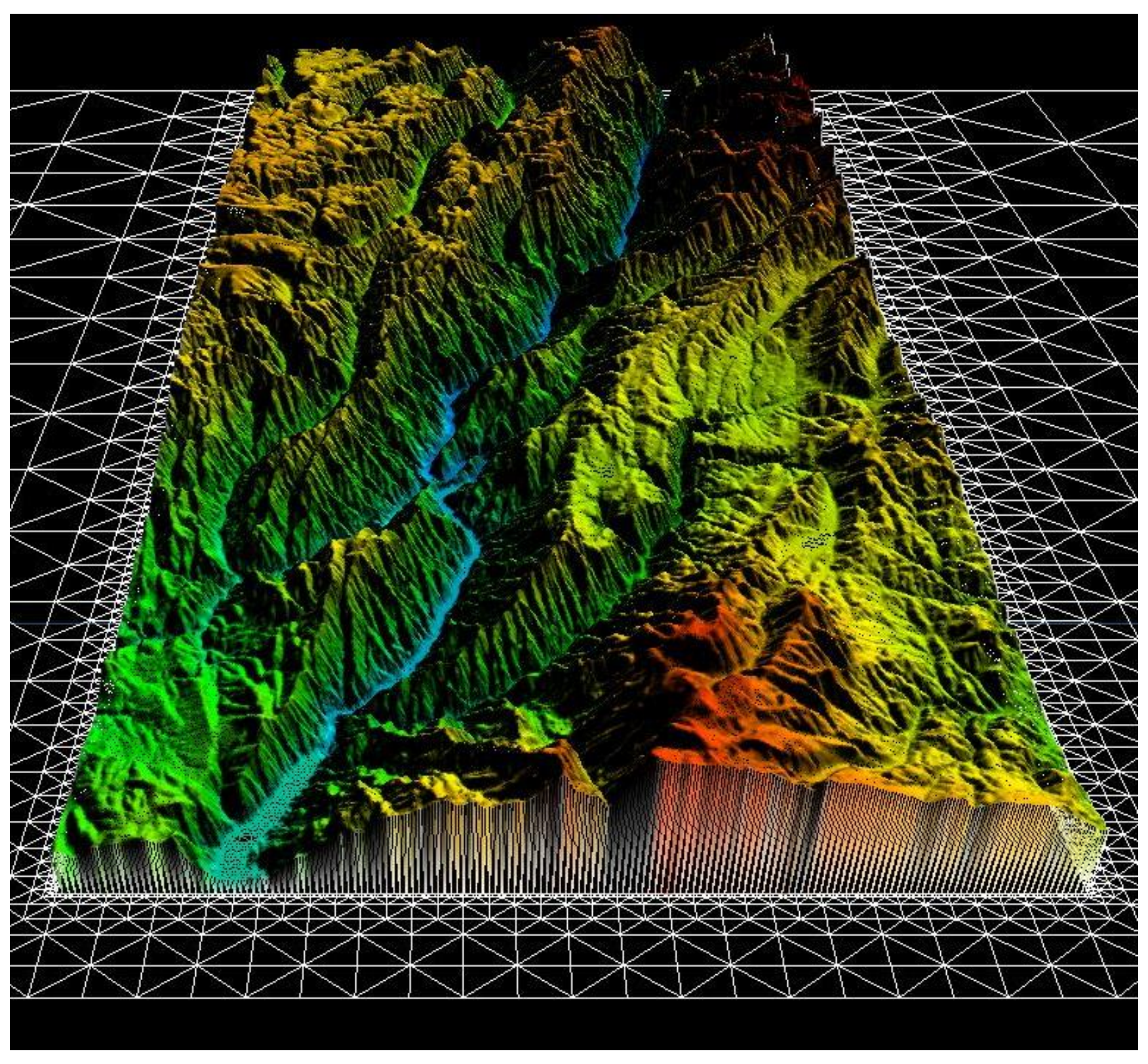

Fig. 1: Three dimensional image of Hell's Canyon terrain.

A grid for this region is constructed with the same 30 meter spacing as the elevation data, and with a non-uniform vertical grid with 5 meter resolution near the ground level, 10 meter resolution up to 100 meters, followed by pseudo-log spacing up to 3500 meters. The mesh for the horizontal domain and vertical spacing is shown in Figure 2. The entire domain contains of a total of 85 million cells. Due to computational limitations, running on a grid this large is not favorable. Instead, this domain is split into two separate domains with several kilometers of overlap, so that each domain is about 55 millions cells each. The CFD code solves the Reynolds-averaged Navier Stokes (RANS) equations using the standard *k*-ε RANS model for turbulent kinetic energy and dissipation rate. The code is run in parallel on 12 CPUs for incoming wind sectors equally spaced by 30 degrees. Several kilometers of buffer are added around the outside of the region to dampen boundary effects.

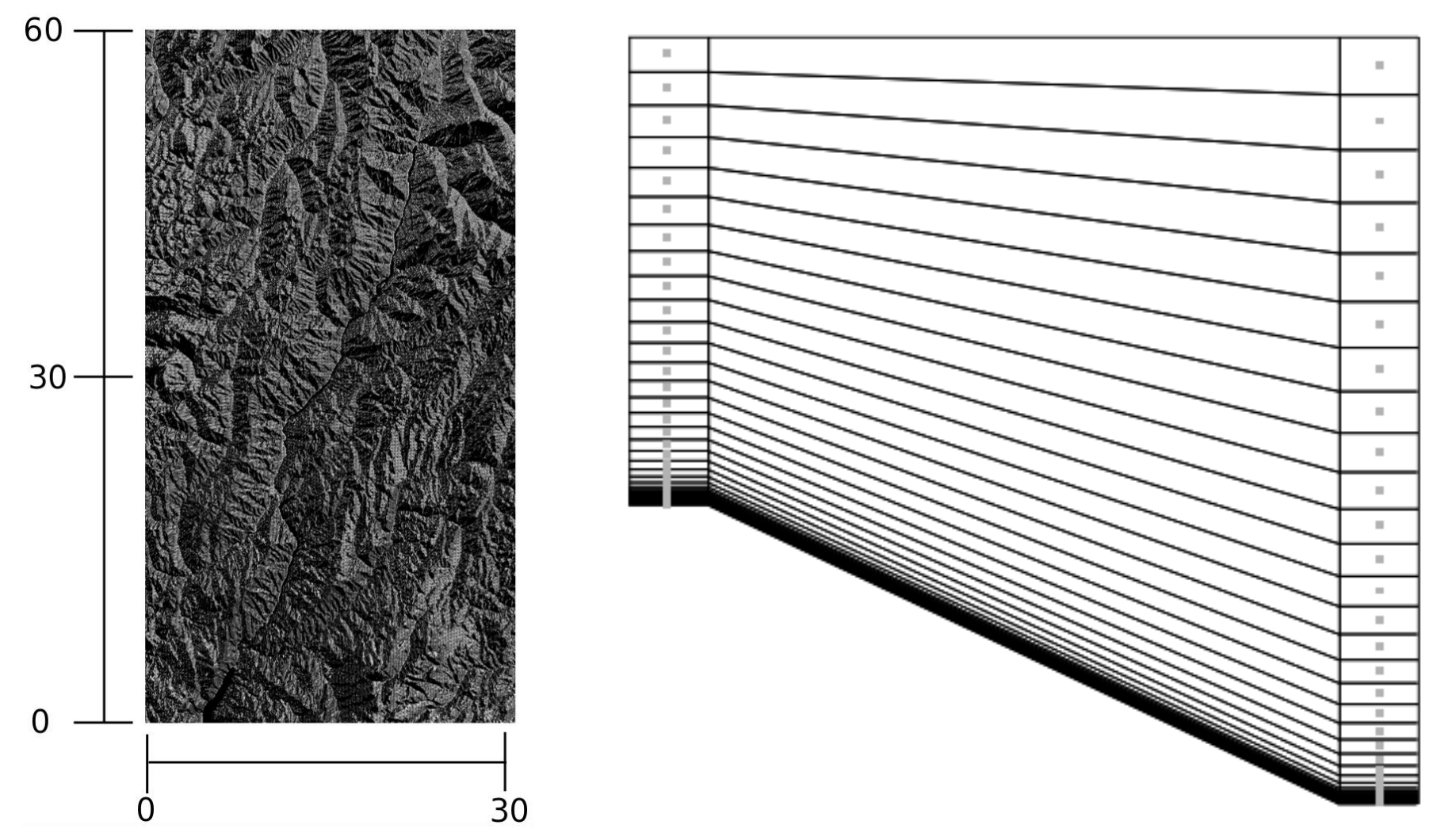

Fig. 2: Mesh of the x-y plane and the vertical grid spacing.

There is a series of power line structures which run along the gorge. These are shown with black dots in Figure 3. There are currently six installed weather stations in this region which have gathered data. A future weather station has been proposed at the north end of the line. The locations of all these weather stations are marked with stars in the figure.

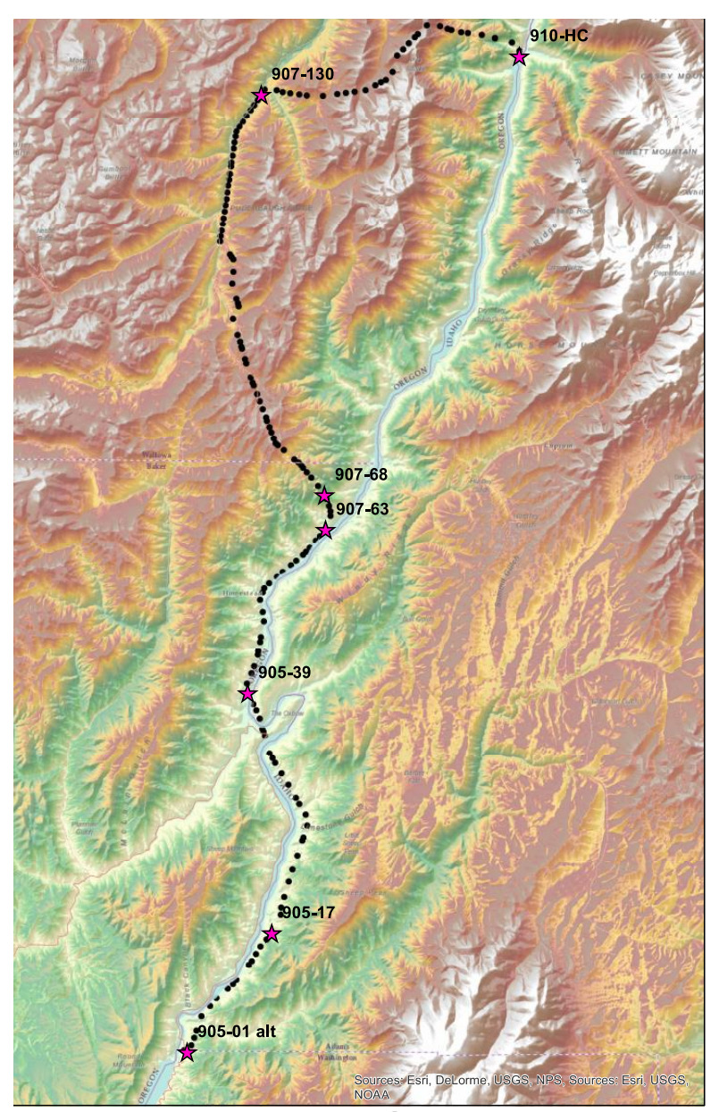

Fig. 3: Locations of power lines and weather stations in the region.

Results

For each of the 12 sectors of the incoming wind sectors, a separate CFD simulation is run for each of the two domains. The results of these simulations are extracted at 10 meters, the approximate minimum height of the power line's span midpoints. The wind field at 10 meters above ground level for the 0° incoming sector is shown in Figure 4 for both the north and south sections. In this case, where the domain has been split apart, a method referred to as Wind Atlas is used which will conglomerate data from two separate simulations along the boundary to create a more accurate representation.

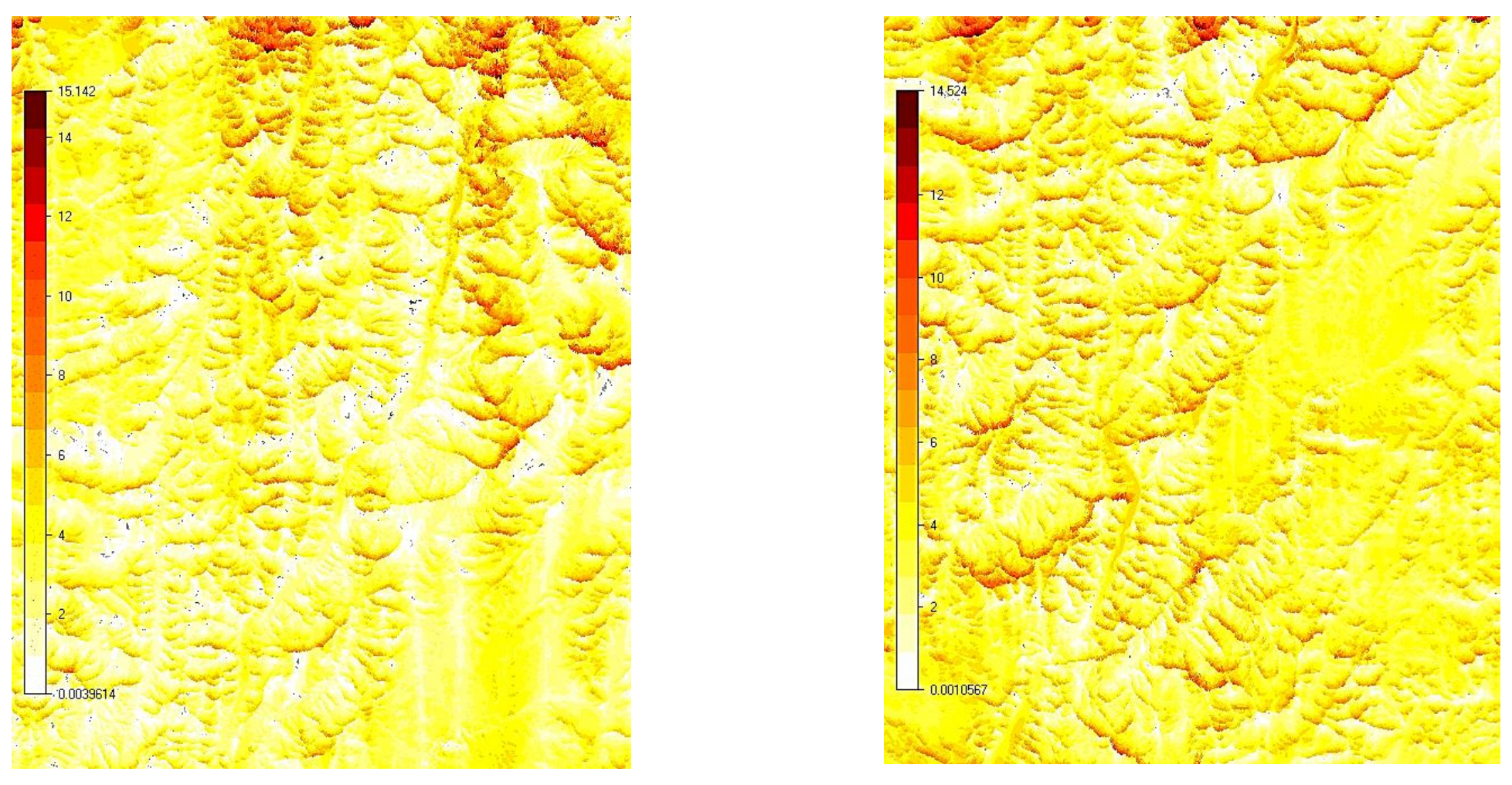

Fig. 4: Wind vector fields for the 0° incoming sector for north and south domains.

At the north end of each of the regions, Figure 4 shows the abnormally high velocities predicted from the simulations. This occurs due to having steep terrain so close to the inlet of the CFD domain. The Wind Atlas method should handle this overlapping region and cut out these unphysical values near the boundaries.

The entire overlap of the two regions in the north-south direction is about 20km, this area is highlighted in Figure 5. From each region about 5km is cut off from the edges of the simulation to avoid the inclusion of recirculation zones near the boundary. This clipping is especially important due to the power lines running across the boundary of the two domains. In smaller cases the distance around power lines is just expanded.

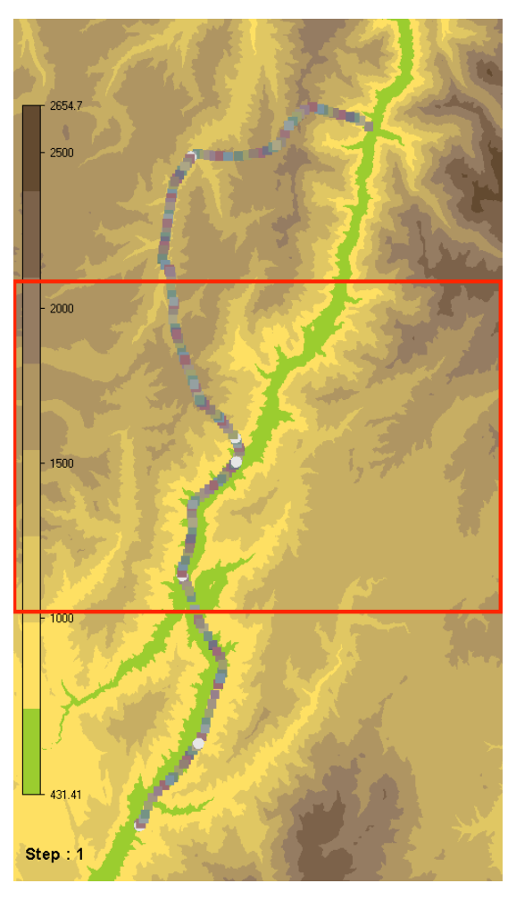

Fig. 5: Overlapping region of the two simulations.

In the overlap of the two regions, there are 66 power line structures located. For the predominate wind flow in the 0° sector, the north, south, and combined Wind Atlas speed ups for these power lines are plotted in Figure 6. The WindSim code uses data from the nearby weather stations to find scaled values for wind direction changes and speed ups for each of the midpoint locations for every incoming wind sector and stores this in a tabular form that is used by INL's general line ampacity state solver (GLASS). The figure shows the wind speeds relative to the nearest weather stations, there is mostly agreement between the two regions and the combined method, except for the area near structures 50 to 60. Here unphysical values occur from the close boundary conditions occurring in the two individual regions. However, the Wind Atlas methodology accounts for the boundaries and corrects the values here such that they are realistic.

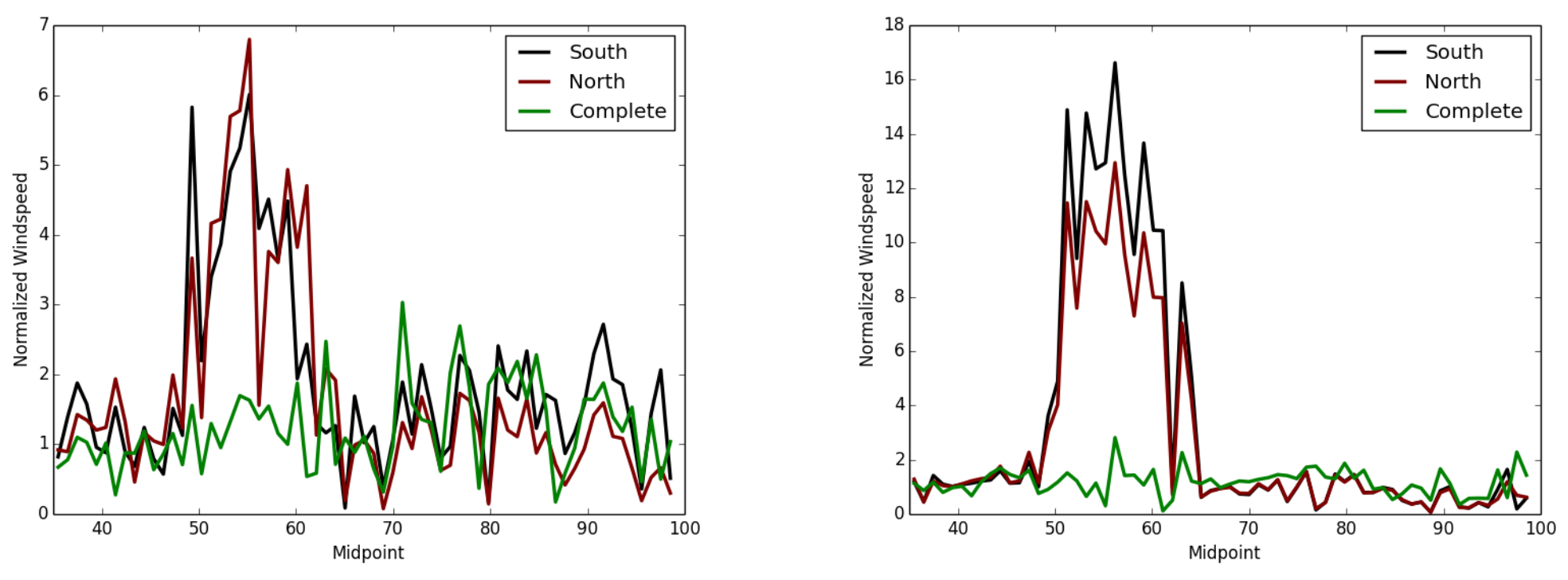

Fig. 6: Predicted wind speed up across power line midpoints.

The GLASS software was developed at INL to process historical, real-time, and forecasted weather data and calculate weather based ampacity ratings and conductor temperature estimates using a variation of the IEEE 738 standard informed by the CFD models. DLR can have significant impact on wind integration and utility operations. This technique has potential to significantly improve DLR, because the CFD data has much more resolution than other methods being attempted.

Conclusions

Idaho National Laboratory has performed CFD calculations with the WindSim code coupled with field weather data to provide wind field predictions that can be used to calculate dynamic ampacity ratings of power lines over a highly complex region of terrain. The Wind Atlas methodology has been used to crop boundary effects across the two divided domains.

- J. Gentle, K. Myers, J. Bush, S. Carnohan and M. West, "Dynamic Line Rating: Research and Policy Evaluation," PES General Meeting, pp. 1.5, 27-31, 2014 IEEE.
- J. Gentle, W. Parsons, M. West, and S. Jaison, "Modernizing An Aging Infrastructure Through Real-Time Transmission Monitoring," PES General Meeting, 2015 IEEE