CAN THE WRF MODEL CHARACTERIZE ATMOSPHERIC STABILITY FOR WIND ENERGY PURPOSES?

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1) INTRODUCTION

A key factor in the development, design, and operation of wind farms is an accurate representation of the environmental conditions and flow variability in their location areas. This implies a correct characterization of the atmospheric stability. The wakes produced by each wind turbine or the whole wind farm affect not only the power production but also the lifetime of the wind turbines located downstream. The intensity and extent of the wake strongly depend on the turbulent state of the flow in which it is immersed (Han et al., 2018; Doubrawa et al., 2020). Therefore, a detailed characterization of the atmospheric stability will help to reduce the Levelized Cost of Energy (LCOE). In this work, the stability is studied in the location of a Patagonian onshore wind farm, analyzing the capacity of the WRF (Skamarock et al., 2008) mesoscale model to characterize the low-layer atmospheric stability in one of the regions with the best wind resource in the world.

2) METHODOLOGY

To analyze the stability at the Rawson Wind Farm (RWF) location and the capacity of the WRF model to represent the different stability regimes, a statistical study and comparison between model outcomes and measurements are proposed. All this analysis is performed for the period corresponding to the pre-feasibility study of the farm, from October 2010 to mid-September 2011, approximately one year. Due to the limited instrumental of the RWF met mast, a way to characterize the stability is through the bulk Richardson number (Rib). Following Bodine et al, 2009, the Rib can be estimated with the following equation:

$$Rib = \frac{g\,\Delta z_u^{\,2}\left[\frac{T_2 - T_1}{\Delta z_T} + \Gamma_d\right]}{T_1\left[u_2 - u_1\right]^2} \qquad (1)$$

where T_1, T_2 and u_1, u_2 are the temperatures and wind speeds at two different vertical levels. Then, Δz_u and Δz_T are the differences between each variable levels and $\Gamma_d \approx 0.01\ K/m$ is the dry adiabatic vertical gradient. Table 1 specifies the separation of the stability regimes as a function of Rib suggested in Newman and Klein, 2014.

Table 1. Rib stability classification limits (Newman and Klein, 2014)

Stability classification	Rib
Very Unstable	$Rib < -0.2$
Unstable	$-0.2 \leq Rib < -0.1$
Neutral	$-0.1 < Rib < 0.1$
Stable	$0.1 < Rib < -0.25$

Very Stable	$Rib \geq 0.25$

For the period considered, the simulations with WRF, as in Hahmann et al., 2016, were made in overlapping series of 11 days length, discarding the first day of each simulation as spin-up time. ERA5 data was used as initial and boundary conditions. Simulations were performed with 3 nested domains, with horizontal resolution of 9 *km*, 3 *km*, and 1 *km*, respectively, and with the inner domain centered on the RWF. With the simulation results for the closest grid point to the RWF center, the Rib was estimated considering the temperature at 2 *m* and 80 *m*, and the wind speed (u_2) at 80 *m*, assuming $u_1 = 0$ in order to compare with the measurements.

3) RESULTS

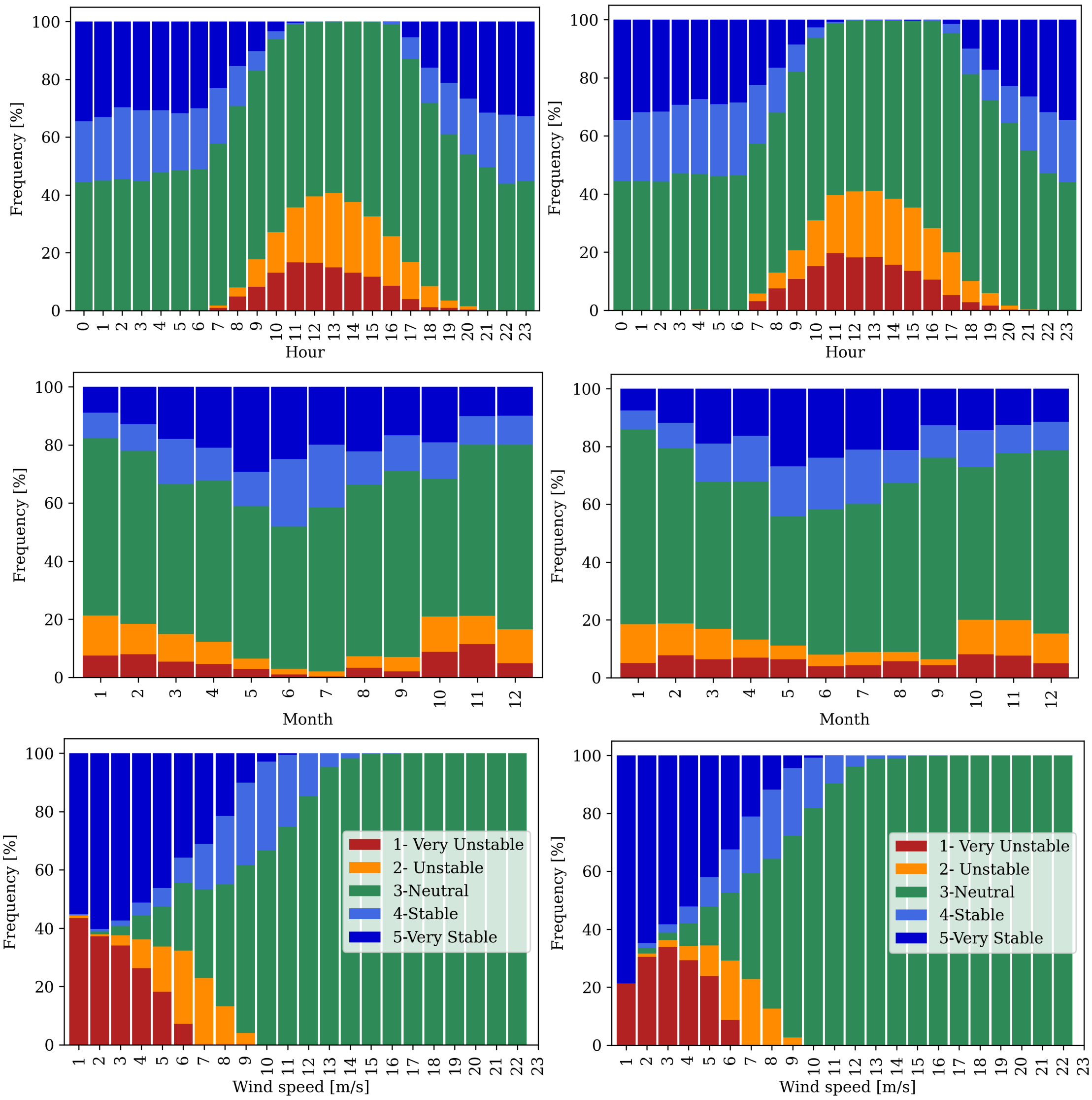

Figure 1. Stability occurrence frequencies based on the Rib estimated from WRF simulations (left) and observations (right). Per hour (top), per month (center), and per wind speed (bottom).

With all the simulations performed, a comparative statistical analysis was conducted where the behavior of the different stability regimes estimated through the Rib resulting from the WRF simulations and measurements were compared. The classification of the different stability conditions was carried out following the limits defined in Table 1. Figure 1 shows, for both observations and simulations, the frequencies of occurrence of the different stability regimes for the different hours of the day, the different months of the year, and according to different wind intensities at 80 *m* height. It can be observed that the resulting frequency distributions of the simulations are very similar to those estimated from the observations. In both top images, the diurnal cycle is evidenced with a predominance of neutral and stable conditions during the night and an increased frequency of unstable regimes during daytime. Regarding the variation throughout the year (Figure 1 center), it can also be observed, in both figures, an intra-annual variation in the behavior of stability. Although the number of neutral cases seems to remain approximately constant throughout the year, there is evidence of an increase in stable stratifications for the winter months. Concerning the distribution of frequencies for different wind speeds at hub height, Figure 1 (below), it is observed, in both graphs, a marked increase of the neutral conditions with the wind intensity, evidencing the dominance of mechanical turbulence over turbulence with thermal origin in situations of high wind speed. The global proportion of each stability condition was also investigated, and the correct categorization of the simulated values with respect to the observed ones was analyzed through a contingency table. In both cases, not shown in this abstract, it was again demonstrated that the classification resulting from the simulations was very similar to the one from observations.

4) CONCLUSIONS

Since the simulation results for frequency distributions and percentages of occurrence of the different stability conditions are almost analogous to the ones resulting from observations, it can be concluded that the WRF model has a good capacity to characterize the low-layer atmospheric stability at the RWF location. This result encourages the use of mesoscale models to assess the stability conditions for places or periods where no measurements are available, and thus extend the availability of information on the environmental conditions that impact and modulate the behavior of a wind farm.

REFERENCES

Bodine D., Klein P. M., Arms S. C., and Shapiro A., 2009: Variability of surface air temperature over gently sloped terrain. Journal of Applied Meteorology and Climatology, 48 (6):1117–1141.

Doubrawa P., Quon E. W. , Martinez-Tossas L. A., Shaler K., Debnath M., Hamilton N., Herges T. G., Maniaci D., Kelley C. L., Hsieh A. S., et al., 2020: Multimodel validation of single wakes in neutral and stratified atmospheric conditions. Wind Energy 23 (11): 2027–2055.

Hahmann A. N., Peña, A. and Carsten J., 2016: WRF mesoscale pre-run for the wind atlas of Mexico. DTU Wind Energy.

Han X., Liu D., Xu C. and Shen W. Z., 2018: Atmospheric stability and topography effects on wind turbine performance and wake properties in complex terrain. Renewable energy, 126:640–651.

Newman J. and Klein P., 2014: The impacts of atmospheric stability on the accuracy of wind speed extrapolation methods. Resources, 3 (1):81–105.

Skamarock, W. C., Klemp J. B., Dudhia J., Gill D. O., Barker D. M., Wang W., and Powers J. G., 2008: A description of the Advanced Research WRF version 3. NCAR TN-475+ STR".