Assessing the Impact of Atmospheric Stability on Vertical Wind Profile Evolution During PECAN Low-Level Jet Events

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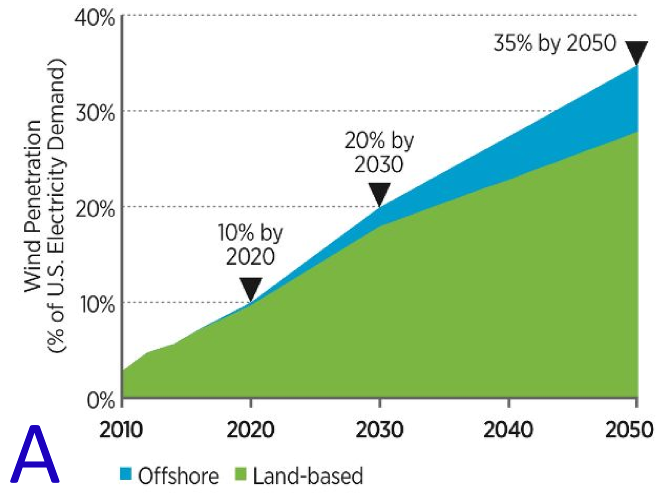
SUMMARY

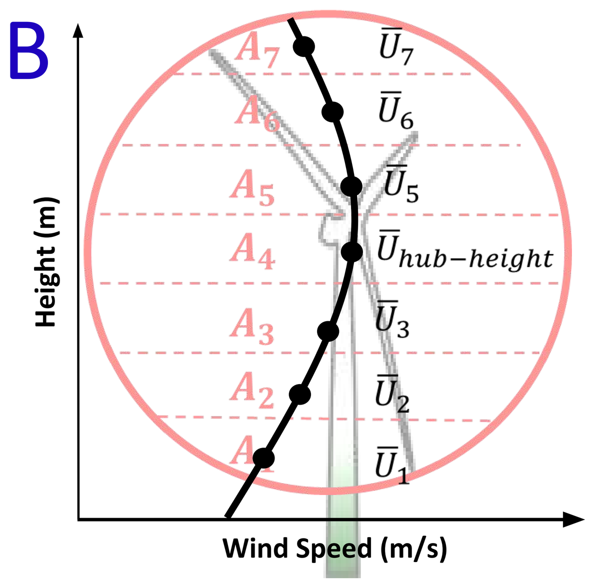
Motivation:



Onshore and offshore wind energy provides a tremendous opportunity to meet future US electricity demand (Figure A). However, wind resource and turbine available power uncertainties exist during wind farm development, and in-part contribute to the wind energy industry challenge known as 'wind farm underperformance bias'; in which an operational wind farm produces significantly less energy output than the amount anticipated prior to construction.

Overcoming this challenge is important, as it could cause sub-optimal wind farm layouts, thus further delay the cost-competiveness of this technology [1].

Background:



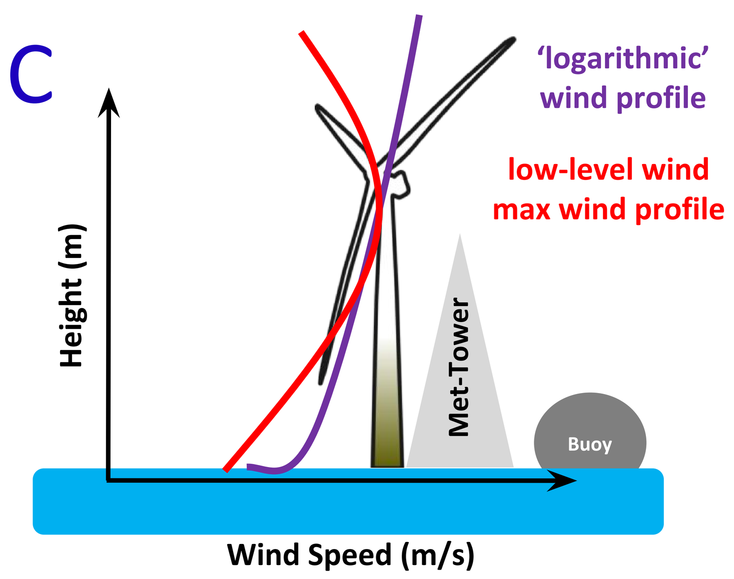
The Rotor-Equivalent Wind Speed (REWS) method was created to better account for non-logarithmic, rotor-layer (RL) wind profile 'shapes' on turbine available power (replacing the traditional hub-height wind speed available power assessment method, which assumes all wind profiles were logarithmic-like) (Figure B).

Research demonstrates the REWS technique reduces uncertainty in predicting turbine available power; thus helping predict more accurate pre-construction energy yields [2-3].

Research Challenge:

Unfortunately, often times RL wind and other atmospheric measurements across an entire hypothetical turbine's rotor-layer (~40-200m) are sparse, both spatially & temporally.

Therefore, during a pre-construction wind resource assessment, RL wind profiles are assumed to be logarithmic-like, using the power-law method to extrapolate surface or lower-height data. In reality, RL wind profiles may be very different; notably during the evolution of the Low-Level Jet (LLJ) phenomenon (Figure C).



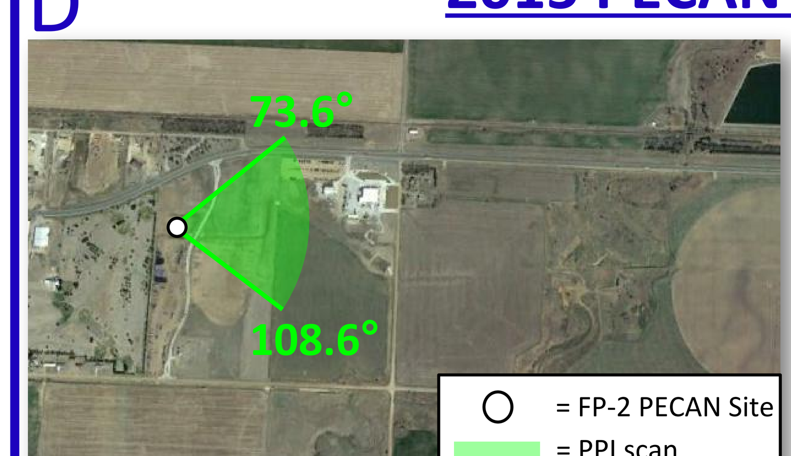
Research Questions:

1 What are average RL wind profile shapes during the evolution of LLJ events?

2 During LLJ events, do relationships exist between RL wind profile shapes and atmospheric stability?

DATA COLLECTION

2015 PECAN Measurement Campaign:



PECAN: **P**lains **E**levated **C**onvection **A**t **N**ight

Dates: June 1st – July 15th 2015

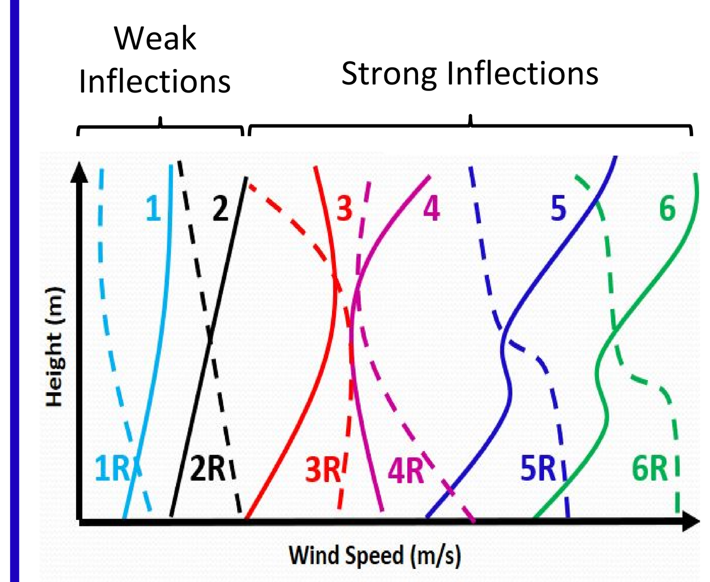
Where: Great Plains; where LLJ are often observed

Instrumentation: Microwave Radiometer Profiler, Radiosonde Launches, Leosphere Windcube 200s Doppler wind lidar

Experiment set up with overlay of horizontal wind retrieval technique, a sector width of 35° and a radius of 460 m (Figure D).

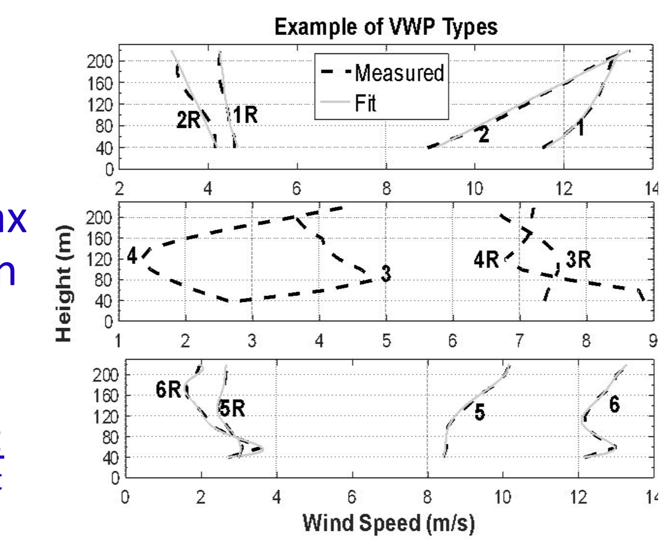
METHODOLOGY

Classifying Rotor-Layer Wind Profile Shapes:



Criteria RSS ≤ 0.10:
Type 1: Power law Fit
Type 2: Linear Fit
Type 3: Low-Level Wind Max
Type 4: Low-Level Wind Min
Type 5: Fourier Fit (2 term)
Type 6: Fourier Fit (3 term)

Criteria Relative Max/Min:
'R' Types= max and min wind speed at 40m & 200m, respectively



Classifying Rotor-Layer Stability:

Bulk Richardson Number (R_B):

$$R_B = \frac{g\Delta\theta_v\Delta z}{\theta_v(\Delta u^2 + \Delta v^2)}$$

- R_B method to assess stability only considers magnitude of RL wind speed change with height

g = gravity, $\Delta\theta_v$ = change in virtual potential temperature across a layer of thickness Δz (vertical depth), Δu and Δv are changes in horizontal wind components across same layer

- To overcome the limitations of using R_B for stability assessment during 'reversed' wind profiles, a new RLS term is introduced

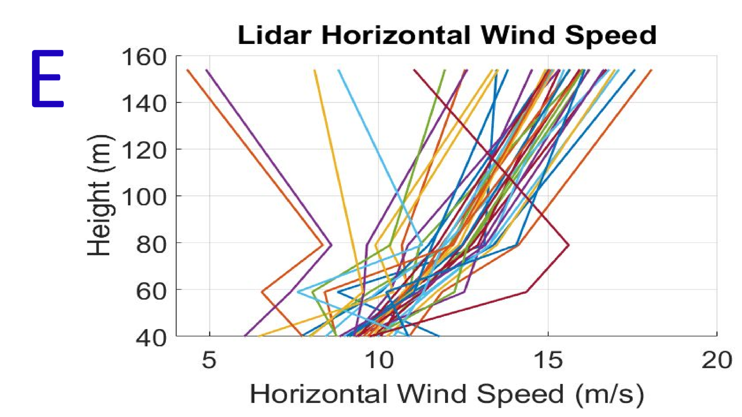
Rotor-Layer Stability (RLS):

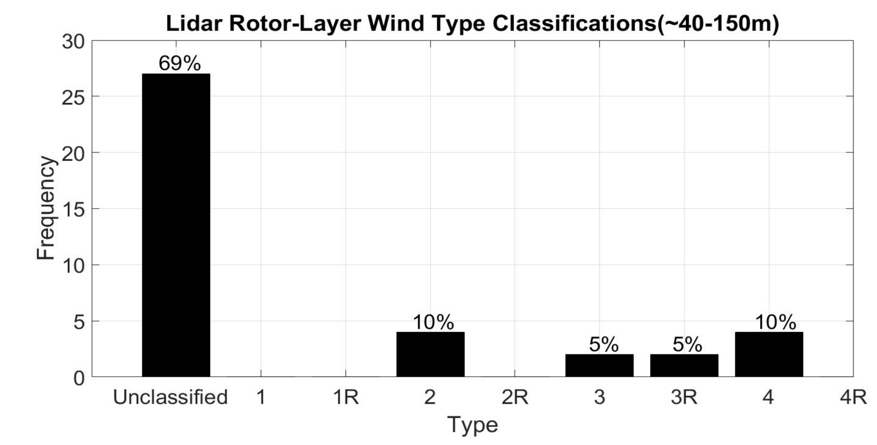
$$RLS = \sum_{i=1}^{24}(\Delta\theta_{vi})$$

$\Delta\theta_{vi}$ = change in virtual potential temperature each measurement height z_i (i=1-24)

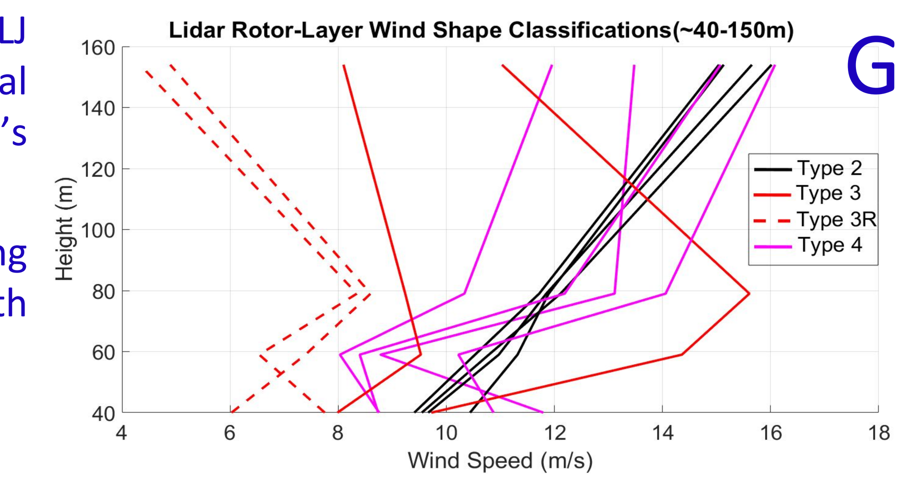
RESULTS: June 03, 2015

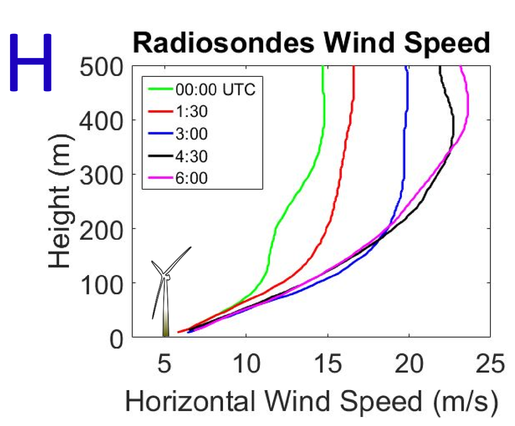
Rotor-Layer Wind Profile Classification:

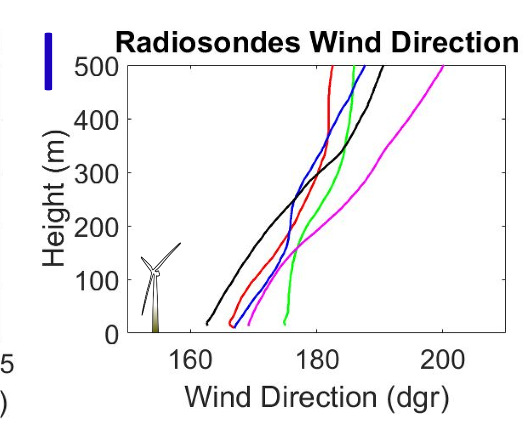


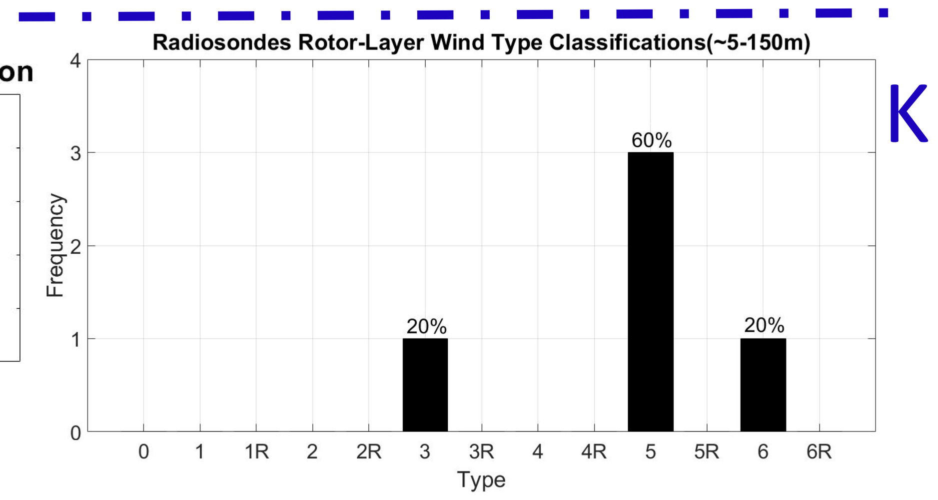


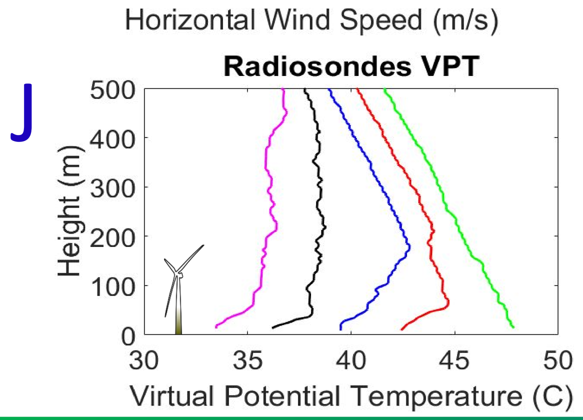
- 10 min average RL wind profiles demonstrate LLJ events; however, understanding the impact atypical shapes have on turbine available power during the LLJ's evolution is difficult (Figure E).
- The majority of the data are 'unclassified', yet strong inflection shapes of Type 3 and Type4, along with reversed profiles are also identified (Figure F).
- Figure G illustrates classified RL wind profiles.











- Instantaneous radiosonde measurements also demonstrate LLJ wind profile evolution; with the LLJ core extending near 500m (Figure H).
- Directional wind shear increases as winds increase overnight (Figure I)
- Virtual Potential Temperature (VPT) with height suggests a shallow stable layer develops near the surface as winds transition towards LLJ feature; despite cooling temperatures (Figure J)

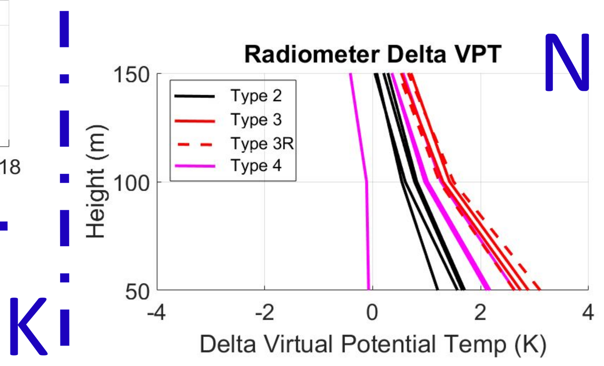
Rotor-Layer Wind & Stability Classification :

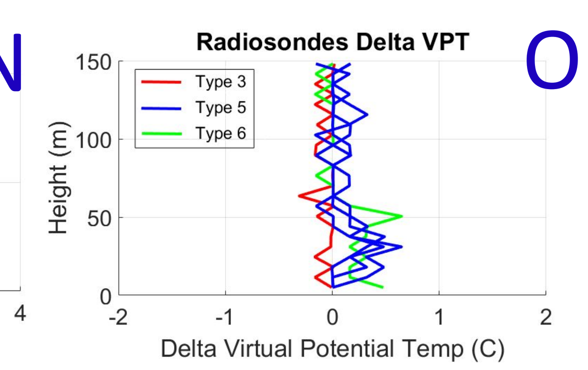
L

RL Wind Type (40-150m) (lidar)	Rotor-Layer Stability Term (radiometer)	Hub-Height Wind Speed (~60m)	Hub-Height Wind Direction (~60m)
Weak Inflections	2.37	10.90	340.15
Strong Inflections	3.40	9.89	292.16
Strong Inflections *Reverse	4.80	6.97	177.77

M

Time (UTC)	RL Wind Type (5-150m)	Rotor-Layer Stability Term	Hub-Height Wind Speed (~72m)	Hub-Height Wind Direction (~72m)
00:00	3	-1.49	9.9	175.6
1:30	6	2.21	10.3	168.4
3:00	5	2.48	11.6	170.4
4:30	5	2.38	11.5	165.4
6:00	5	2.21	11.7	171.6





- Compared to weak inflection types, lidar and radiometer results suggest strong inflection Types 3-6 are associated with higher stability on average (higher RLS terms), as well as slightly weaker hub-height winds and more westerly flow (Figure L)
- Classified radiosonde data demonstrates only strong inflection Types 3-6; however also with high RLS terms (Figure M)
- Delta VPT values, which comprise the RLS term, further elucidate the greatest change in VPT with height occurs at lower heights; suggesting the important role of the stable surface layer and atypical RL winds (Figure N & O)

CONCLUSIONS

- Classifying RL wind profile shapes proved to be a helpful tool for quantifying the wind resource during non-logarithmic, atypical conditions; and therefore has the potential to help reduce wind resource uncertainties that contribute to wind farm underperformance bias.
- Future stability analyses will incorporate more LLJ events from PECAN along with higher measurement heights to understand the broader impact of atmospheric stability on RL wind conditions during LLJ events
- Further, future work will calculate the impact of LLJ events on estimated turbine available power using REW methods.

ACKNOWLEDGEMENTS

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[1] Clifton et al. "Wind Plant Preconstruction Energy Estimates: Current Practices and Opportunities." NREL (2016); [2] Wagner et al. 2011, "Accounting for the speed shear in wind turbine power performance measurement", Wind Energy 12 348–62; [3] Choukulkar et al. 2014.,"A New Formulation of Equivalent Wind Speed and Power Calculations Using Data from the High Resolution Doppler Lidar", AMS conference paper