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Best practices for quantifying, interpreting, and utilizing atmospheric stability measurements using standard wind resource assessment sensors and CFD simulations

WindSim User Meeting 2018

Objectives

- Review state-of-the-art methods for measuring, modeling, and classifying atmospheric stability.
- Identify improved atmospheric stability metrics from existing wind resource assessment sensors.
- Recommend best practices for accounting for stability effects in numerical models.

Field test sites

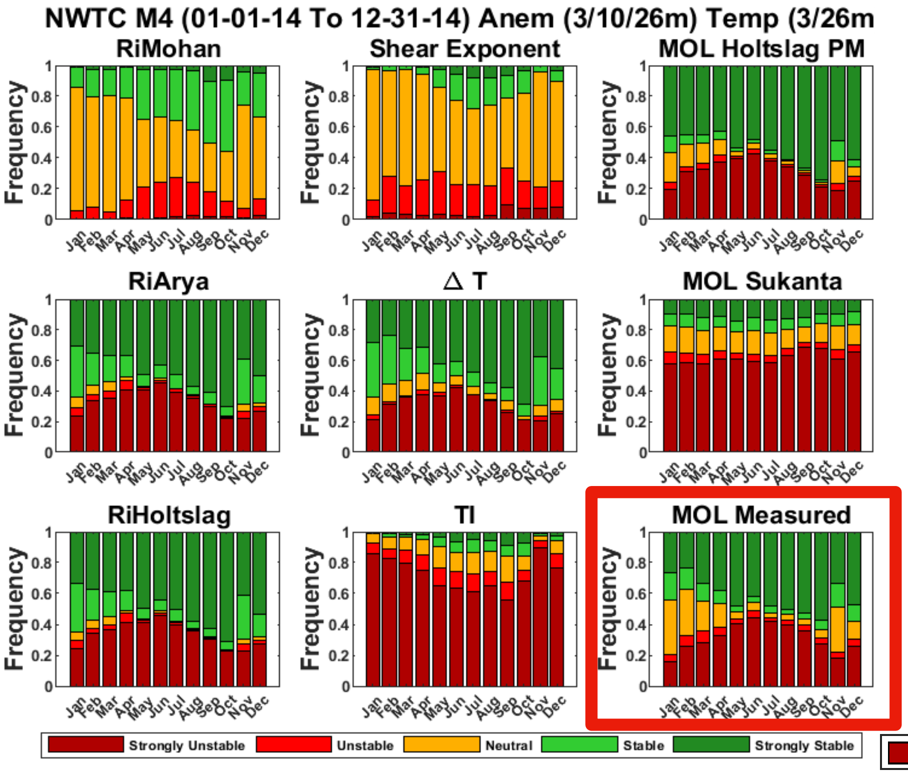
Field Test Sites	Location	Terrain	Meteorology	Number of Met Masts (Height)	Wind Speed Sensors	Temperature Sensors
NWTC	Colorado US	Flat	Thermally driven flow	2 (135m)	ATI Sonic, Thies FCA, Met One 5-6 levels	Met One
Site 2	Northern Europe	Medium complexity, Forested	Cold winter climate, stable conditions	6 (100m & 120m)	Thies FCA (50m/60m, 75m/80m and 100m/120 m) WindCube LiDAR	NRG 110S at 10m/15m and 100m/120m
Site 3	South Africa	Complex	Thermally driven flow	3 (80m)	Thies FCA at 40m/60m/80m	NRG 110S at 5m/80m on 2 masts
Site 4	Northern Europe	Medium complexity, Forested	Cold winter climate, stable conditions	1 (80m) 3 (100m) 1 (120m)	Thies FCA at 50m/60m, 75m/80m, and 100m	5m/98m on 1 mast
Site 5	North America	Medium complexity	Thermally driven flow	(6) 60m	Thies FCA at 20m/40m/60m	Thies 3m/58m on 2 masts

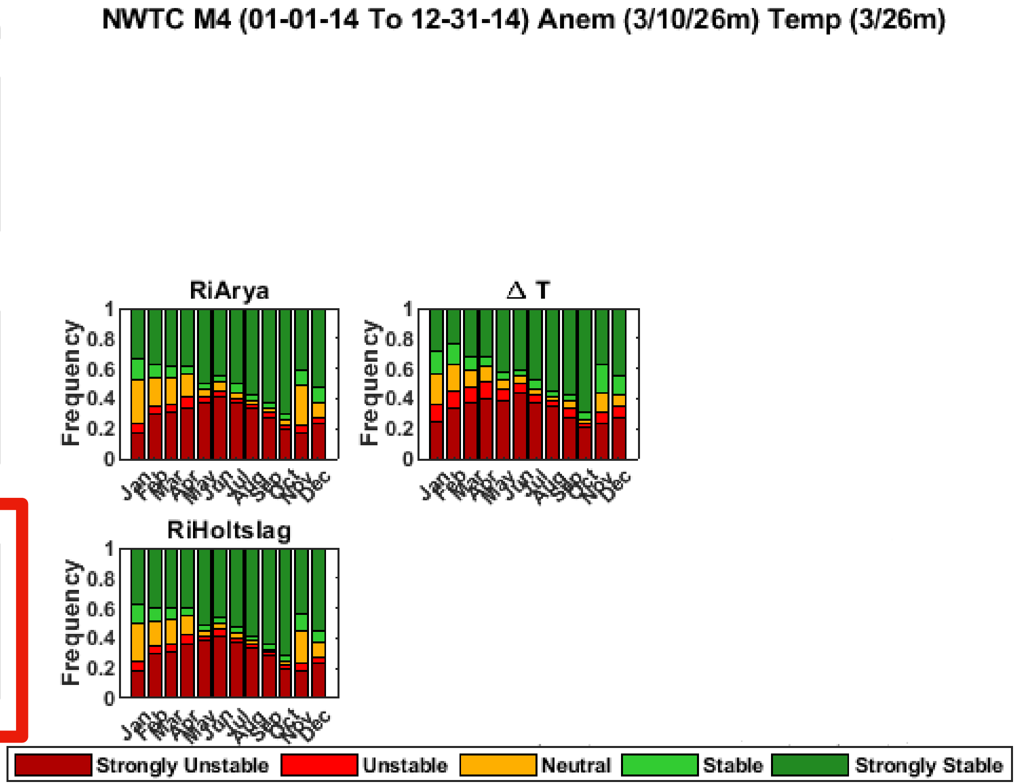
Atmospheric stability and its metrics

Stability classes (left to right on each scale): Strongly Unstable | Unstable | Neutral | Stable | Strongly Stable

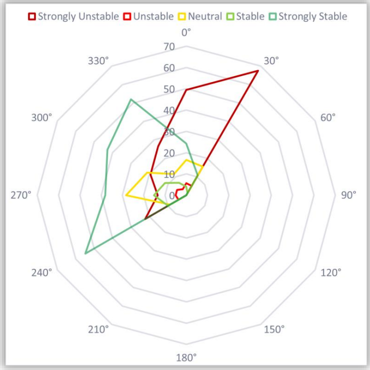
Delta-T	$\frac{dT}{dZ} = 100\frac{\Delta T}{\Delta Z}$	-∞	-1.5	-0.5	0.4	1.4	∞
Shear Exponent	$\alpha = \frac{\ln\left(\frac{v_u}{v_l}\right)}{\ln\left(\frac{h_u}{h_l}\right)}$	-∞	-0.14	0.1	0.17	0.25	∞
Turbulence Intensity	$TI = \frac{\sigma}{\overline{\overline{U}}}$	∞	18%	15%	12%	8%	0
Richardson Number (Ri_g)	$Ri_g = \frac{g\Delta\overline{\theta_v}(\Delta z_{anem})^2}{\Delta z_{temp}\overline{\theta_v}(\Delta\overline{u})^2}$	-∞	-0.07	-0.01	0.04	0.08	∞
Monin-Obukhov Length (MOL)	$L = \frac{-\overline{\theta}_v u_*^3}{kg\left(\overline{w\theta_v'}\right)} = \frac{\overline{\theta}_v u_*^2}{kg\theta_*}$	0	-213	-417	417	189	0

Atmospheric stability metrics





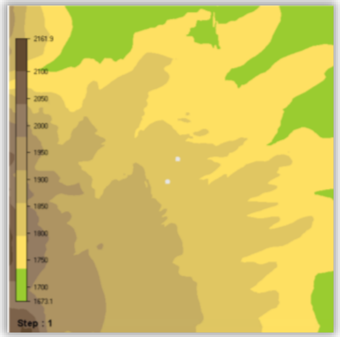
CFD numerical modeling with stability



Select tower met mast least influenced by terrain

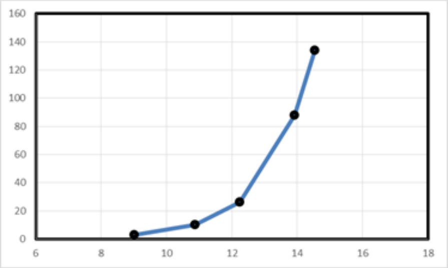
Verify Vortex data represents well the wind rose by direction and if measurements are available, stability class

Generate Vortex Series (wind speed and rate direction, MOL, Ri)



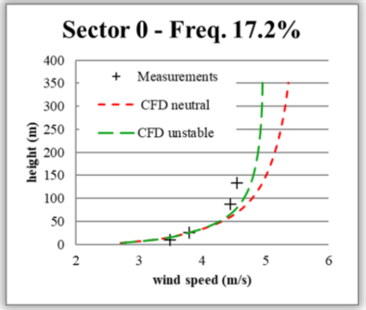
Run CFD with neutral stability

Impose stability profile



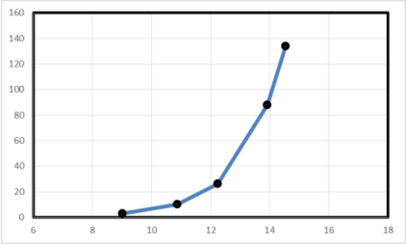
Run CFD with stability

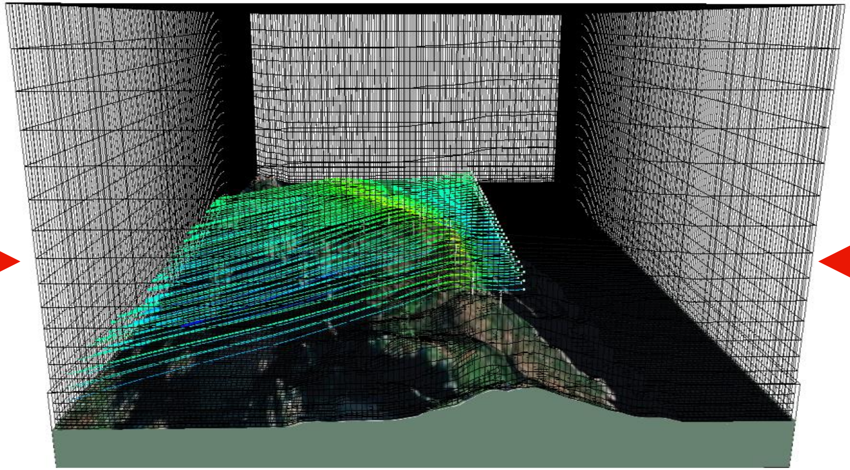
Cross-predictions

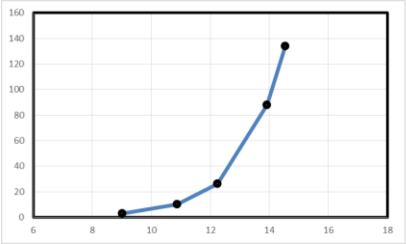


CFD numerical modeling with stability

CFD modeling applies neutral profiles



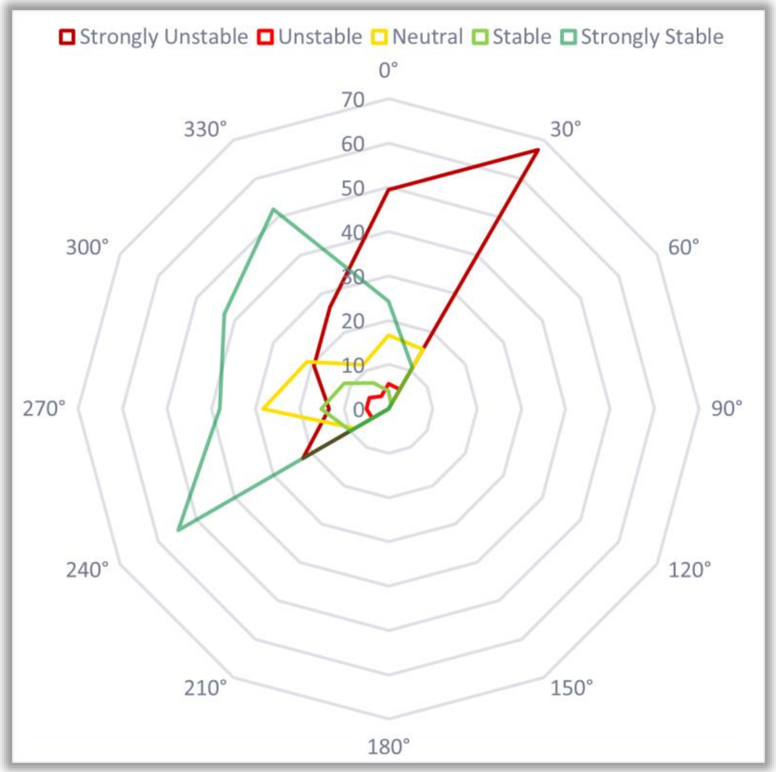




- Proposed adding stable or unstable profiles when:
- Wind rose binned by stability shows an imbalance.

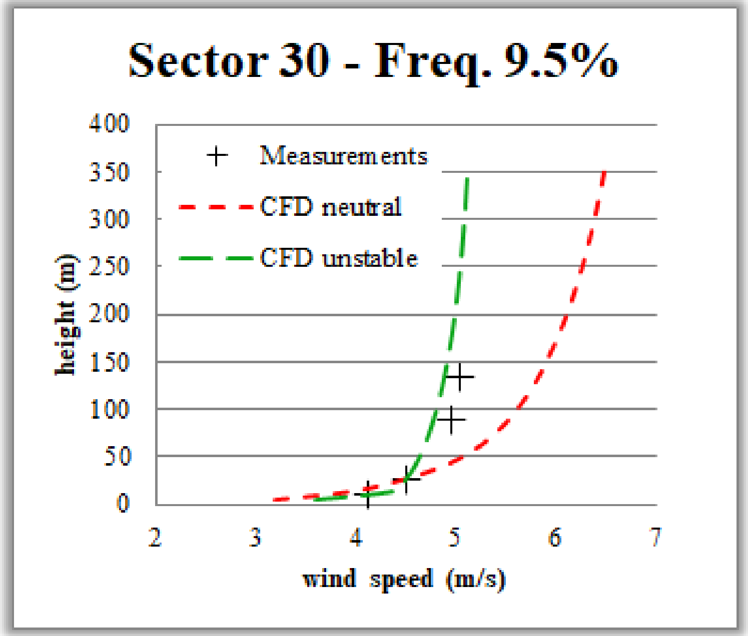
CFD numerical modeling with stability

- Apply stable/unstable boundary conditions when imbalance observed.
- Stability from sensors and Vortex Series data.

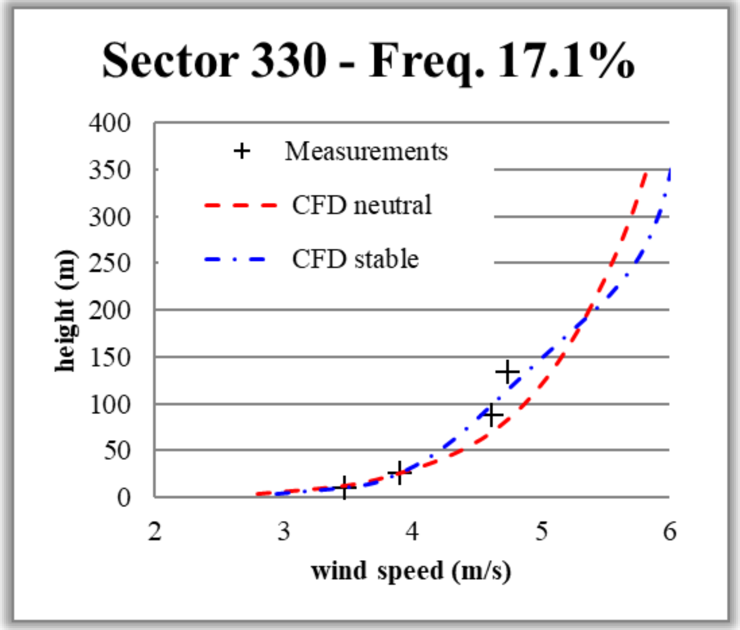


CFD numerical modeling at NWTC

Model with unstable conditions

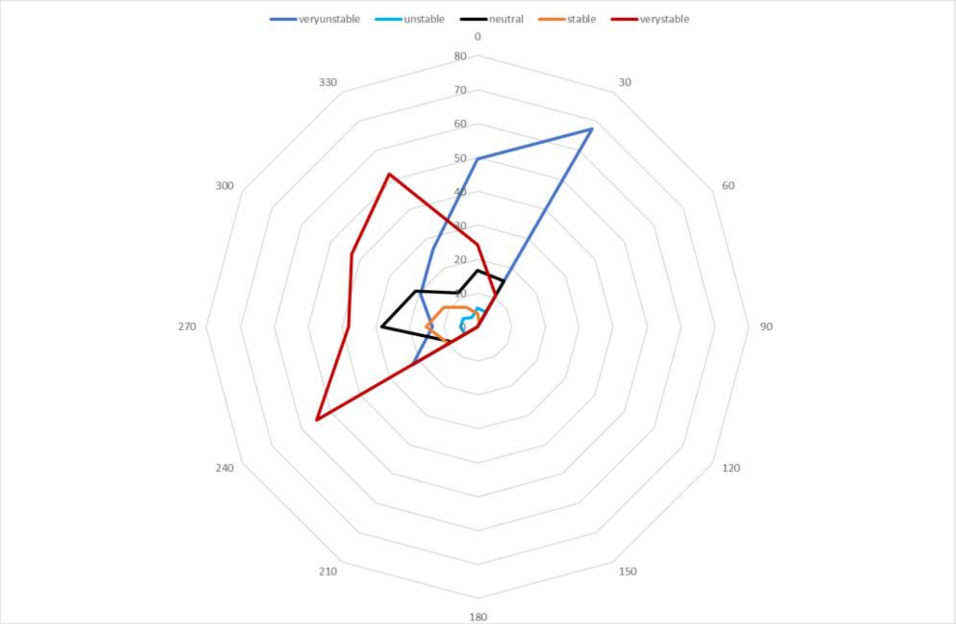


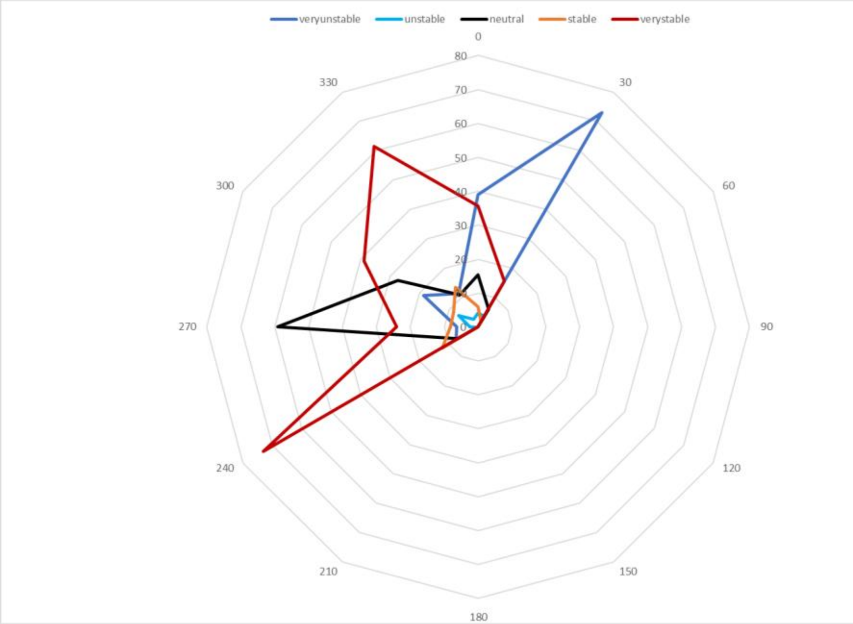
Model with stable conditions



CFD results improve when accounting for atmospheric stability

Using modeled stability information in CFD



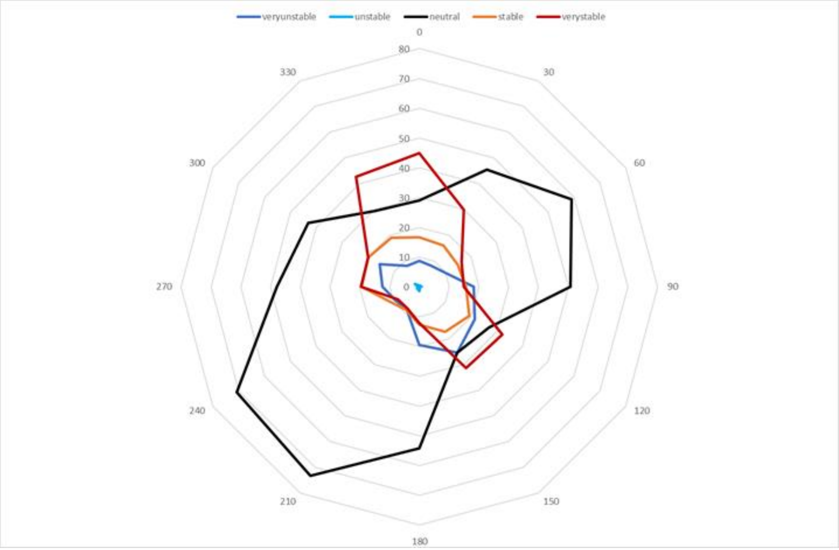


Measured MOL

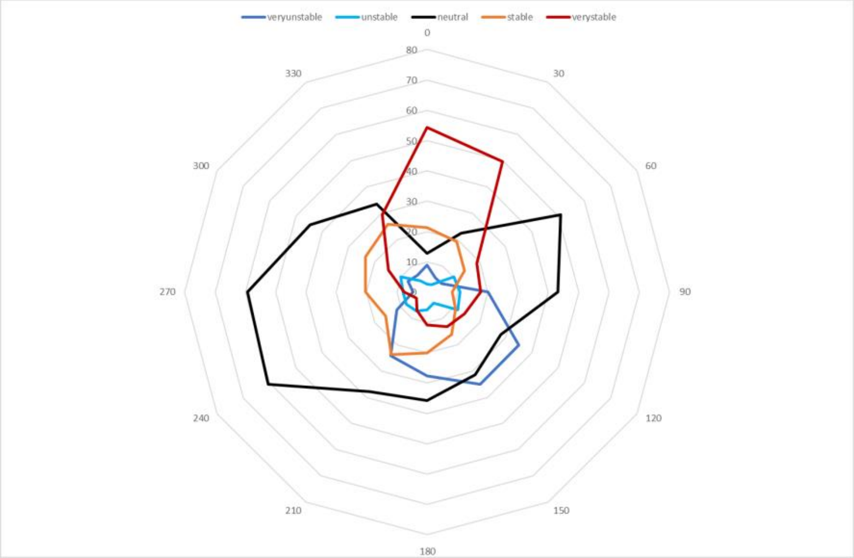
Modeled MOL

- Vortex MOL is calculated near the ground and therefore it is necessary to be careful in using.
- Vortex MOL can be a good complement when measured data has gaps.

Using modeled stability information in CFD



Measured Ri



Modeled Ri

- Vortex Ri can be calculated for every 20m using available speed and temperature data.
- If measurements are available at the same height as Vortex, then Vortex Ri can be a good complement for the measured data when there are data gaps in the measured

Summary of CFD modeling results

Field Test Sites	Location	Terrain	Meteorology	CFD Simulations Incorporating Atmospheric Stability
NWTC	Colorado US	Flat	Thermally driven flow	Improvement in Results
Site 2	Northern Europe	Medium complexity, Forested	Cold winter climate, stable conditions	Improvement in Results
Site 3	South Africa	Complex	Thermally driven flow	Improvement in Results
Site 4	Northern Europe	Medium complexity, Forested	Cold winter climate, stable conditions	N/A • Balanced wind rose • Good neutral-stability CFD results
Site 5	North America	Medium complexity	Thermally driven flow	N/A • Balanced wind rose • Good neutral-stability CFD results

Conclusions

- Accurate atmospheric stability prediction can be made using Richardson number (Arya and Holtslag), ΔT, and the MOL (Holtslag).
- Accurate stability measurements requires 2 levels of wind speed and temperature sensors in the surface layer; 10-minute statistics sufficient.
- Unsupervised machine learning successfully automated stability criteria.
- Use of modeled stability data in a sector-wise basis is a good complement when measured data is not available but it is not a substitution for the actual measurements.
- Developed a method for incorporating measured and modelled stability into CFD models, resulted in improved model predictions at 3 sites.

NRG Systems windsim e·on VORTEX

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