PO. 210

Effects Of Varying Atmospheric Stratification On Vertical Wind Profile and Energy Yield In Complex Terrain

THEOLIA

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Abstract

• The neutral stratification approximation is commonly used for vertical wind profile interpolation/extrapolation and wind field modeling. This is often due to missing heat flux or thermal stratification measurement sets.

• However, consideration of stratification can influence dramatically both the vertical profile and the horizontal extrapolation of the wind field. These effects can change significantly the wind farm energy prediction and its variations in time.

• Mast data (with temperature measurements at several heights) from three different THEOLIA wind sites are interpreted here in terms of stability parameters and wind shear to reveal over-/underestimation in the energy production compared to the neutral stratification approximation.

Site and Stability Classification

For each site, the 10-min wind velocity time records are classified in stable, neutral and unstable conditions according to the measured potential temperature gradient.

Site 1 Germany **Site 2 France** **Site 3 Italy**

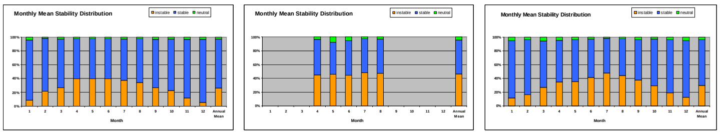


Fig. 1: Monthly stability distribution at different geographic sites and annual mean percentage of stable cases

Site 1, located in southern Germany, is in medium complex terrain, with dense, 30m-height forest. Stable cases range from 58-91% during the year, leading to **71%** average stability.

Site 2, located in southern France, is moderately hilly with no relevant impact from vegetation. Data are available only for the summer period and exhibit, uniformly, around **50%** stable cases. Thus, for this site, seasonality affects the stability percentages.

Site 3, located in central Italy, is in rough terrain with significant orographic effects on wind flow. On average, stable cases are **64%**. Winter months also are very stable.

Vertical Interpolation including Stability Parameters

For **Site 2**, the wind speed extrapolated to 72m with stable or neutral profile equations is compared to the according measurement values for stable cases (44.7% of the period from 1.4.-31.8.2010) after quality filtering the data. The aim was to validate the extrapolation with a stable profile of vertical wind speeds for the periods considered as stable.

	Input Parameters			Comparison Velocity Interpolation				Comparison Energy Yield				
	Fixed z0 (m)	Anemometers used for fitting (m)	Extrapolation to 72m from (m)	v_ext 72m (m/s)	v_meas 72m (m/s)	Relative Difference in Wind Speed	Standard Deviation of Relative Difference	Energy Production* from v_ext (MWh)	Energy Production* from v_meas (MWh)	Relative Difference in Production	Standard Deviation of Relative Difference	Median of Relative Difference in Energy
Stable 1	0.0697	60 - 50 -35	60	6.71	6.59	**1.86%**	4.14%	1021.08	983.58	**3.81%**	15.34%	0.79%
Stable 2	0.0697	60 - 50	60	6.63	6.59	**0.57%**	3.23%	994.26	983.58	**1.09%**	15.06%	0.90%
Neutral 1	0.0697	x	60	6.38	6.59	**-3.24%**	3.76%	913.68	983.58	**-7.11%**	11.11%	4.71%

Tab. 1: Comparison of different wind speed interpolation and energy output. *Energy production was calculated from a commercial power curve (2MW) for the stable periods indicated above.

Stable1: Profile fitted according to stable MOL and 60,50 and 35m Anemometer
Stable2: Profile fitted according to stable MOL and 60 and 50m Anemometer
Neutral1: Logarithmic profile with fixed z0, extrapolated from 60m Anemometer

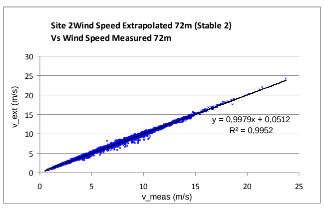


Fig. 2: Correlation of measured and interpolated velocities for stable cases

Main findings:
Stable fitting achieves better results than neutral.

Neutral profile tends to underestimate wind speed in case of stable conditions.

Accuracy can be improved by neglecting the 35m Anemometer (effected by trees in the North.

Horizontal Windfield Modification with CFD

CFD simulations with neutral and stable stratification are compared for Site 2:
• In the stable stratification the vertical wind shear is increased towards neutral simulation. This yields to increased mean wind velocities at 100m height.
• The stable flow behaves differently, indicating more blocking, separation, recirculation or channelling effects.

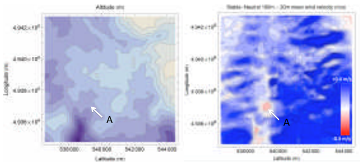
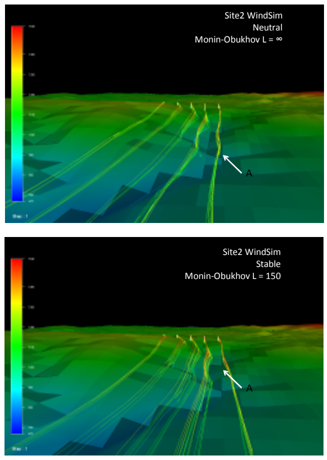


Fig. 3: Site 2, elevation model and spatial distribution of wind shear difference (stable vs. neutral)

Wind shear increase is evident over most of the observed region, whereas its magnitude changes according to individual flow modification. In areas negative trend, we observe some channelling/circulation phenomena in the stable flow.



Investigation of some areas with negative trend in wind gradient for stable cases for the example of **area A** (valley) reveal some typical flow characteristics:

- Significant channelling of the low-height stable flow into the valley
- Acceleration of velocities in lower heights
- Decreased differences between 100m and 20m wind velocities

Fig.4: Example for area A from Fig.3, streamlines (north-south) and their orographic modification in neutral and stable cases

Differences in Energy Output

	WINDSIM neutral model								WINDSIM stable model		
	Neutral wind records			All wind records		Unstable wind records			Stable wind records		
	1 WTG at mast [GWh]	Wind farm [GWh]	% of time	1 WTG at mast [GWh]	Wind farm [GWh]	1 WTG at mast [GWh]	Wind farm [GWh]	% of time	1 WTG at mast [GWh]	Wind farm [GWh]	% of time
Site 1	3.6482	34.0070	2.82%	3.6051	32.0198	3.2781	28.83136	26.34%	4.1086	36.9838	70.84%
Site 2	7.4088	79.3120	4.80%	5.5990	57.8864	5.7371	59.7497	45.29%	5.6001	57.7988	49.91%
Site 3	3.6242	32.2417	3.49%	3.6423	32.6095	3.4886	31.2642	32.89%	3.9292	34.7267	63.62%

Tab. 2: Energy output for WindSim simulations with different stability conditions and input data from different stability classes according to Fig.1

	MIX weighted according to stability distribution	
	Neut.+unstab. records + stable records	
	1 WTG at mast [GWh]	Wind farm [GWh]
Site 1	3.8768	34.7522
Site 2	5.7490	59.7153
Site 3	3.7736	33.5011

	MIX vs. Neutral model with all records	
	Relative difference	
	1 WTG at mast	Wind farm
Site 1	**7.5%**	**8.5%**
Site 2	**2.7%**	**3.2%**
Site 3	**3.6%**	**2.7%**

Tab. 3: Difference of stability weighted energy yield in comparison to the common neutral simulation with all data

Conclusions and Future Works

• We implemented a procedure for classifying, fitting and filtering stable, unstable and neutral wind measurements. The procedure provides good validation on Site2.

• The WindSim stable calculation exhibits different vertical shear and relevant flow modifications on the orography. For complex orographic sites it is important to consider stable stratification by appropriate shear fitting and CFD analysis.

• For our three sites, the classical neutral approximation yields a general energy **under-estimation of about 2-9%.** A geographical variation is observed but the site characteristics do not allow to find a trend.

• Future improvements include roughness length fitting (here z0 is fixed), directional z0, unstable CFD model, models sensitivity to M-O length range.

EWEA 2011, Brussels, Belgium: Europe's Premier Wind Energy Event