On the use of rotor equivalent wind speed to improve CFD wind resource mapping

Yavor V. Hristov, PhD
Plant Performance and Modeling
Vestas TSS

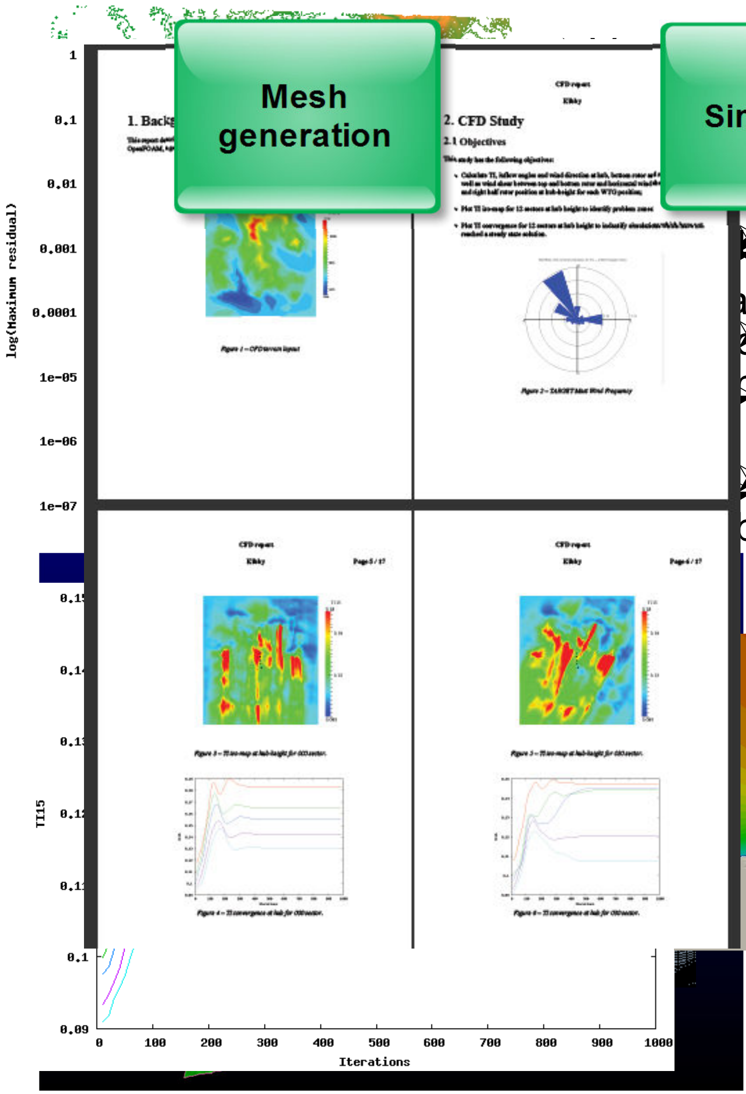
9/19/2013

Firestorm- Number 53 on Top500 list from June 2011

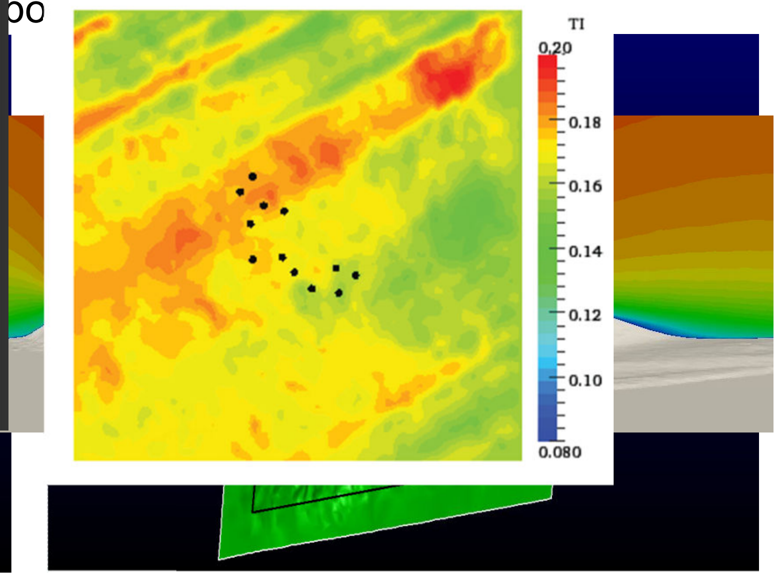
- 14664 processors on 1222 hosts each with 2 Intel X5670 (hex core) processors and 24 GB memory
- 24 GPU’s with 192 GB RAM and M2070Q graphic card
- 4xQDR (40Gbit) Infiniband network
- 2.6 PetaB fast parallel storage
- 150+ TFLOP/S
- Energy consumption -0.5 MW, cooling only uses 10% of the power

VestasFOAM- CFD process based on OpenFOAM

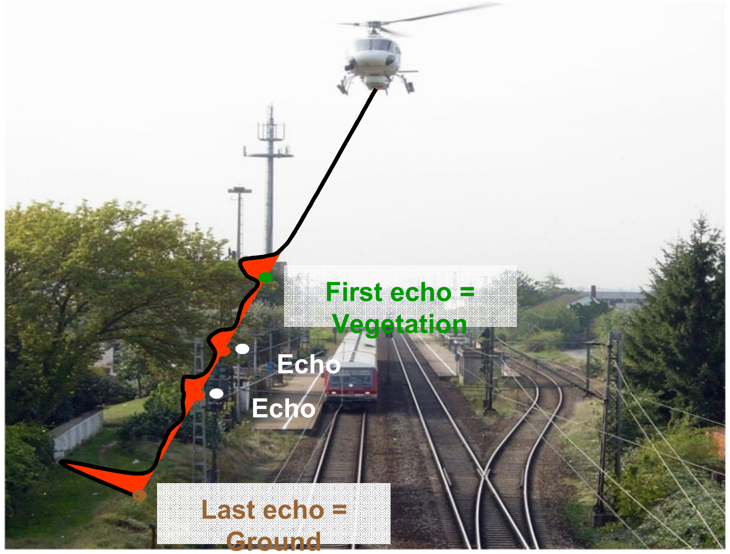
Terrain pre-processing → **Mesh generation** → **Simulation** → **Post-Process**

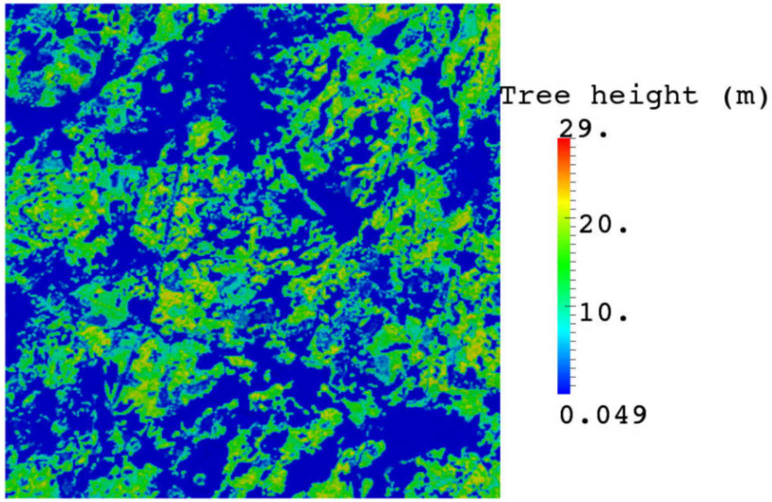


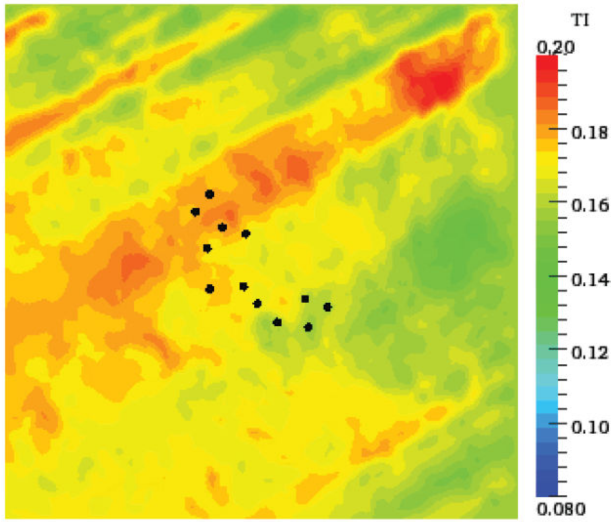
➢ Vestas Site Check input for Load calculations
➢ wind flow parameters at hub height for resource map calculations
➢ standard ABL steady profiles
➢ k-epsilon turbulence model with modified constants
➢ customized inlet/outlet and terrain
➢ unstructured meshing also available

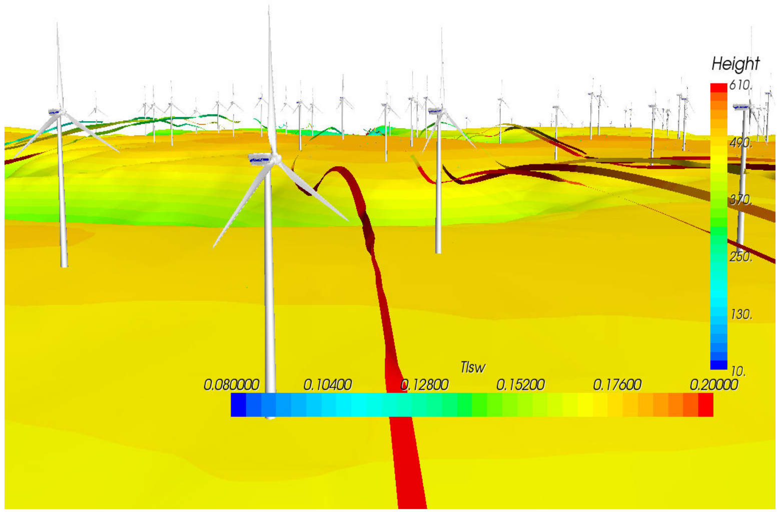


Level 2- VestasFOAM special cases- forest, extremely complex terrain…









Level 3- Unsteady (Hybrid RANS/LES) simulations with VestasFOAM

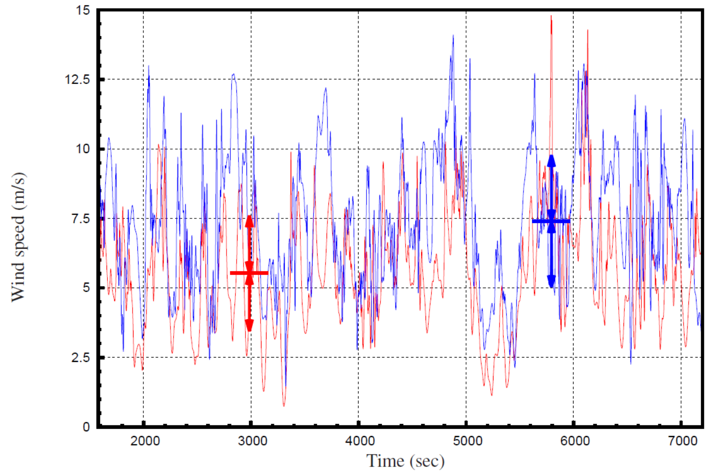


Figure A.53. Time histories of wind speed for WTG14: ——, rotor bottom; ——, rotor top. Horizontal bars and vertical arrows denote mean and standard deviation, respectively.

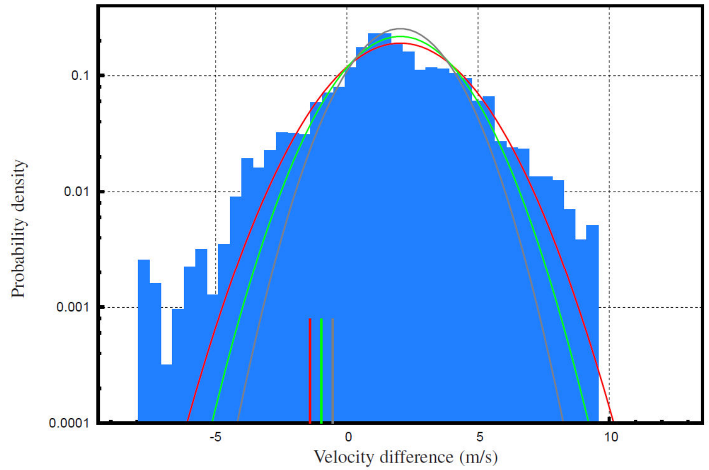


Figure A.54. Velocity-difference PDF between rotor top (140m) and bottom (28m) for WTG14: ——, IEC turbulence class A; ——, B; ——, C. Vertical lines denote the threshold values for *extreme* negative wind shear, which are based on the one-tailed significance level of 5%.

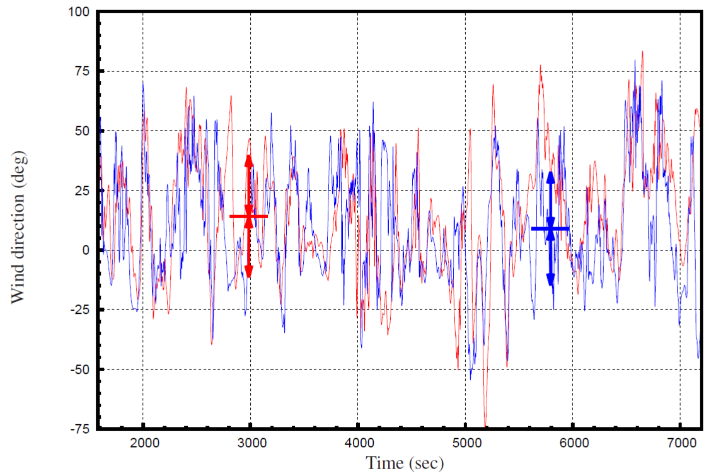


Figure A.55. Time histories of wind direction for WTG14: ——, rotor bottom; ——, rotor top. Horizontal bars and vertical arrows denote mean and standard deviation, respectively.

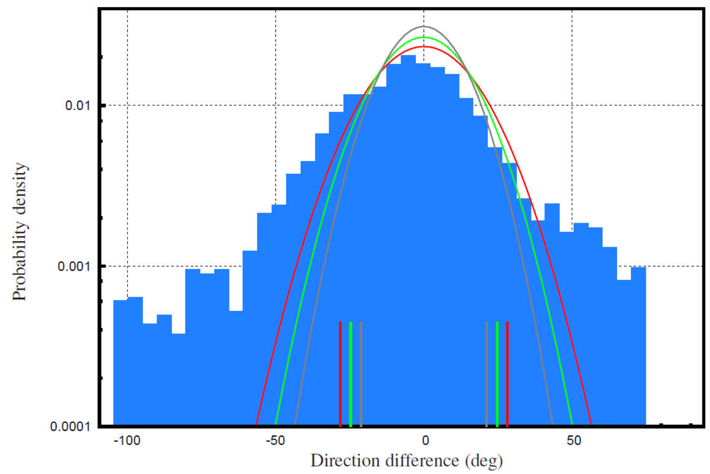
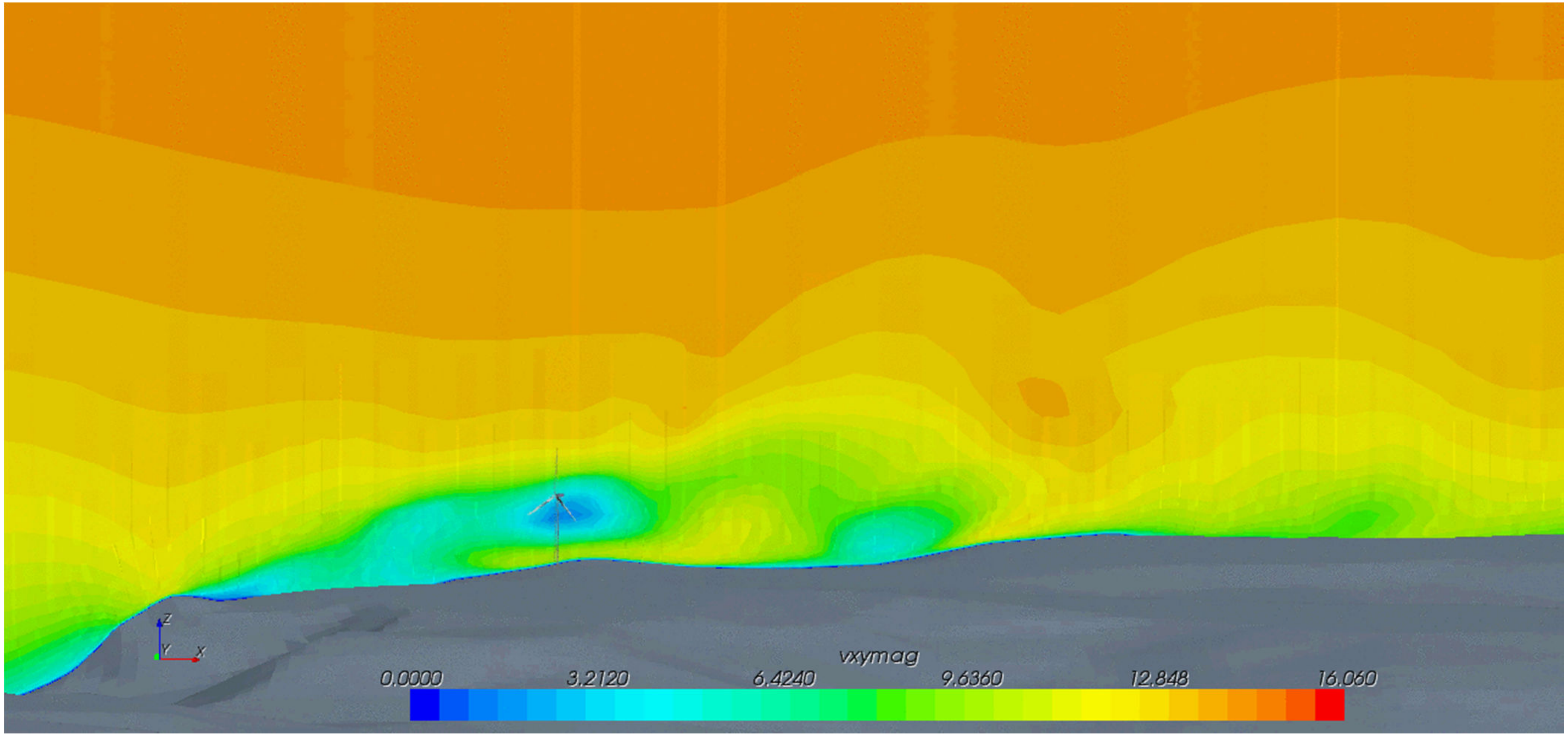


Figure A.56. Direction-difference PDF between rotor top (140m) and bottom (28m) for WTG14: ——, IEC turbulence class A; ——, B; ——, C. Vertical lines denote the threshold values for *extreme* wind veer, which are based on the one-tailed significance level of 5%.

ld to us.™

Level 3- Unsteady (Hybrid RANS/LES) simulations with VestasFOAM

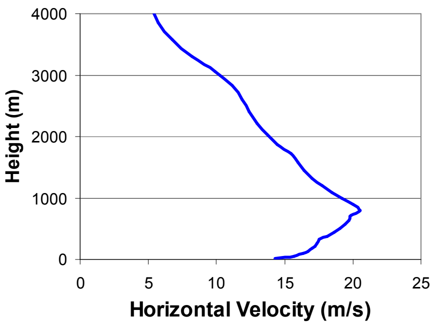


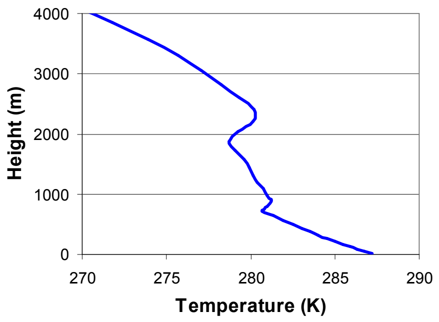
Level 4 – Mesoscale- CFD coupling

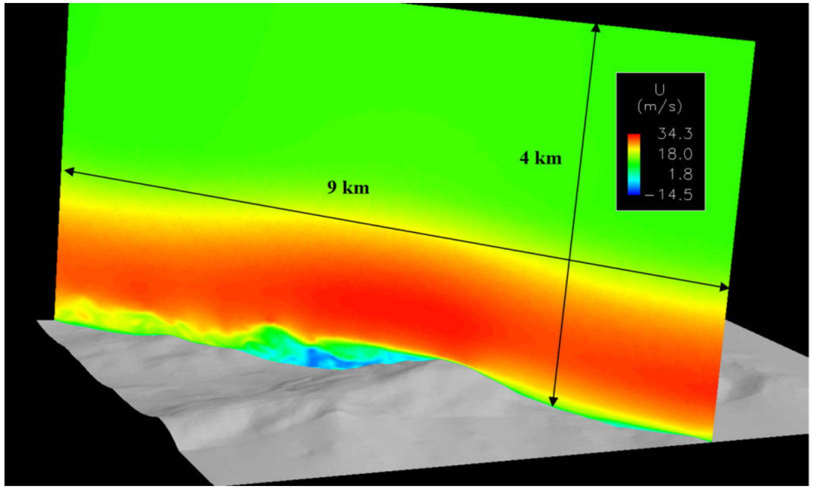
Atmospheric boundary layer stability considered

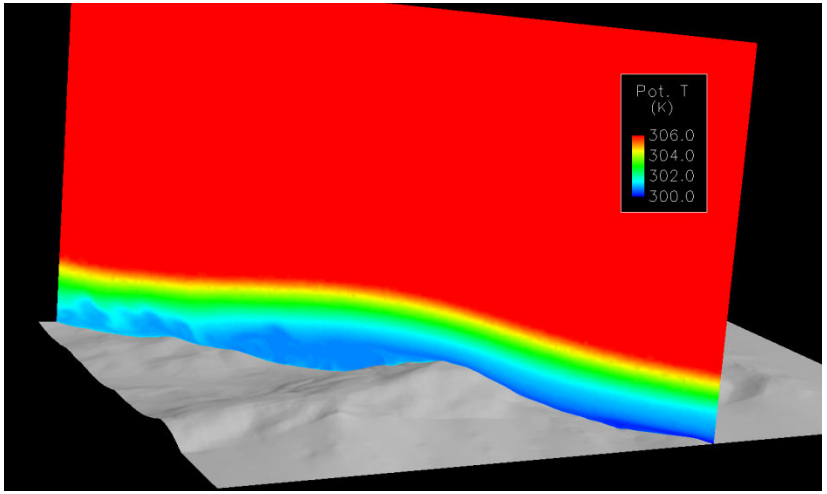
- Customized *buoyantBoussinesqPimpleFoam*
  - surface heat flux
  - buoyancy Boussinesq approximated
  - DES turbulence model

- temperature and velocity profiles obtained from WRF



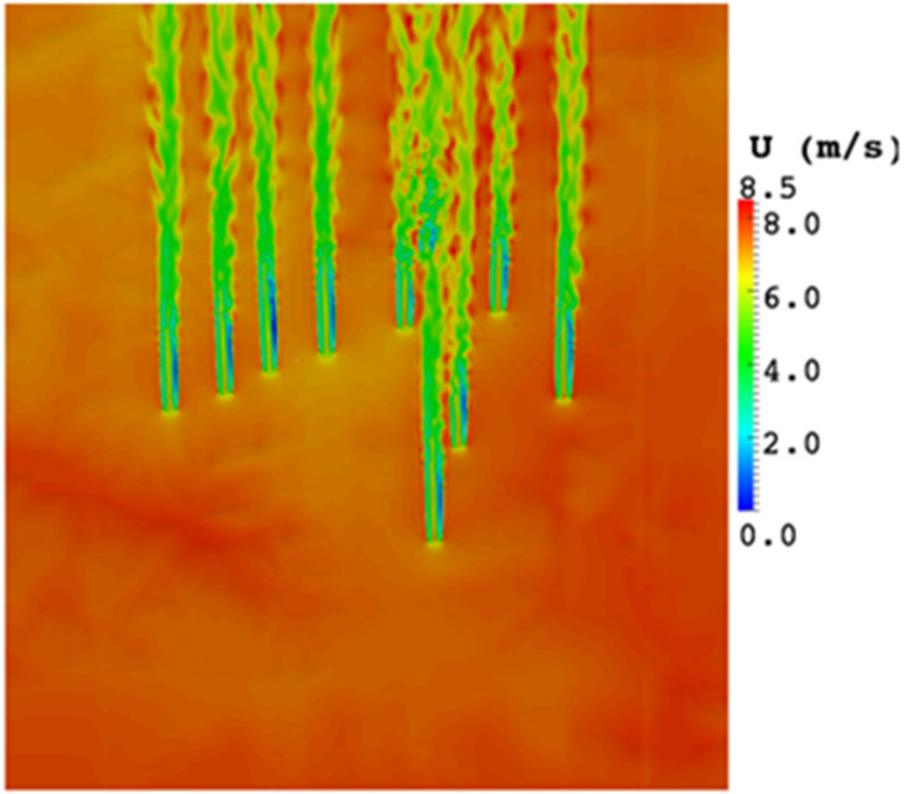






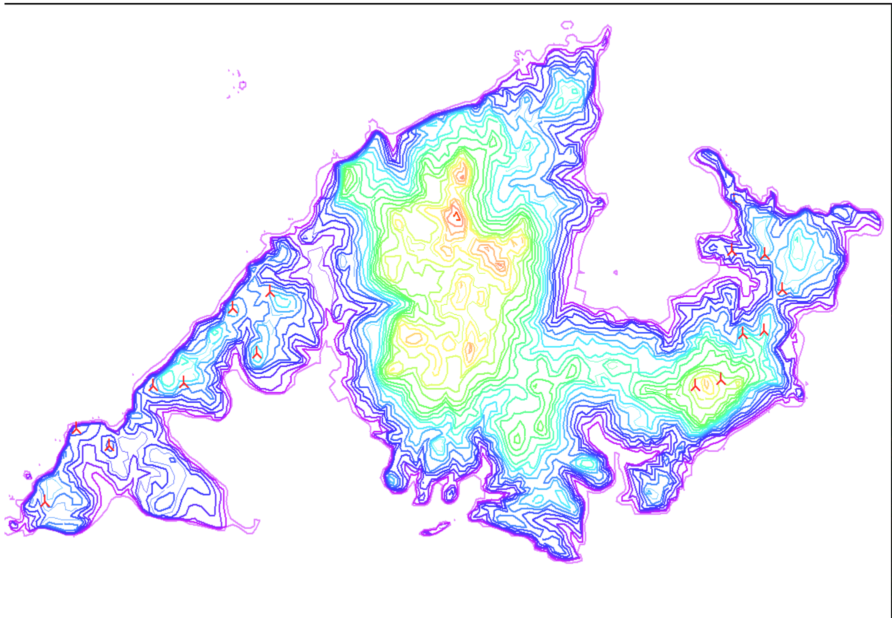
Level 5 – Mesoscale- CFD - ALM coupled model

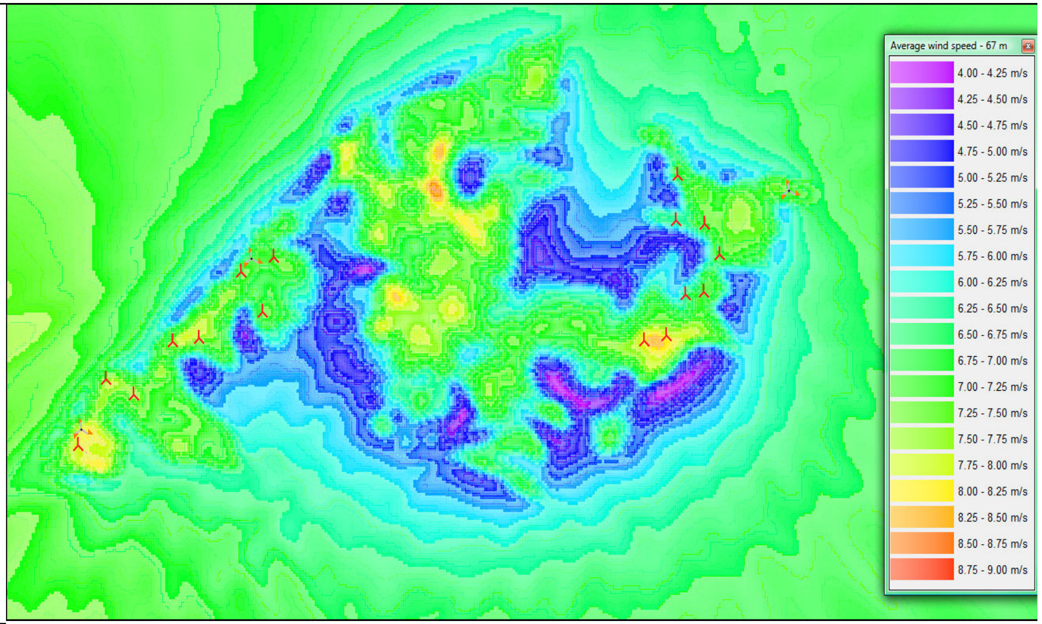
- When mesoscale data indicates predominant non-neutral conditions, mesoscale profiles are dynamically coupled with CFD (LES) in order to link real-wind with the microscale domain. In addition turbine wake interactions are investigated using actuator line modeling.



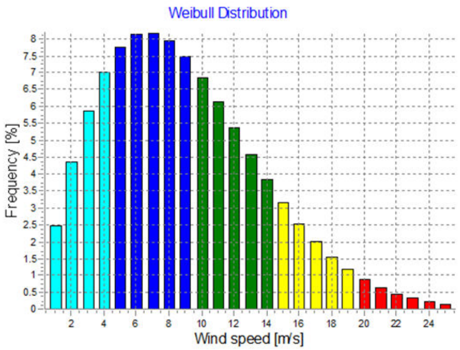
CFD wind resource mapping validation based on 50 projects in operation

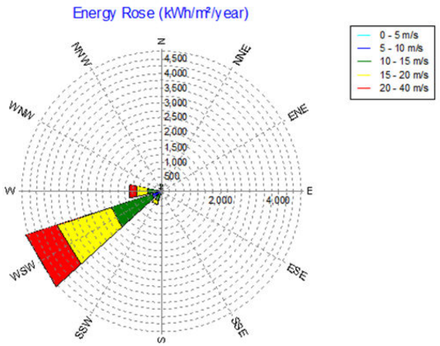
- Run 36 sectors CFD simulation
- Multiple masts Long term corrected to Vestas 13 year mesoscale WRF model data
- Extrapolation of mast data to hub height according to CFD predicted wind shear
- Scaling CFD wind velocity field to match measurements at mast positions
- Inverse distance interpolation together with directional wind distribution frequencies for each met mast is used to calculate the Weibull parameters with 25 m resolution
- Creating RSF file
- Annual production based on SCADA data extracted and compared to CFD predicted AEP

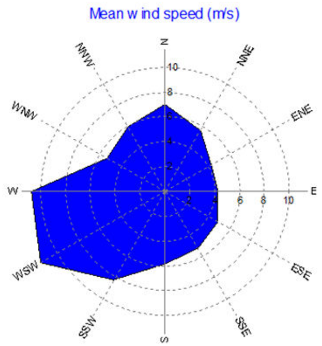


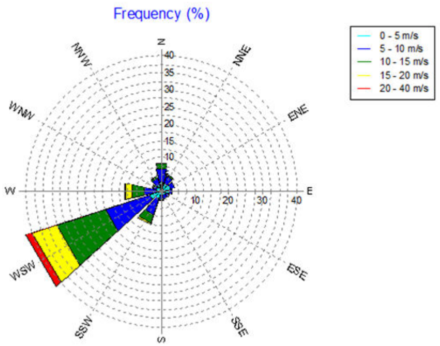


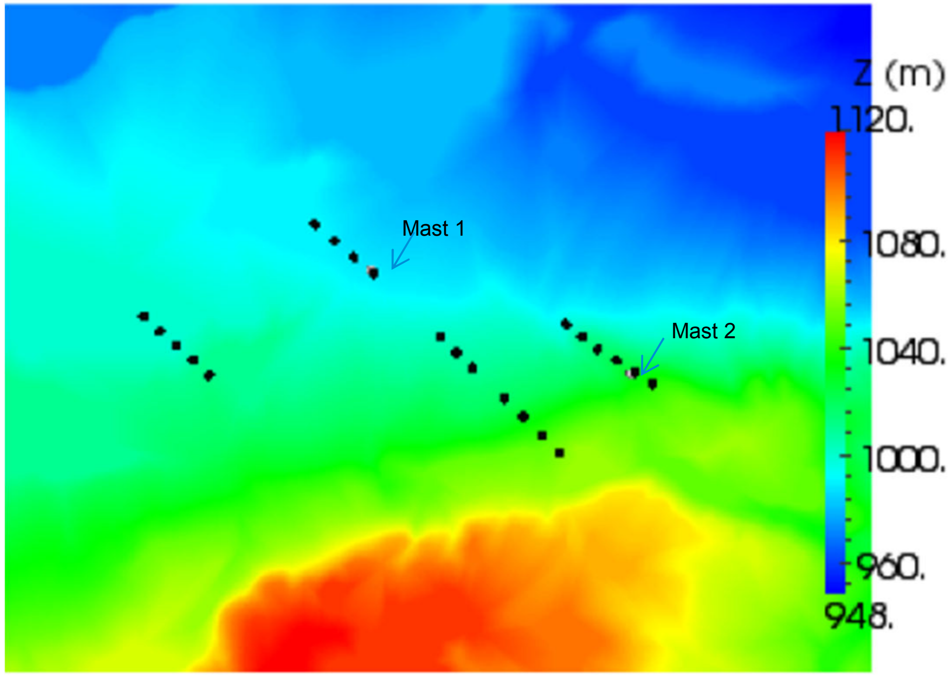
Vestas site 22 V90-3MW with HH 80 m



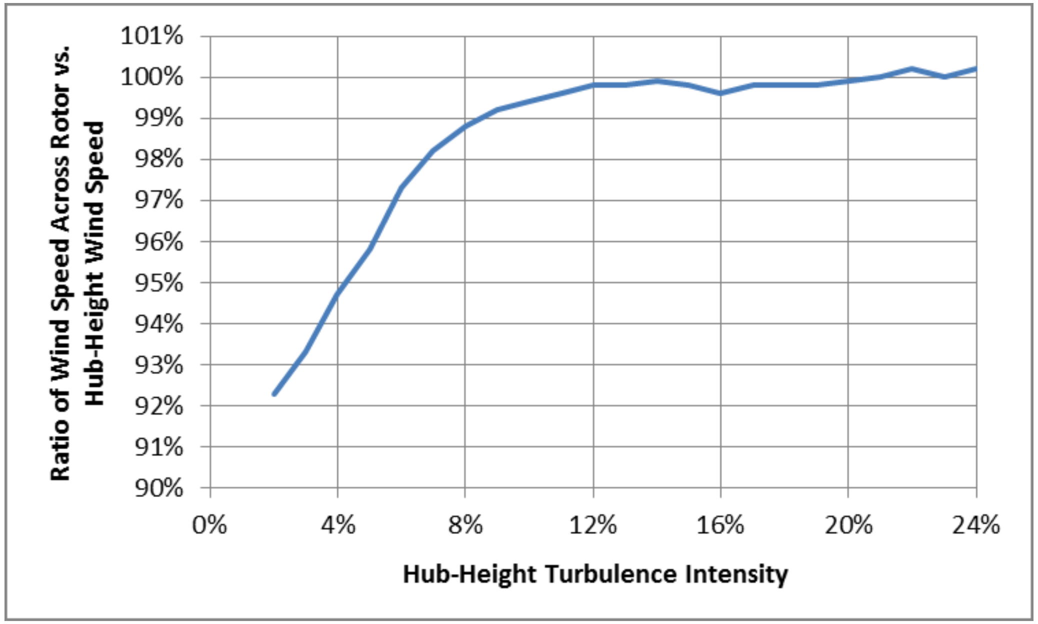




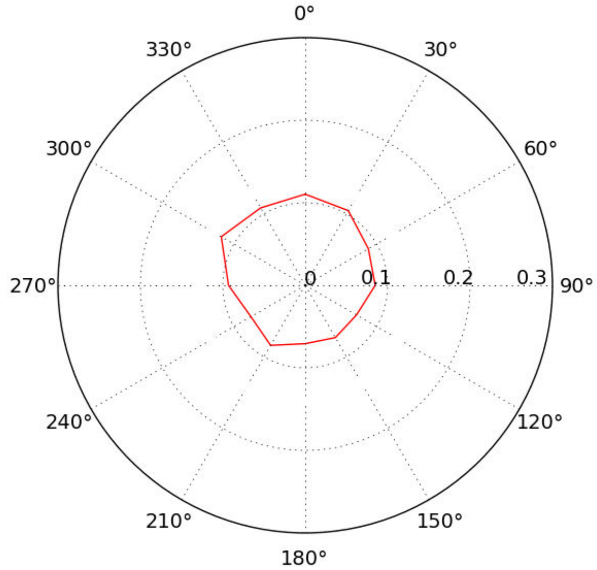




Mast 2 60 m adjustment of wind speed



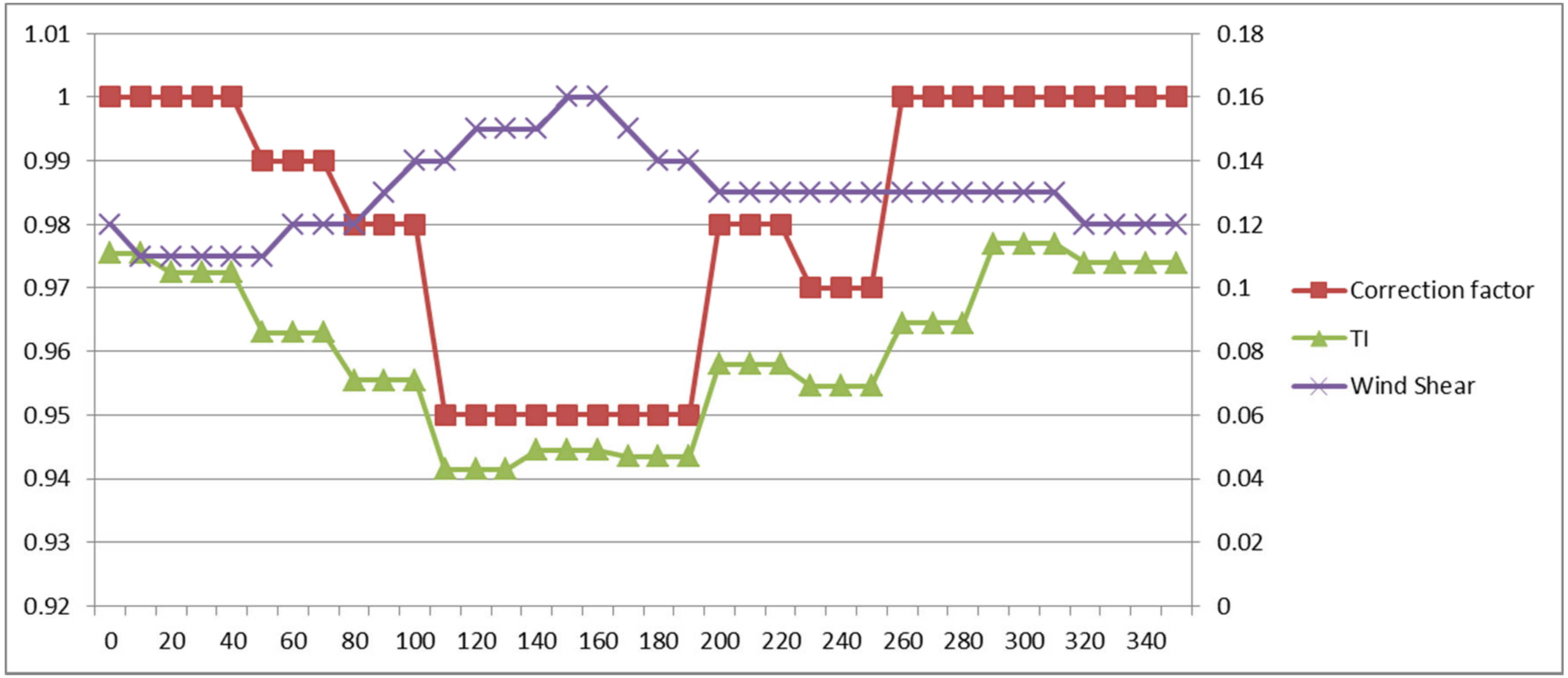
Reference correction function for Mid-West USA



Turbulence intensity measured at Mast 2

Anna Marsh, 2013 “Resource Assessment Methods Incorporating Rotor Equivalent Wind Speed, Density and Turbulence on a Time Step Basis”

Mast 2 60 m adjustment of wind speed



deg	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
Correction	1	1	1	1	1	0.99	0.99	0.99	0.98	0.98	0.98	0.95	0.95	0.95	0.95	0.95	0.95	0.95
TI	0.111	0.111	0.105	0.105	0.105	0.086	0.086	0.086	0.071	0.071	0.071	0.043	0.043	0.043	0.049	0.049	0.049	0.047
Wind Shear	0.12	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.13	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.15

deg	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
Correction	0.95	0.95	0.98	0.98	0.98	0.97	0.97	0.97	1	1	1	1	1	1	1	1	1	1
TI	0.047	0.047	0.076	0.076	0.076	0.069	0.069	0.069	0.089	0.089	0.089	0.114	0.114	0.114	0.108	0.108	0.108	0.108
Wind Shear	0.14	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12

Correction factors, TI measured and CFD simulated Wind Shear per sector

Validation of CFD predicted AEP

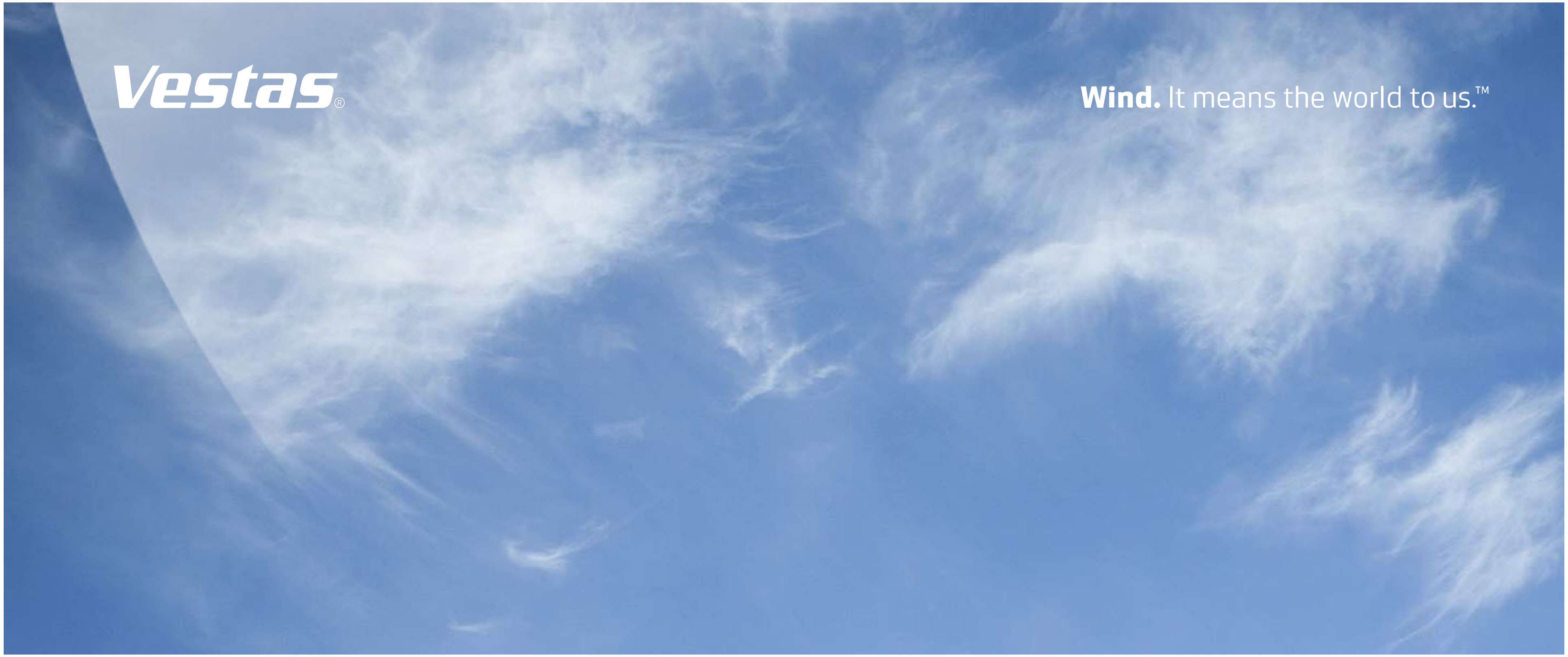
WTG	AEP	CFD AEP	CFD AEP_REWS	Error CFD	Error CFD_REWS	i
1	8.798	10.373	10.225	17.90%	16.22%	
2	8.832	10.315	10.152	16.79%	14.95%	
3	8.756	10.221	10.048	16.73%	14.76%	
4	9.044	10.374	10.210	14.71%	12.89%	
5	9.166	10.531	10.336	14.89%	12.76%	
6	8.988	10.301	10.116	14.61%	12.55%	
7	8.665	10.166	9.956	17.32%	14.90%	
8	8.646	10.109	9.889	16.92%	14.38%	
9	8.757	10.098	9.892	15.31%	12.96%	
10	9.048	10.419	10.219	15.15%	12.94%	
11	9.117	10.400	10.188	14.07%	11.75%	
12	9.266	10.385	10.180	12.08%	9.86%	
13	9.209	10.445	10.236	13.42%	11.15%	
14	9.283	10.495	10.287	13.06%	10.82%	
15	9.586	10.572	10.383	10.29%	8.31%	
16	9.548	10.717	10.502	12.24%	9.99%	
17	8.761	10.078	9.854	15.03%	12.48%	
18	9.256	10.377	10.145	12.11%	9.60%	
19	9.290	10.386	10.160	11.80%	9.36%	
20	9.208	10.425	10.200	13.22%	10.77%	
21	9.458	10.408	10.189	10.04%	7.73%	
22	9.527	10.613	10.381	11.40%	8.96%	
total	**200.209**	**228.208**	**223.748**	**13.98%**	**11.76%**	

Discussion

1. Can rotor equivalent wind speed relation to TI at the assessed site be used for other sites? Under what conditions?

2. What is the microscale/mesoscale phenomena behind strong correlation between wind shear and TI? Stable stratification leading to less mixing hence low TI and high wind shear typical for Mid-West US?

3. What is the uncertainty in deriving the rotor equivalent wind speed through integrating wind profiles based on mesoscale profiles across rotor plane?



Thank you for your attention