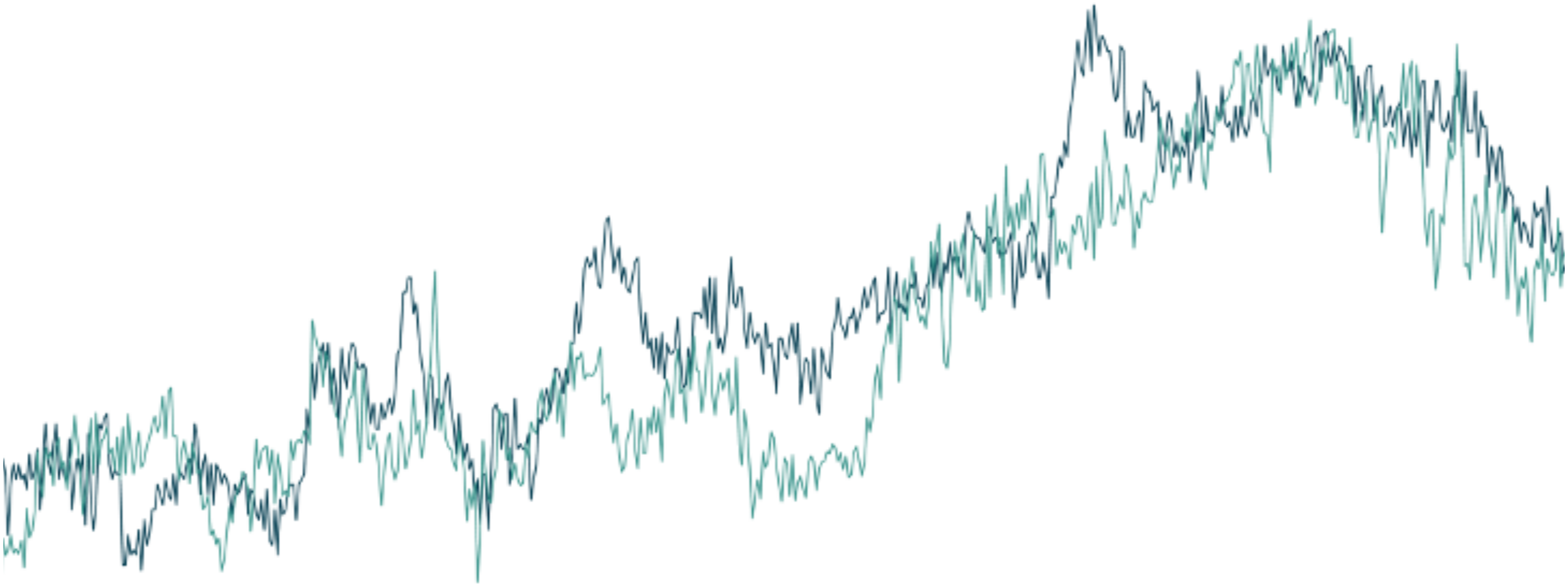
LES* IS MORE!

*LARGE EDDY SIMULATIONS BY VORTEX



WindEnergy Hamburg 2016

OUTLINE

MOTIVATION Pep Moreno. *CEO, Vortex*

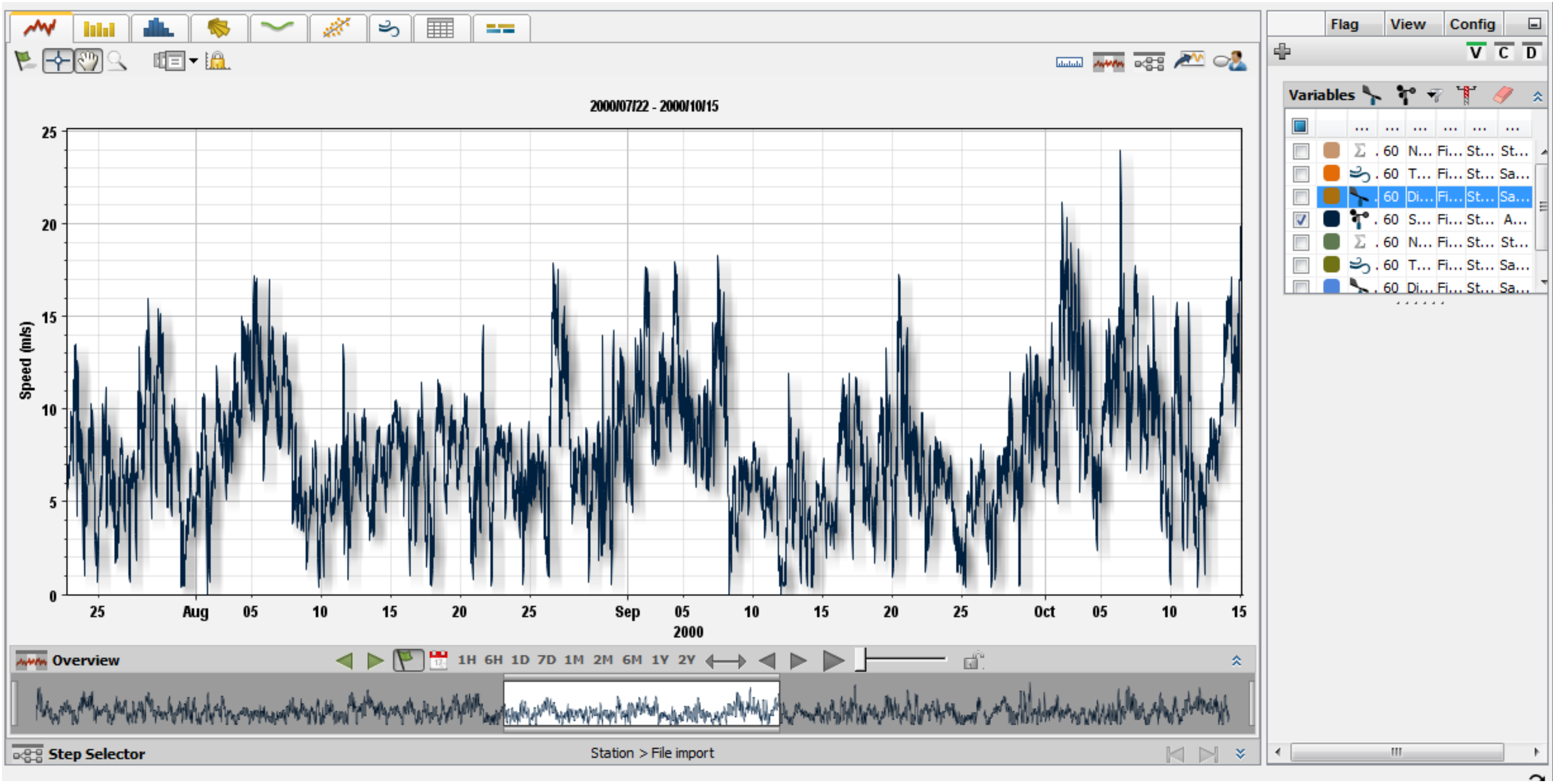
BASIS Alex Montornés. *Modelling Specialist, Vortex*

VALIDATION Mark Žagar. *Modelling Specialist, Vestas*

Q & A

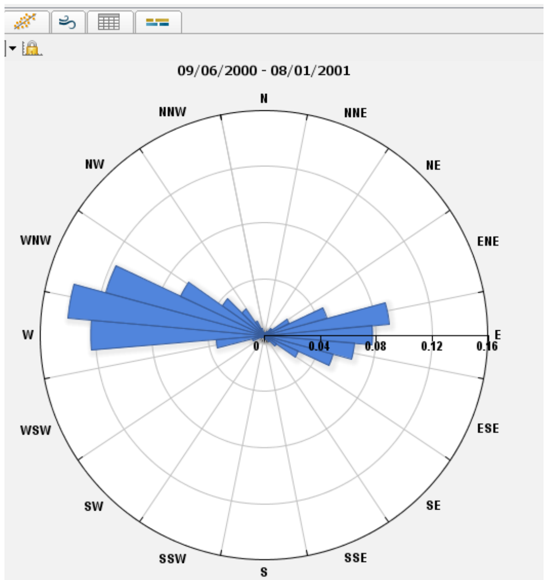
LES IS MORE!

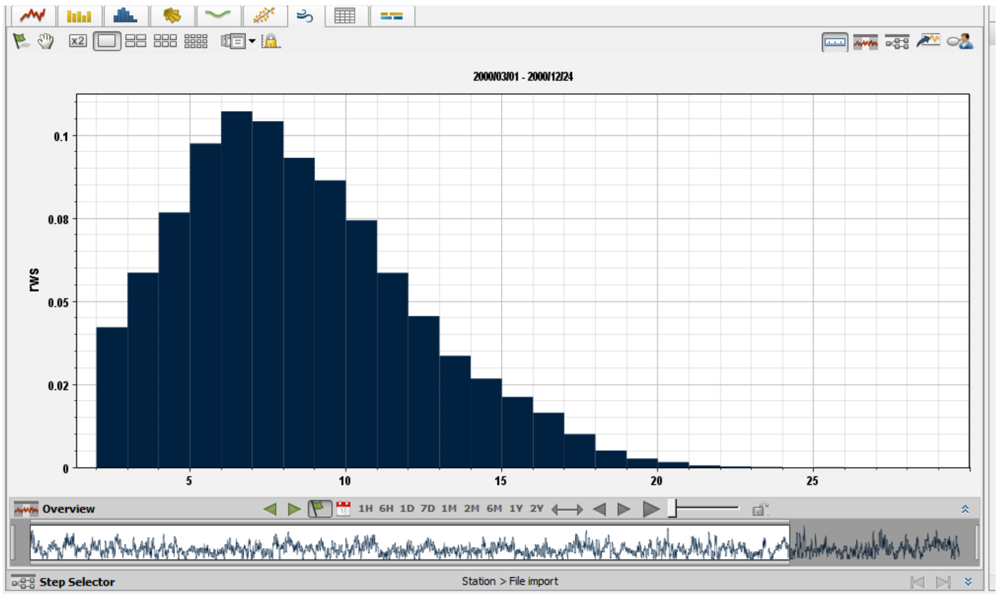
Time series, why?



LES IS MORE!

Time series, why?



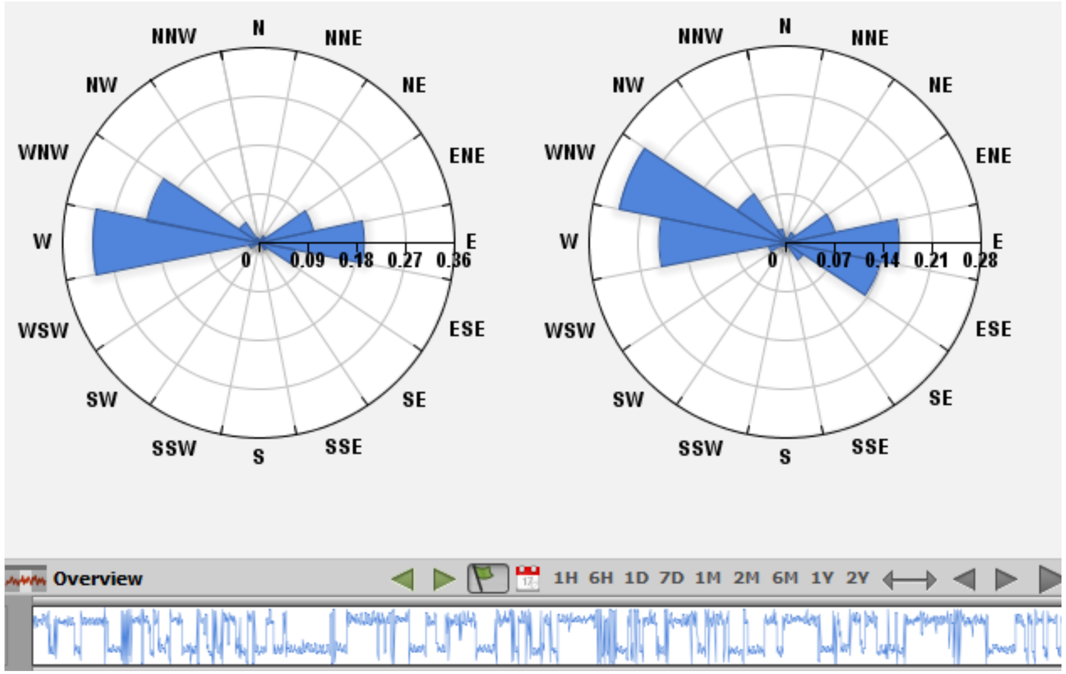


State-of-the-art resource analysis is based on distributions

LES IS MORE!

Time series, why?

If full time series were available, you could…

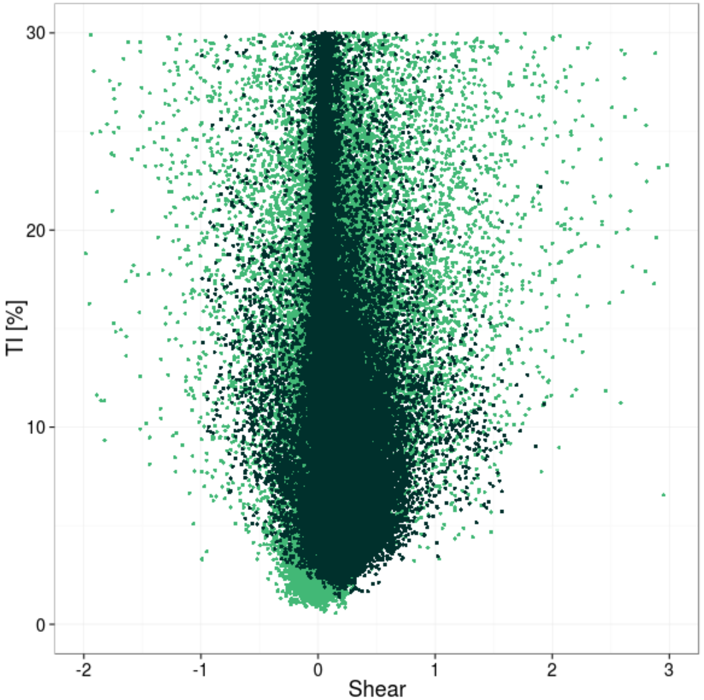


…discriminate (day/night)…

LES IS MORE!

Time series, why?

If full time series were available, you could…

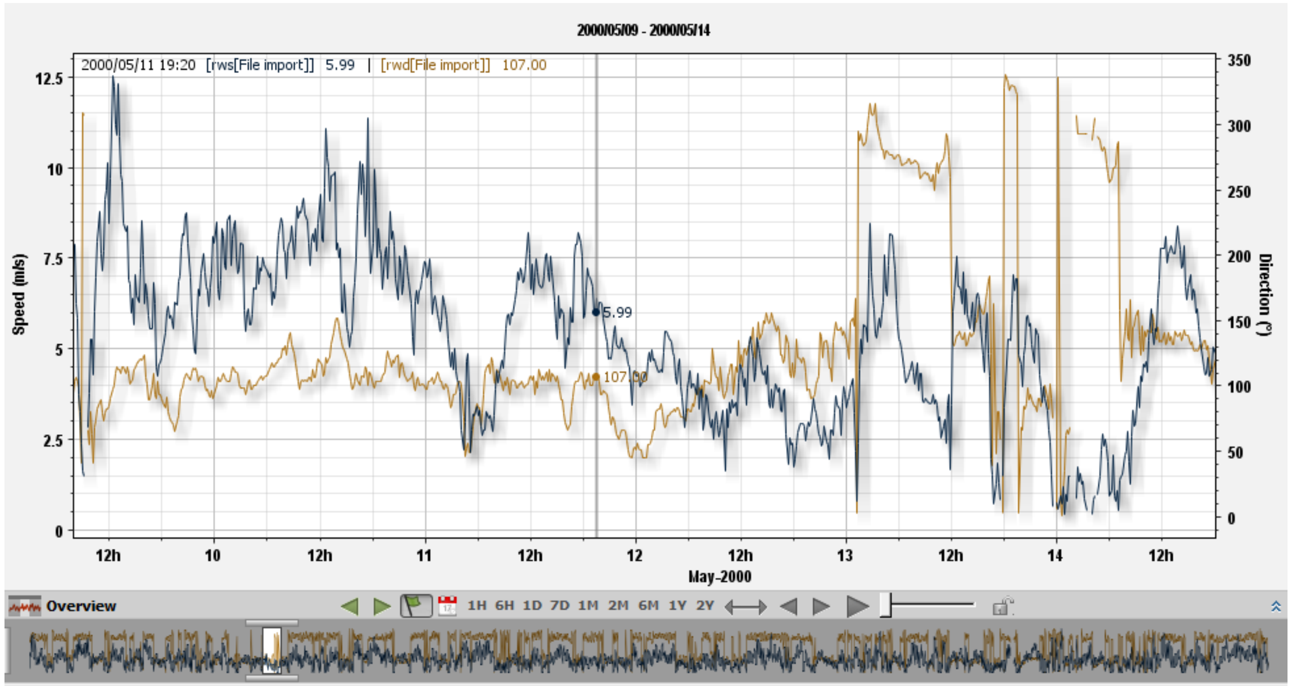


…cross-relate variables (TI vs. shear)

LES IS MORE!

Time series, why?

If full time series were available, you could…



…analyse extreme events (ramps)

LES IS MORE!

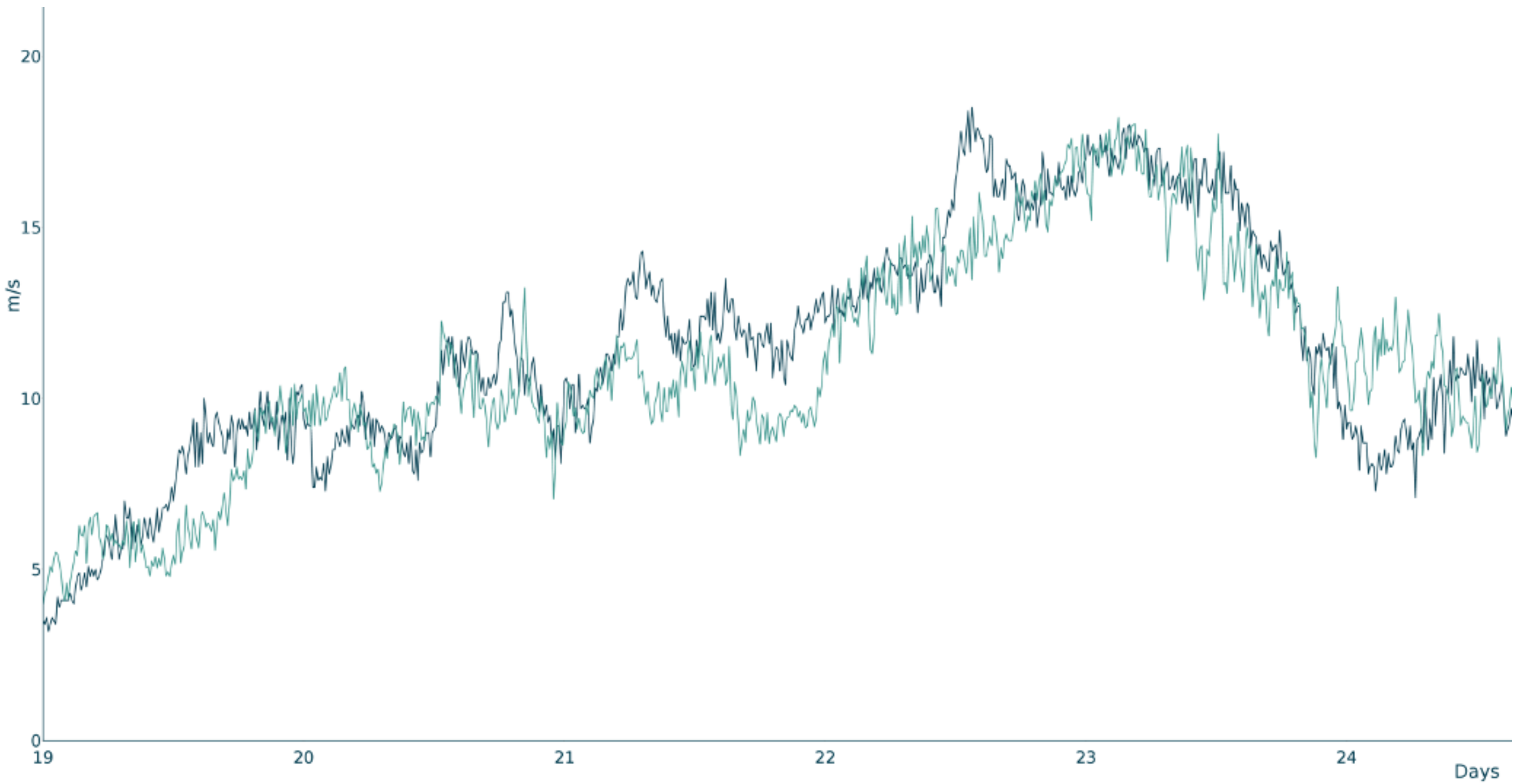
The advantages of measured time series compared to distributions are true

What is not true is that the showed examples were measurements!

Have you ever wished to have a time series of measurements at each turbine position of your planned or existing wind farm?

Large Eddy Simulations (LES) produces something outstandingly similar!

Guess which are the measurements…



…and which are the model results

LES IS MORE!

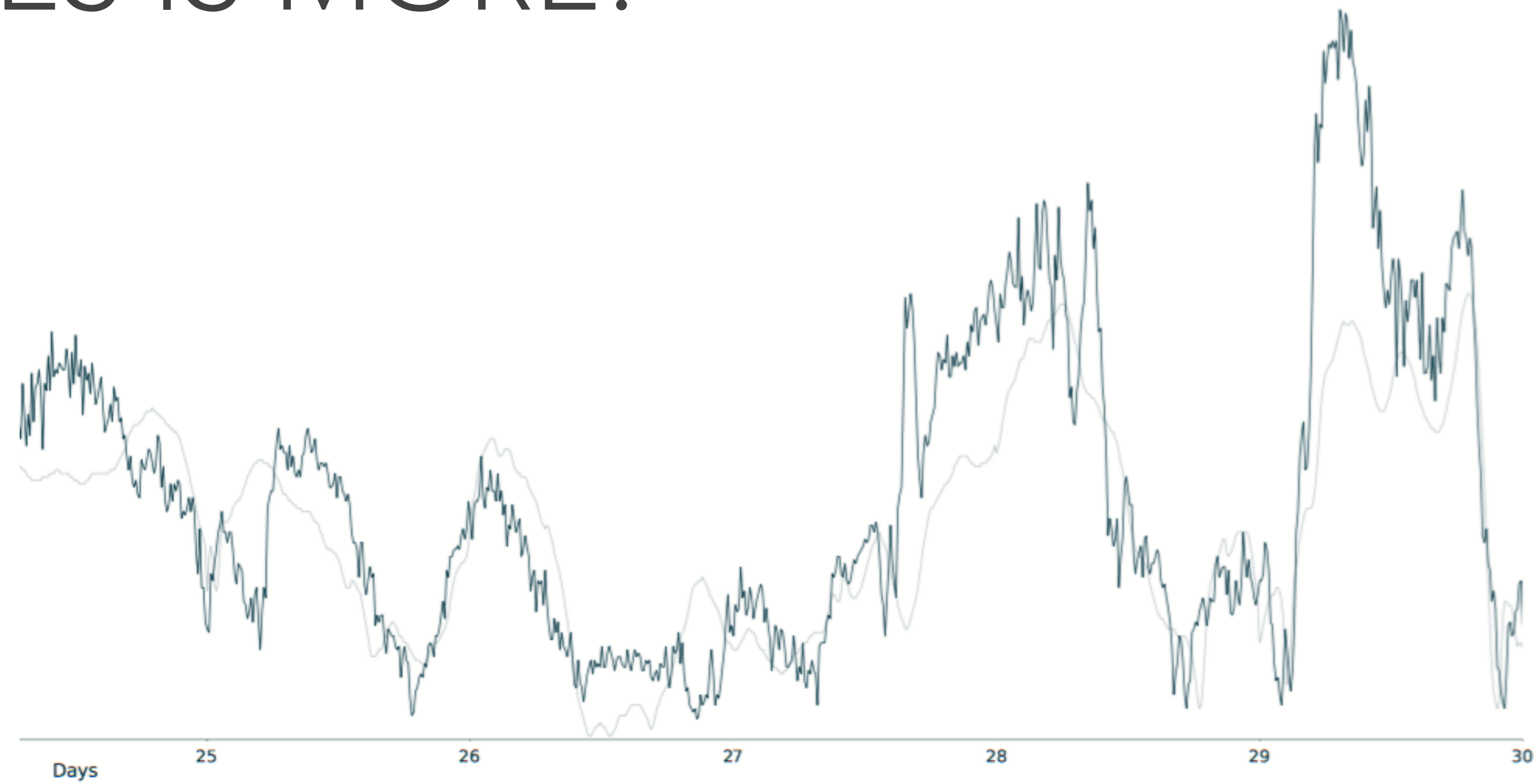
Measured time series are scarce (expensive)

Distributions come mainly from windfield extrapolation (modeling): WAsP, CFD…

LES delivers probably the most measurement-like set of synthetic time series that atmospheric modeling can achieve today

LES IS MORE!

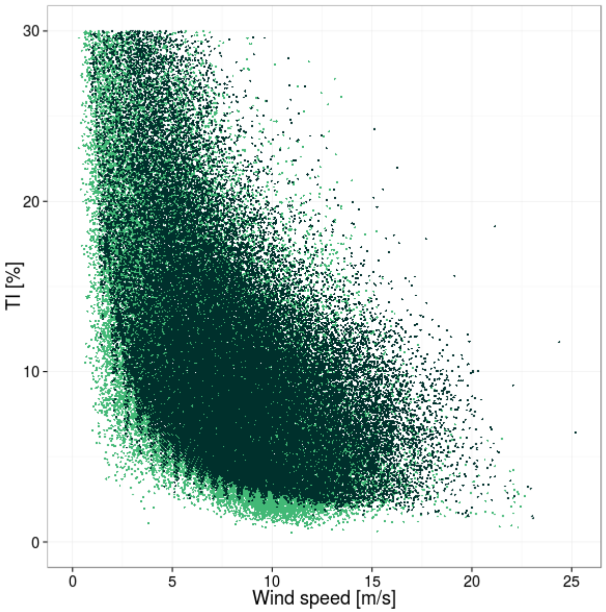
LES IS MORE!

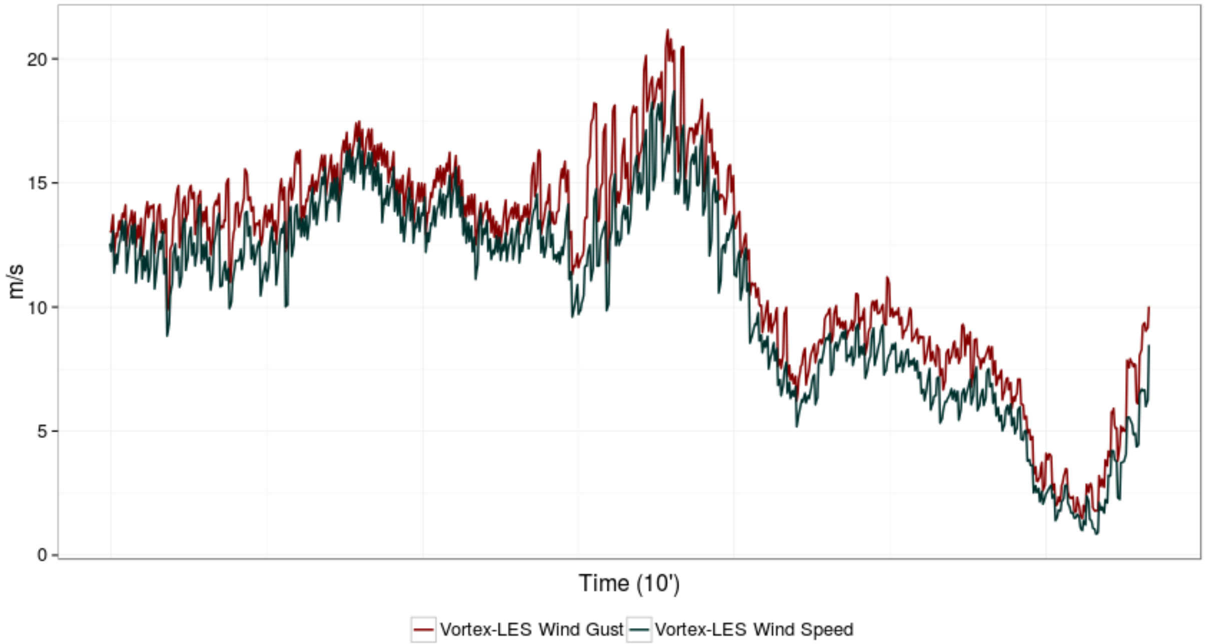


LES produces real (physical) 10′ averages

LES IS MORE!

LES IS MORE!

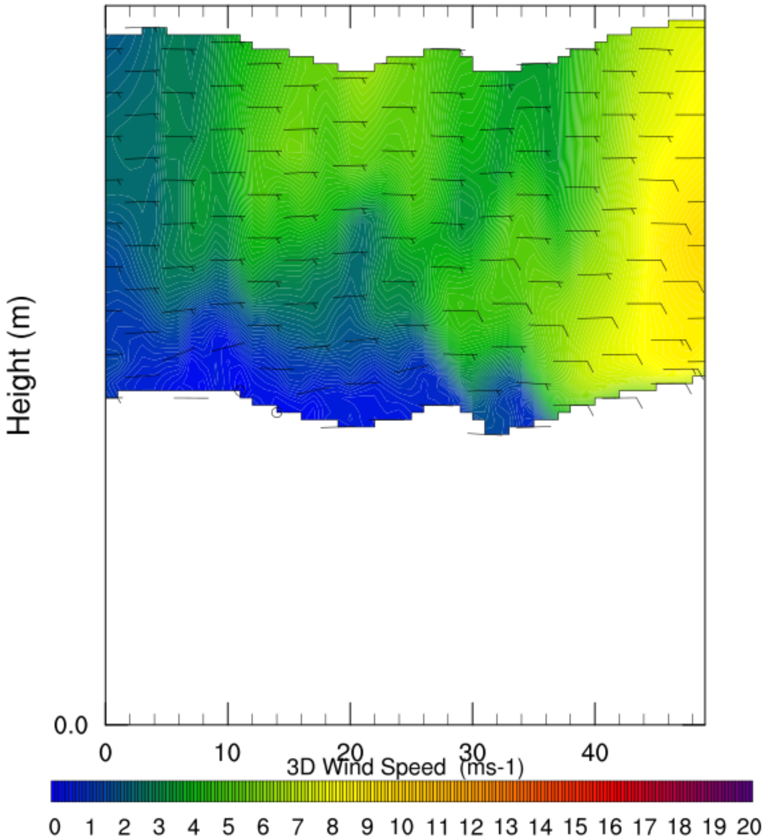




LES produces 3" samples (TI, gust...)

LES IS MORE!

LES IS MORE!



LES produces 3D results (shear and veer)

LES:

-Powered by NCAR's cutting-edge WRF-LES model

-Deliverables: 1 full-year, 10' averages, 3'' standard deviation (speed & direction) and gust (speed)

-All heights included for shear and veer calculation

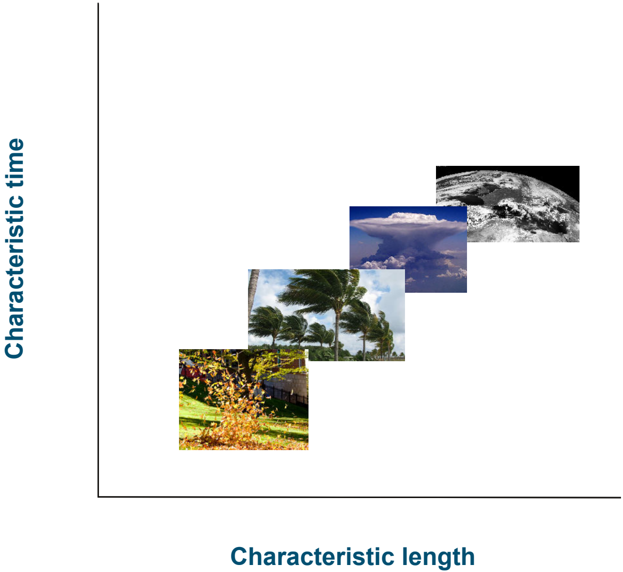
-Available anywhere; no measurements needed

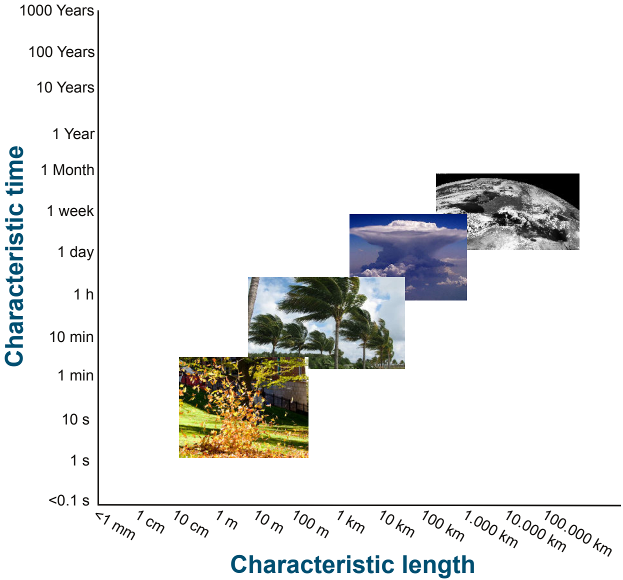
-Validated at 100+ sites

-Delivered in 5-6 days

LES IS MORE!

WRF–LES coming to age


Characteristic time
Characteristic length


Characteristic time
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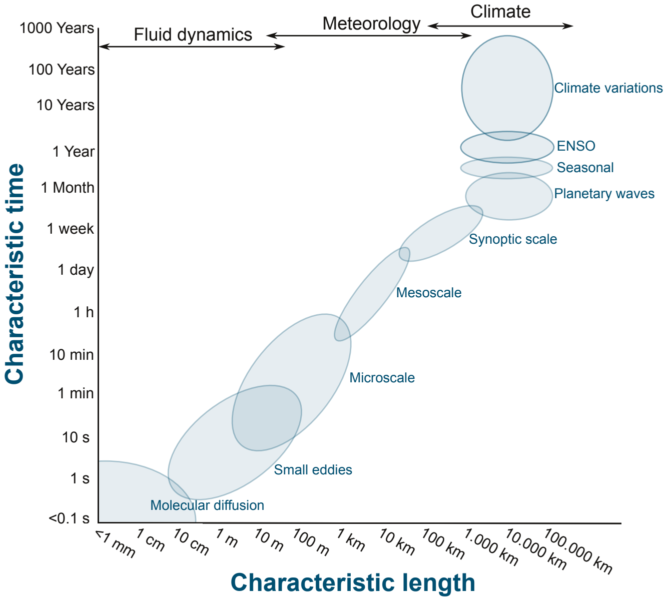
Fluid dynamics
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Characteristic time
Climate variations
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Synoptic scale
Mesoscale
Microscale
Small eddies
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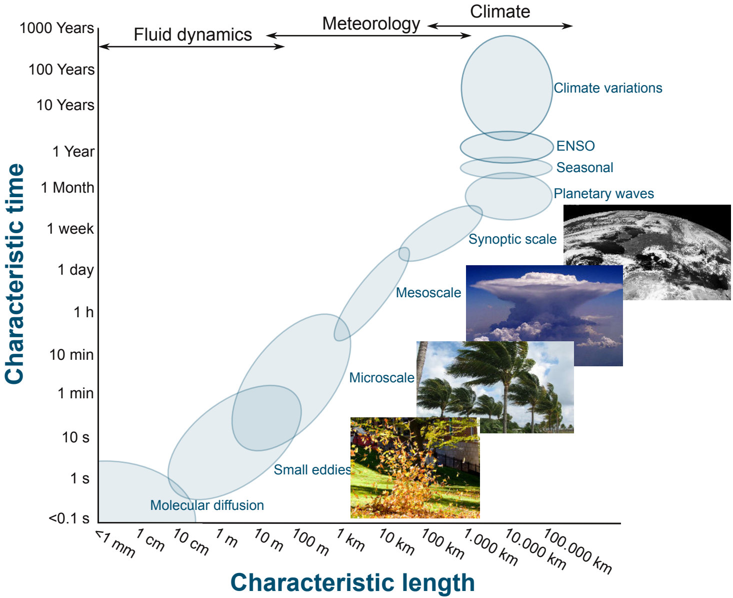
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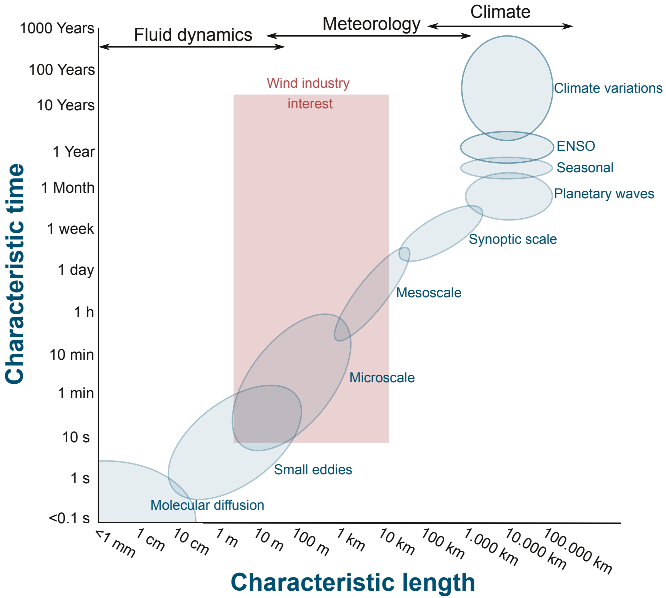
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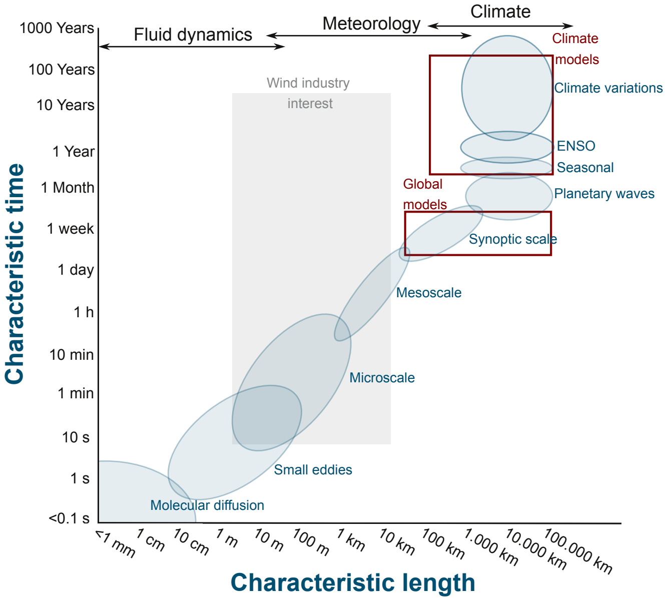
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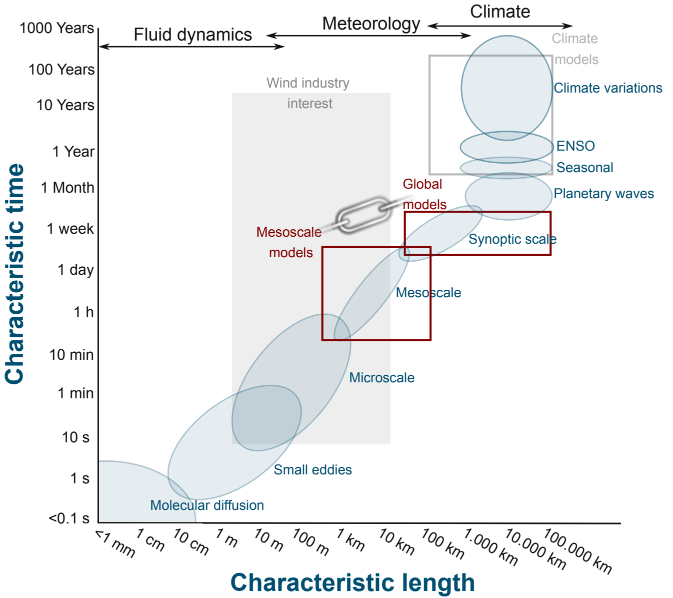
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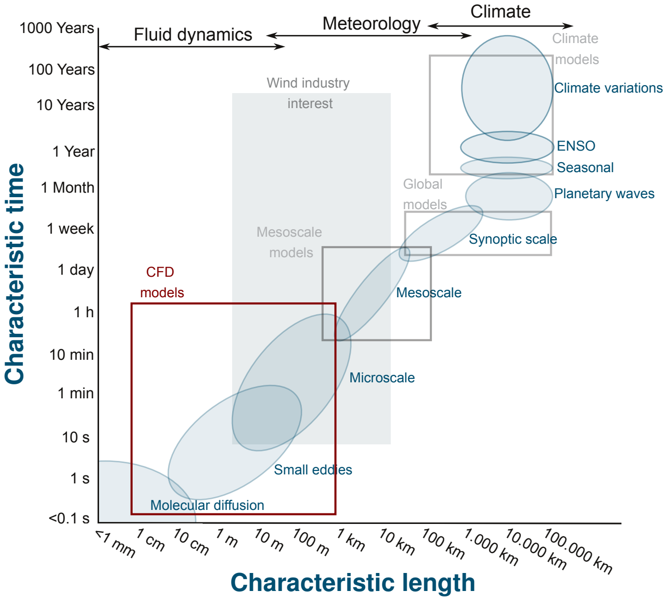
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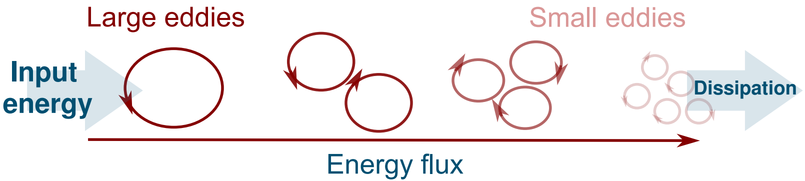
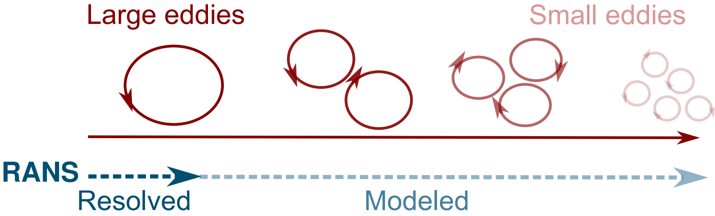
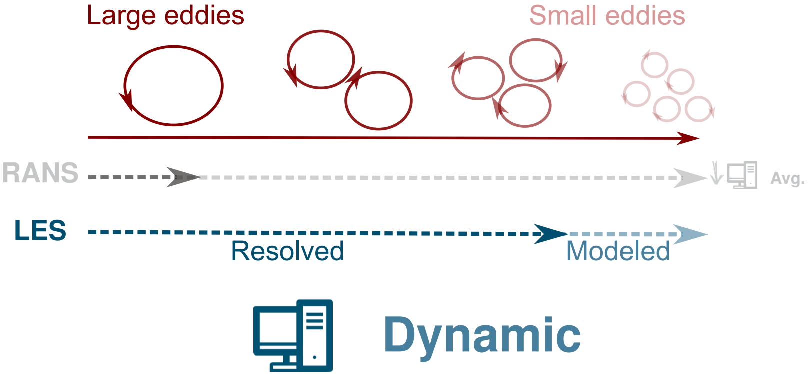
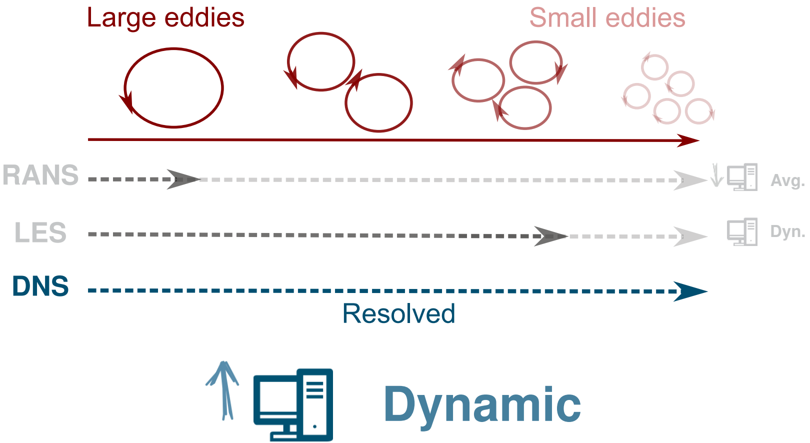

Large eddies
Small eddies
Input energy
Dissipation
Energy flux

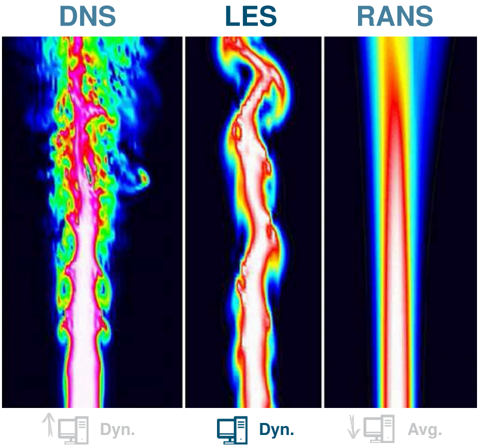


Average


Large eddies
Small eddies
RANS
Avg.
LES
Resolved
Modeled
Dynamic

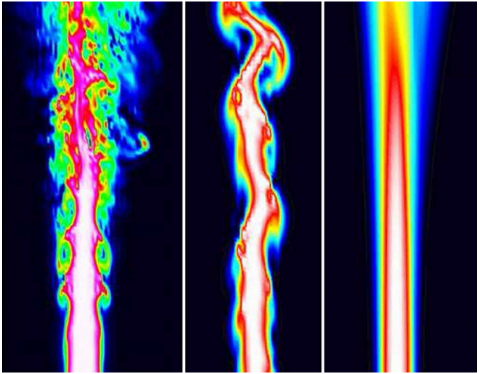


Large eddies
Small eddies
RANS
Avg.
LES
Dyn.
DNS
Resolved
Dynamic



Adapted from Maries, A., Haque, M. A., Yilmaz, S. L., Nik, M. B., Marai, G. E.: New Developments in the Visualization and Processing of Tensor Fields, Springer, pp. 137-156, D. Laidlaw, A. Villanova. 2012

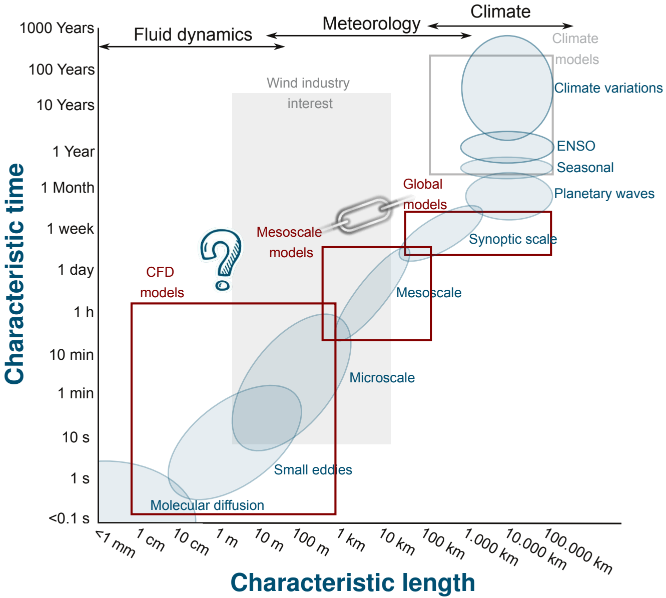
DNS LES RANS



Dyn. Dyn. Avg.

Seconds Minutes Distributions

Different tools for different applications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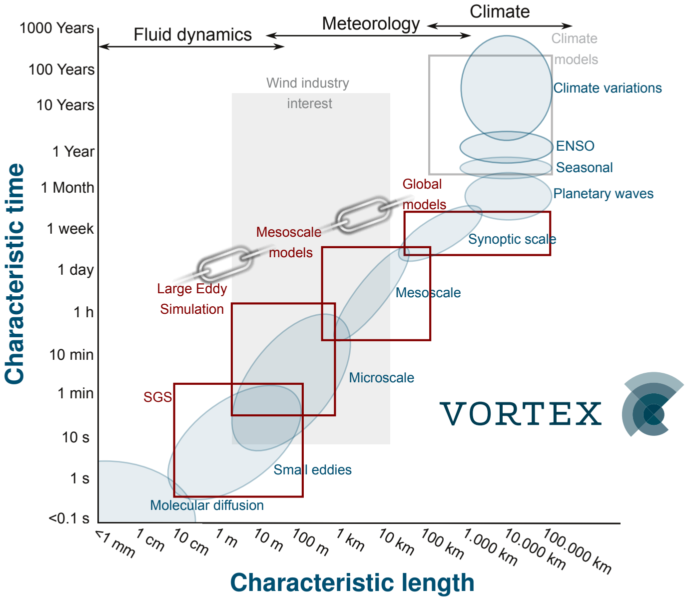
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Large Eddy Simulation
Microscale
SGS
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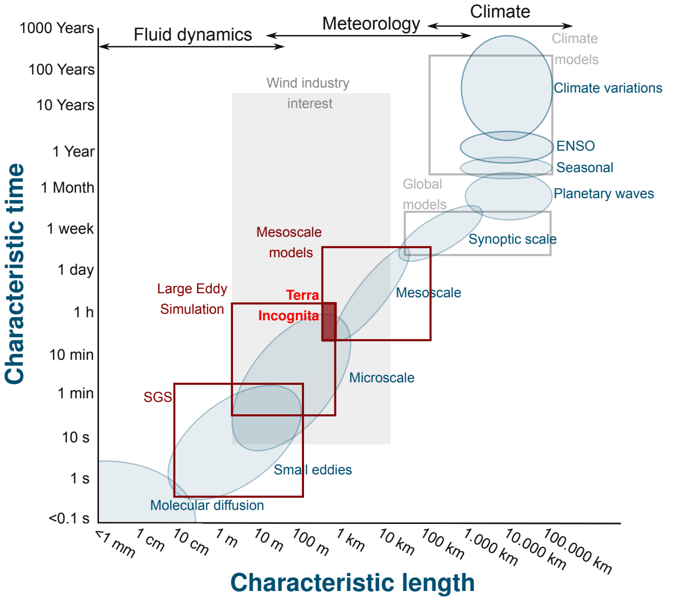
Characteristic length
VORTEX

Coupling mesoscale-LES: Challenges

- Lateral boundary conditions
- Surface layer and Land Surface Model
- Terra-Incognita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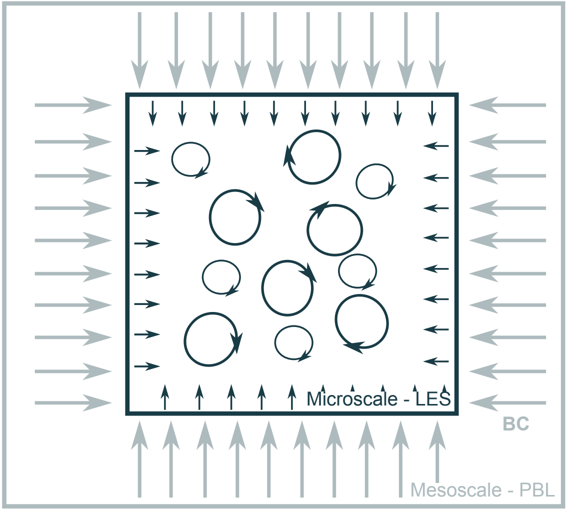
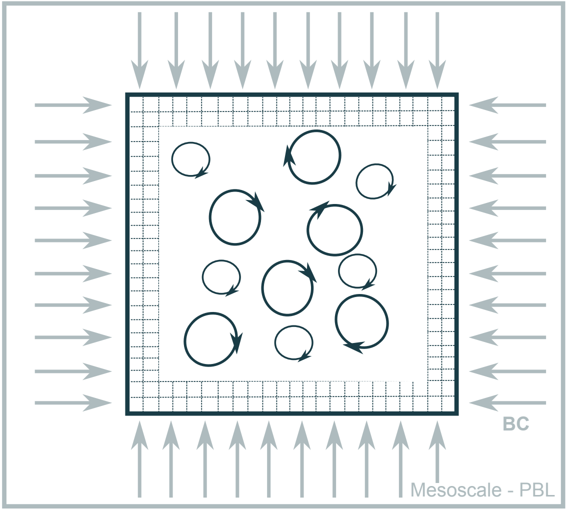
Coupling mesoscale-LES: Challenges

- Lateral boundary conditions
- Surface layer and Land Surface Model
- Terra-Incognita

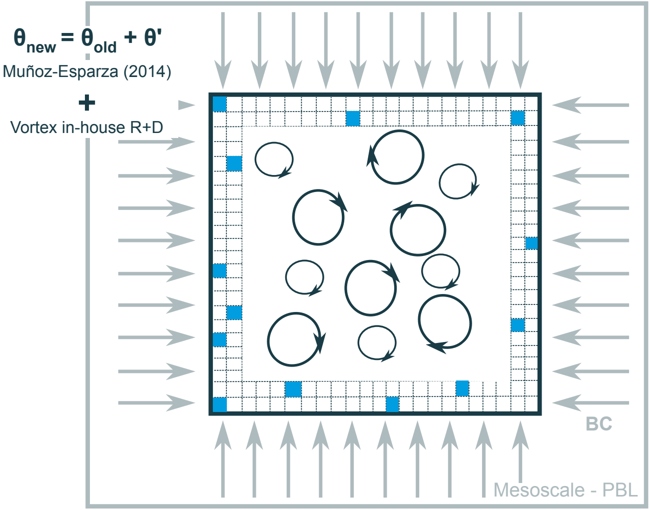
Lateral boundary conditions



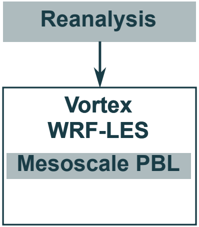
Lateral boundary conditions



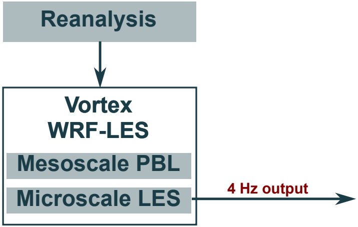
Lateral boundary conditions



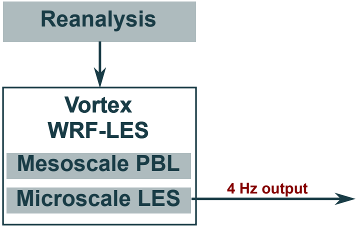
Vortex approach



Vortex approach

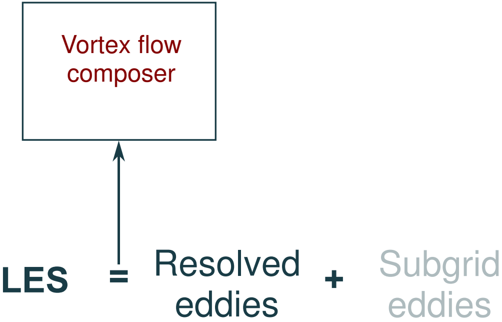


Vortex approach



LES = Resolved eddies + Subgrid eddies

Vortex approach



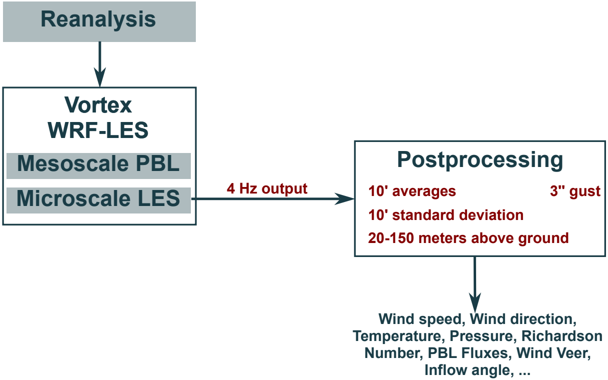
Vortex approach

Vortex flow composer

Physical based model that **reconstruct** the real flow considering the **resolved** and **subgrid** energy

LES = Resolved eddies + Subgrid eddies

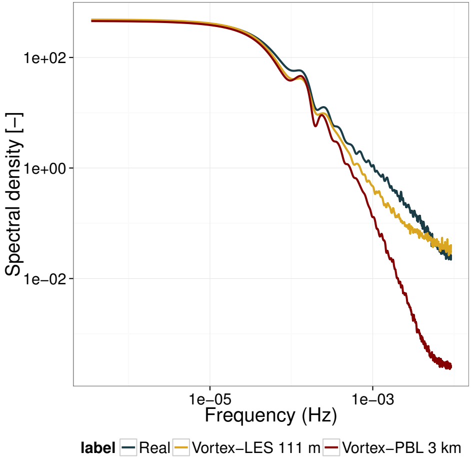
Vortex approach



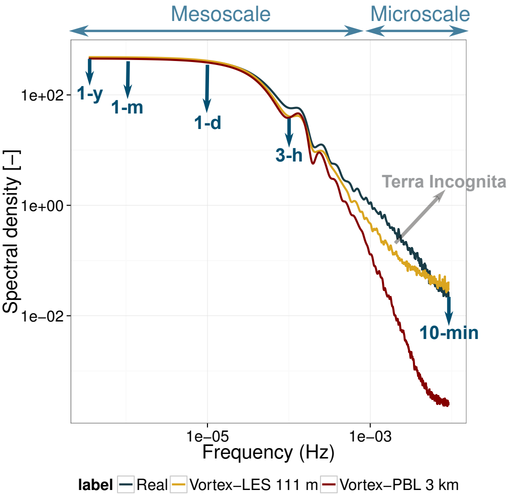
Vortex-LES validation exercise

- Wind metrics validated for **93 sites**
- Turbulence Intensity validated for **51 sites**

Vortex-LES validation exercise



Vortex-LES validation exercise



Vortex-LES validation exercise

Wind metrics validated for **93 sites**

Commonly used wind metrics in the industry:

- MAE
- Correlation
- Weibull parameters

	Average	**Std Dev**
MAE (%)	8.3	4.3
A-shape (%)	8.2	5.0
k-shape (%)	9.3	6.1
R^2 10-min	0.59	0.09
R^2 hourly	0.62	0.09
R^2 daily	0.80	0.09

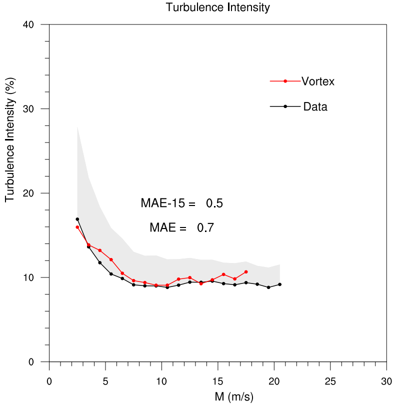
Vortex-LES validation exercise

TI(%) validated for **51 sites**

Which metric to use?

1. MAE between TI-model against TI-obs weighted by bin-ocurrence
2. MAE at 15 m/s bin

	Average	**Std Dev**
MAE	1.8	0.9
MAE-15	1.9	1.1



WRF–LES coming to age

VORTEX

Applications and validation of meso-γ and microscale (WRF / WRF-LES) meteorological modeling in wind energy

Mark Žagar
Specialist, Plant Siting & Forecasting
Vestas Technology & Service Solutions

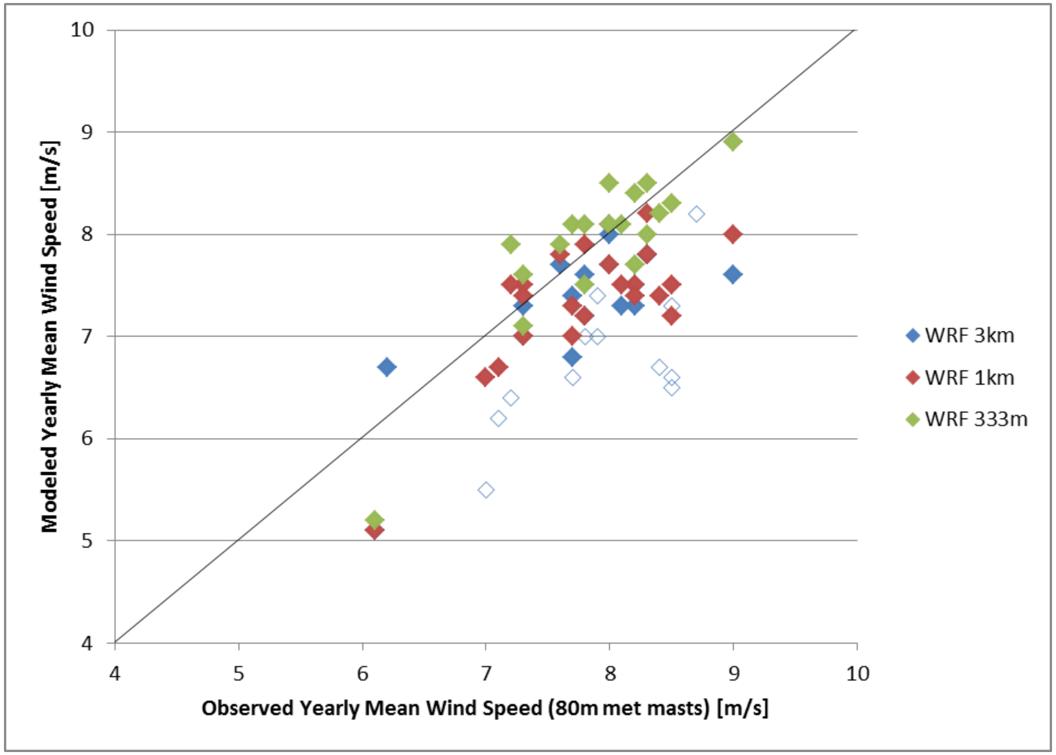
How we are doing at microscale meteorological modeling?

Acchievable accuracy of dynamical downscaling

What is dynamical downscaling?

WRF-ARW, GFS fnl@6h, 48h + 6h spin-up, 60 levels, 27 km-9-3-...

Example 1: comparing long-term average wind speed at the anemometer height;



Campaign, Turkey (complex): Significantly reduced prediction error with increased resolution.

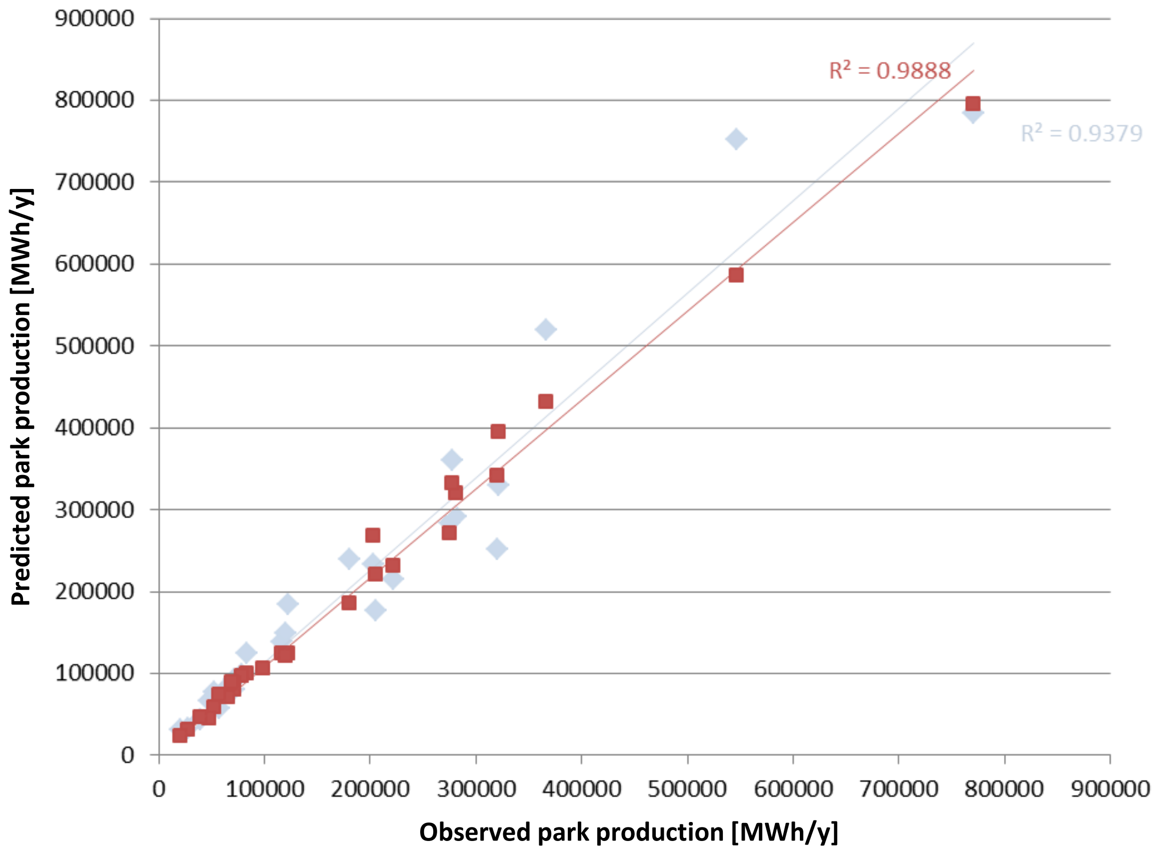
	BIAS [m/s]	MAE [m/s]	STDE [m/s]
3 km	-0.72	0.75	0.54
1 km	-0.44	0.53	0.36
1/3 km	+0.01	0.32	0.22

Acchievable accuracy of dynamical downscaling

- Example 2: wind farm production; estimated and observed

Production data compensated for:

- Downtime
- Wake (based on standard wake models)
- Curtailed operations

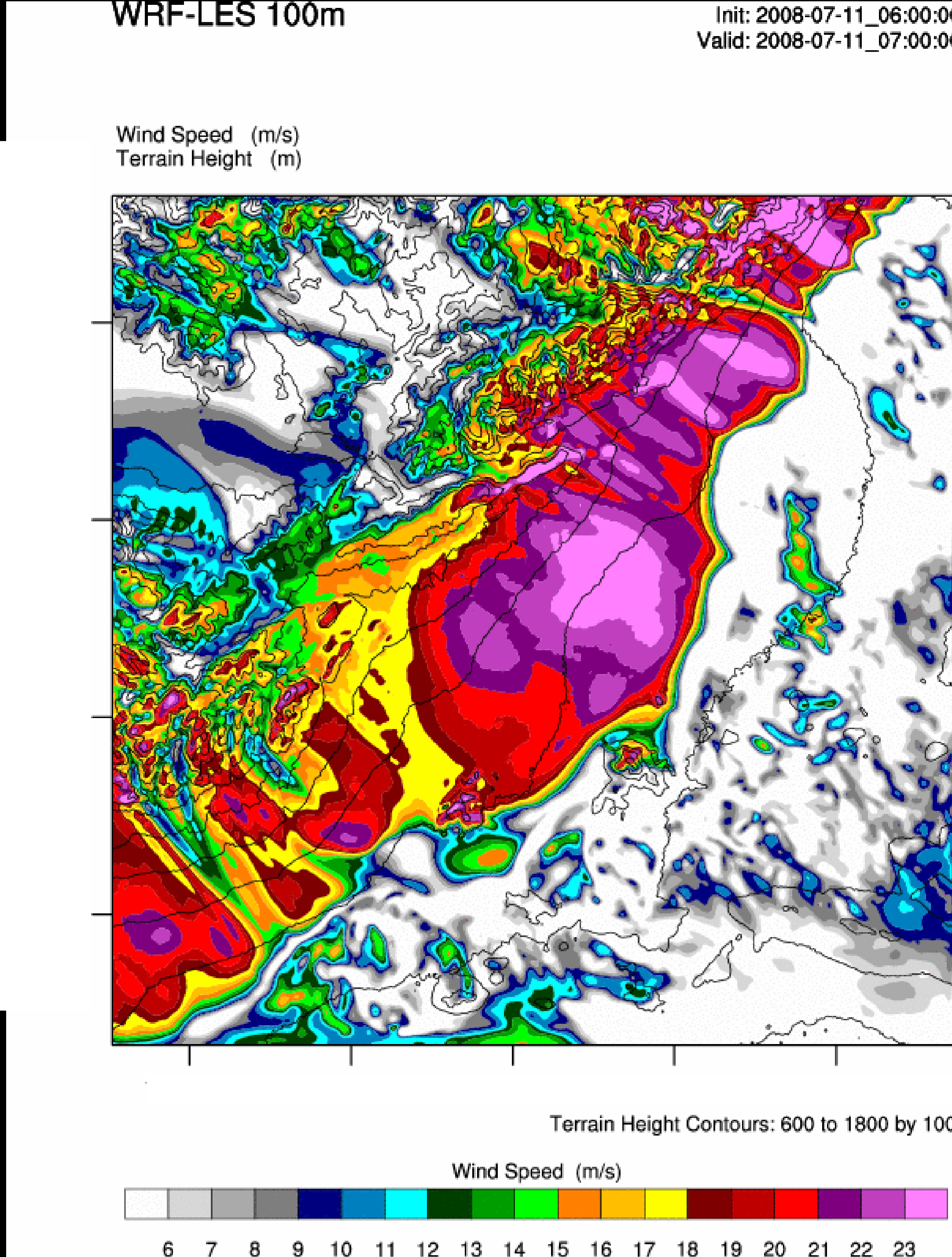


AEP Model only

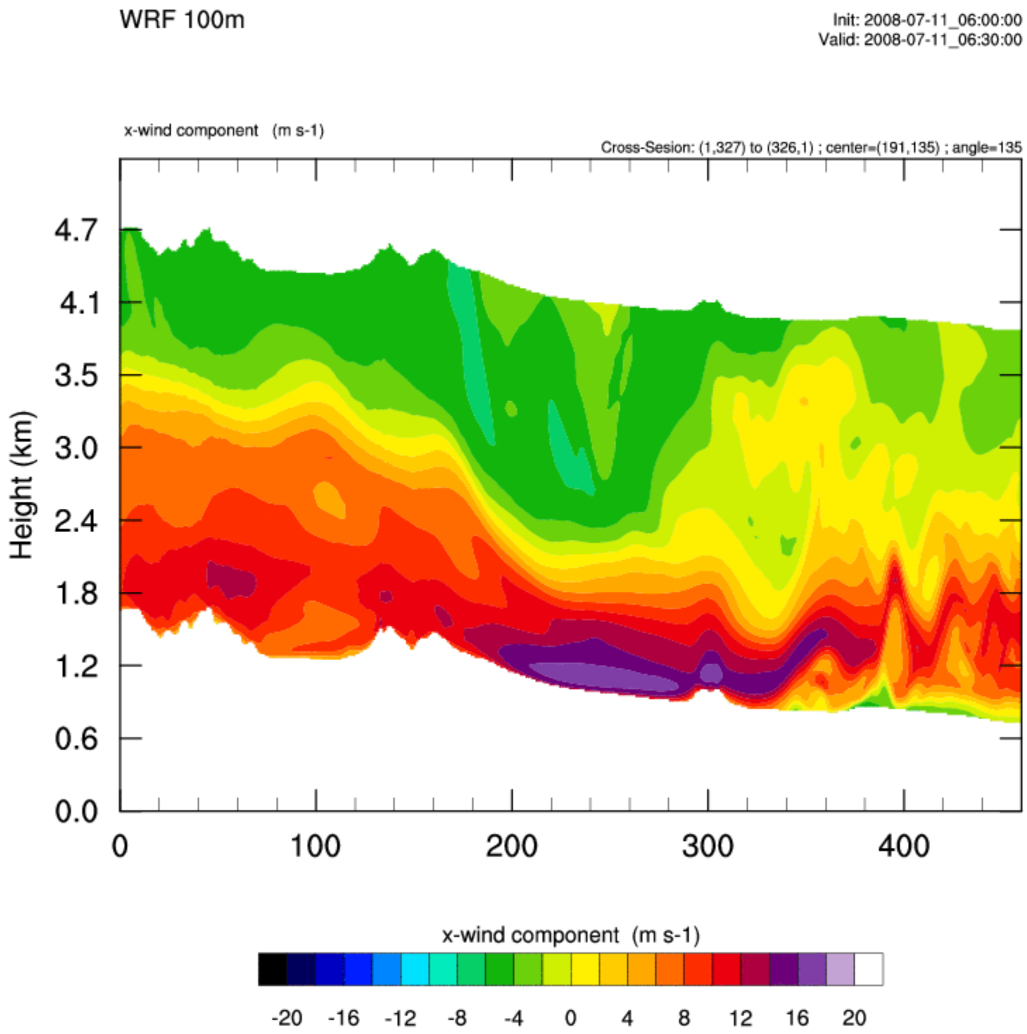
AEP Corrected using mast data

	MAE	STDE	EtotP
WRF raw	16.2%	18.2%	4.7%
WRF corr	8.0%	9.4%	2.7%

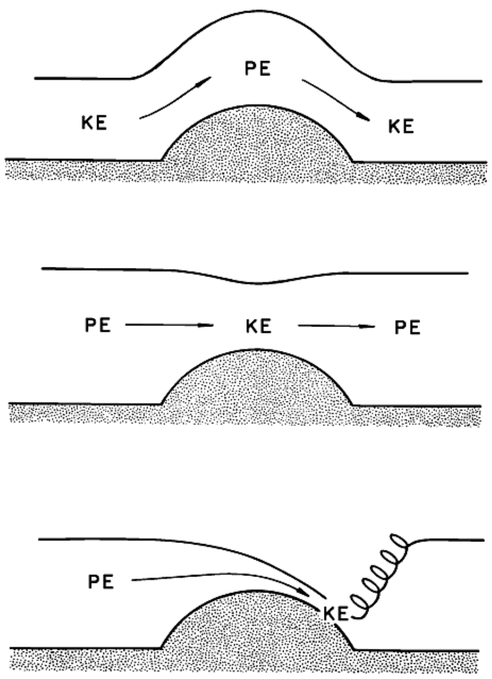
Purely downscaling
1^{o} analyses



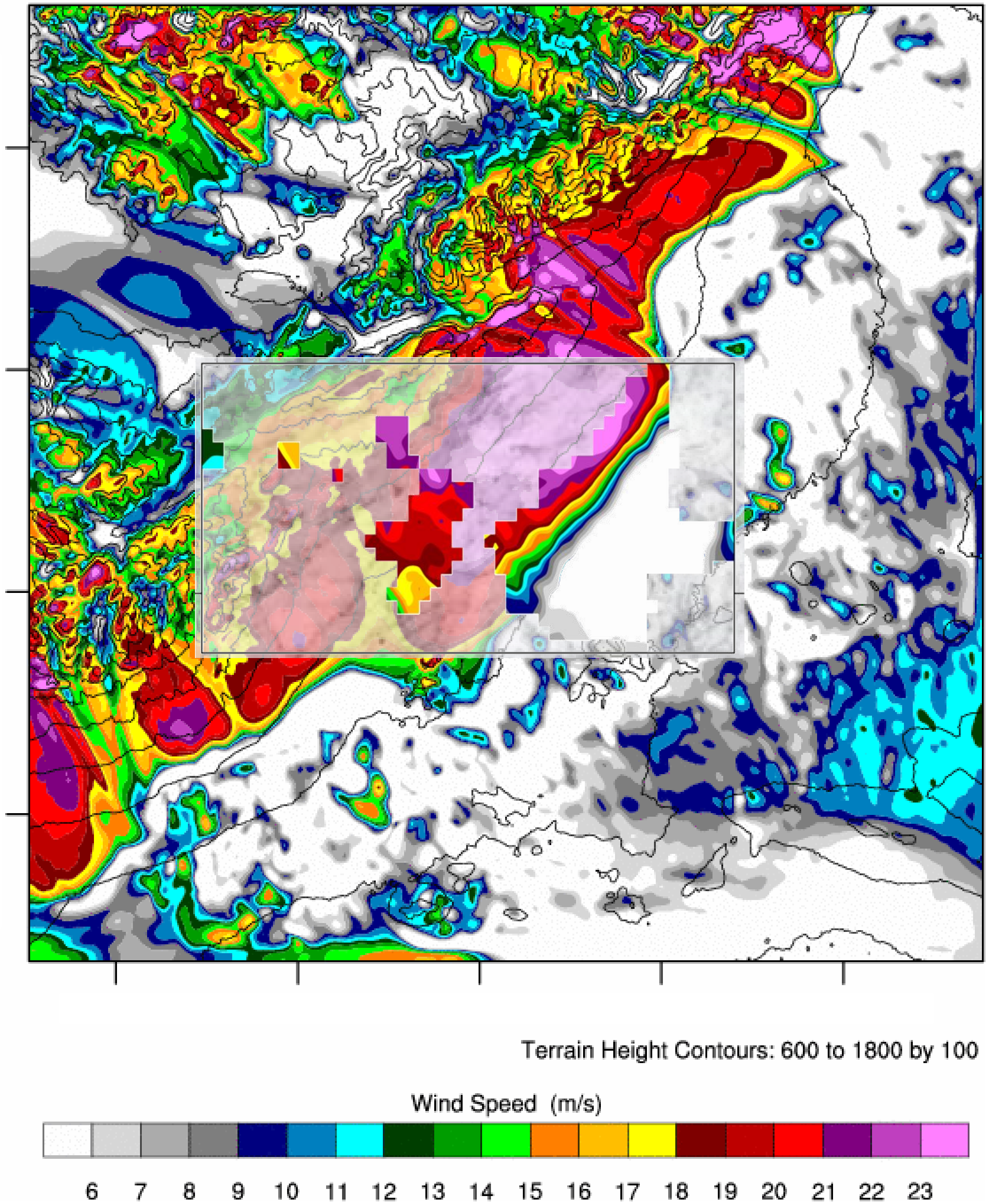
Downslope storm, hydraulic jump



dx=100m



Holton, 1992



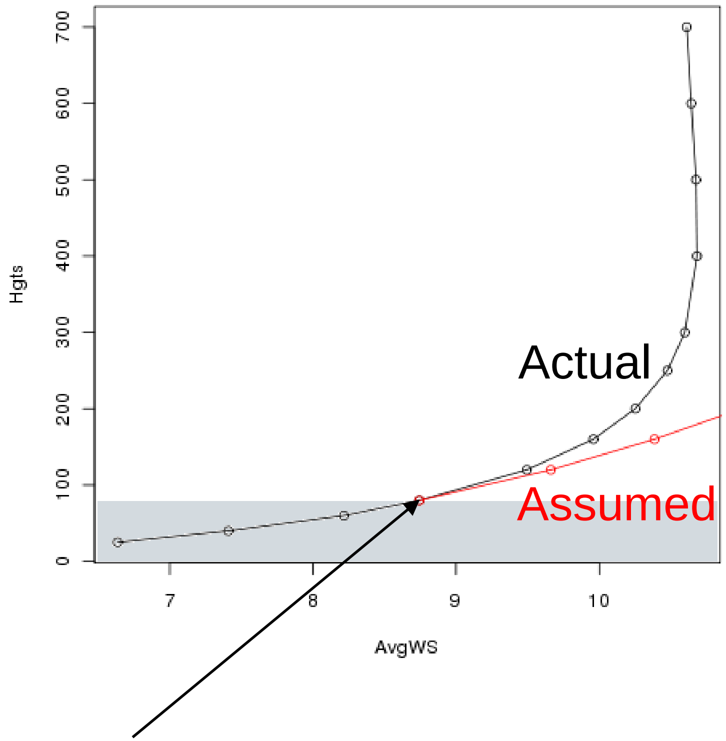
Downslope storm, hydraulic jump

dx=100m

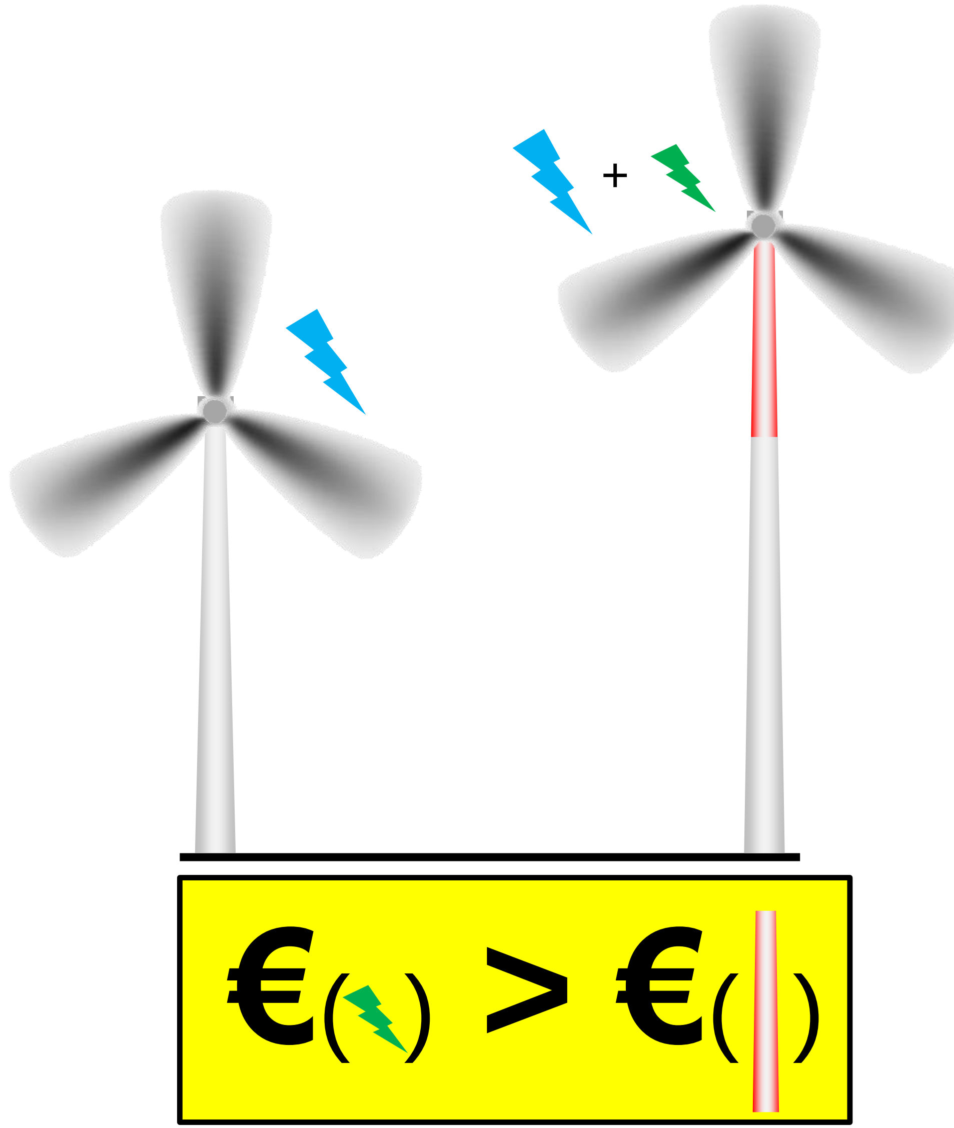
Data from nacelle anemometers overlaid

An example of sensitivity to the ”unknown”

Important to know the wind profile

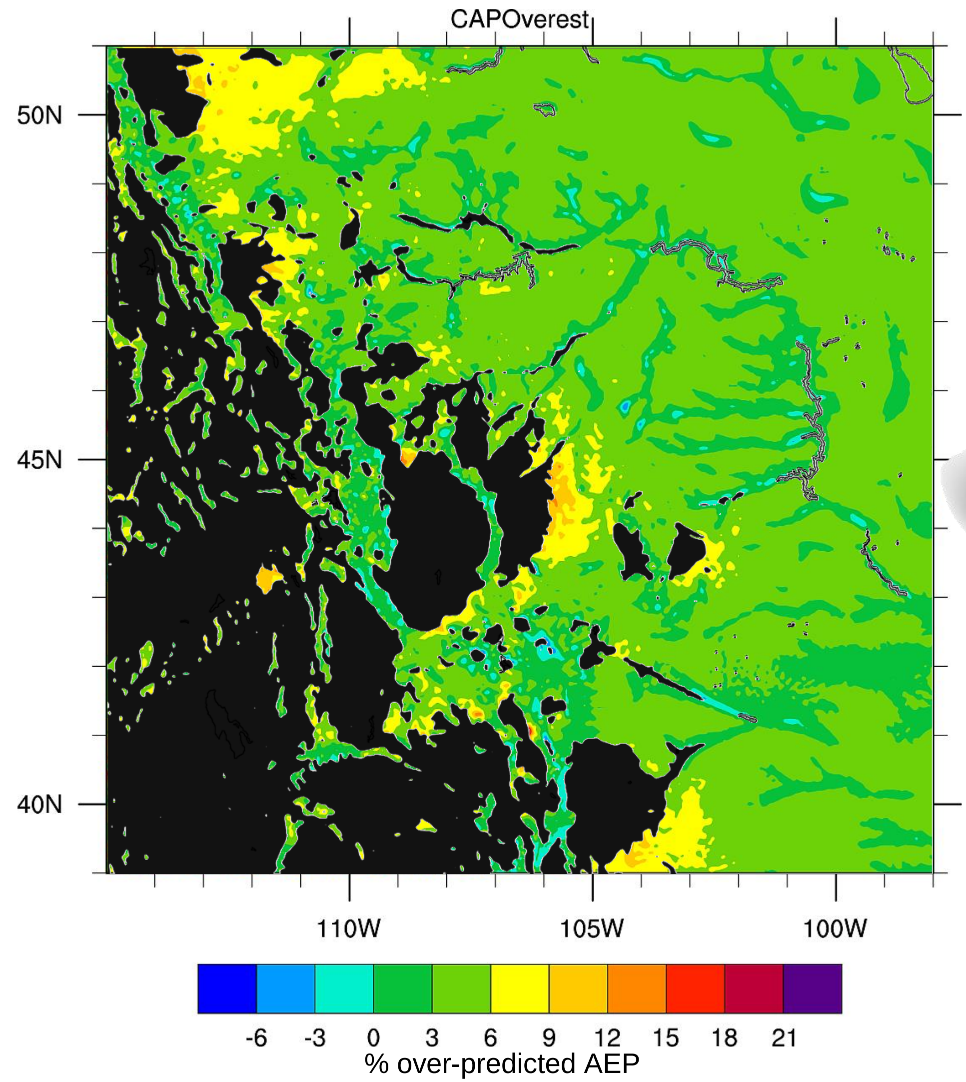


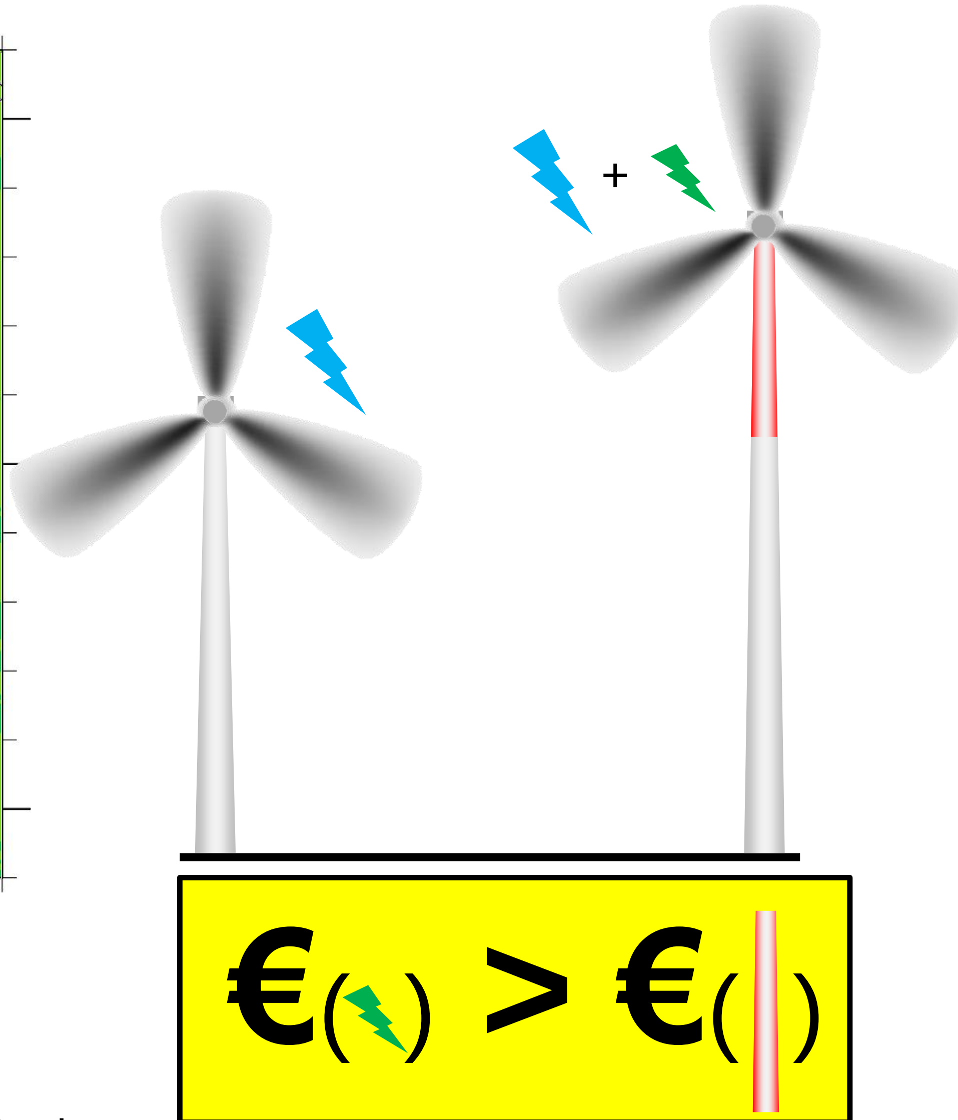
Typical met-mast height



2% wind speed error → 5% AEP error

Important knowing the wind profile





Error committed if the wind shear between 40/80m is assumed to be valid up to 180m: in average 5% AEP!

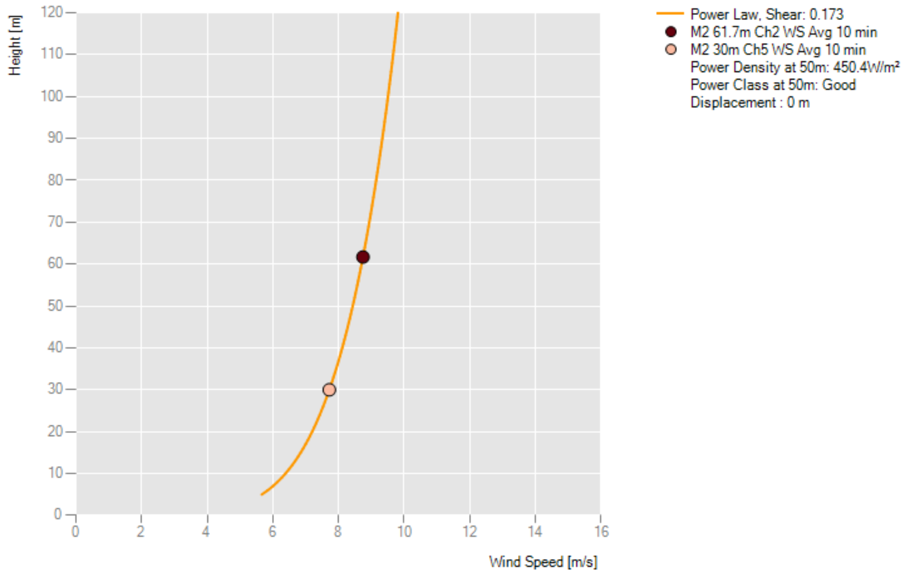
2% wind speed error → 5% AEP error

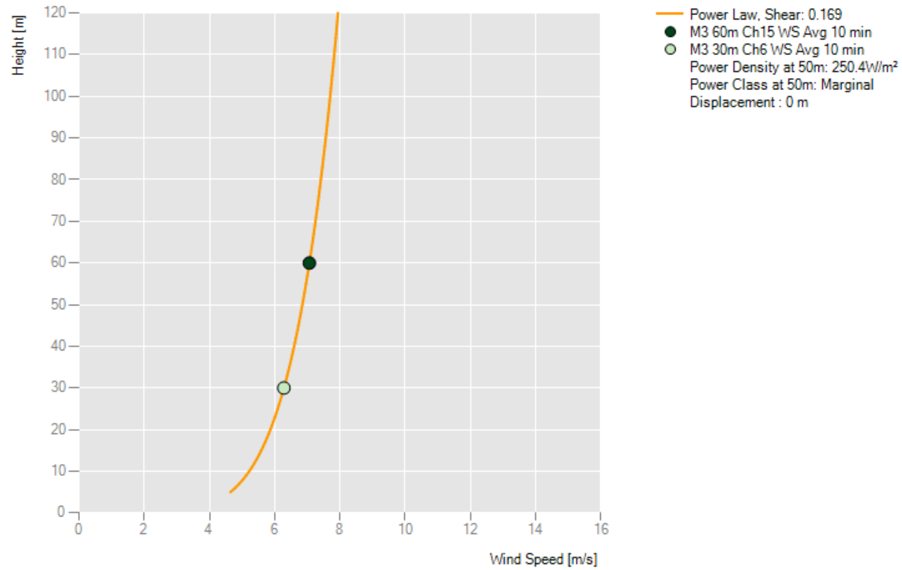
Rule of 👍: 1 % AEP corresponds to 1 mEUR on a 100 MW wind farm

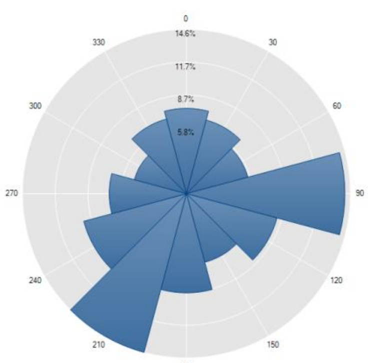
Wind. It means the world to us.™

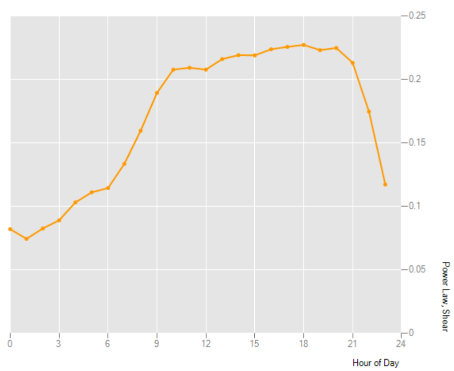
How does WRF-LES do?

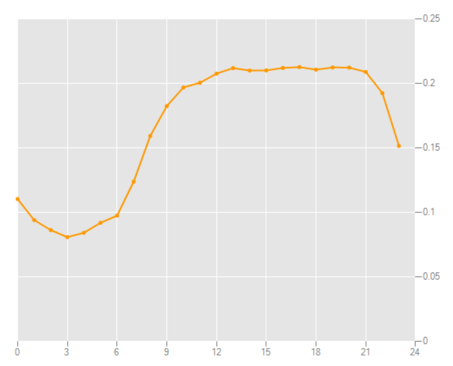
Australia 1

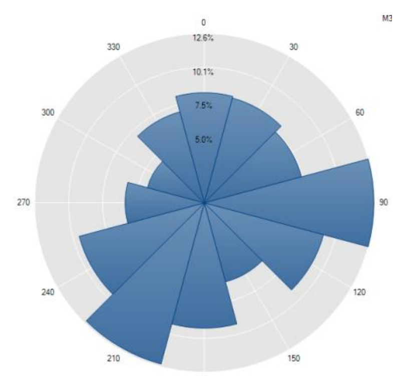






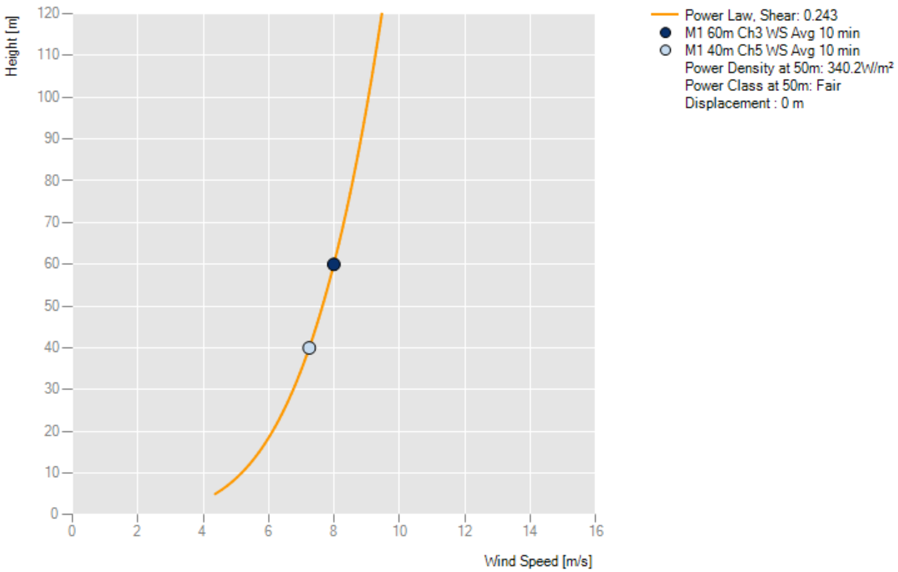


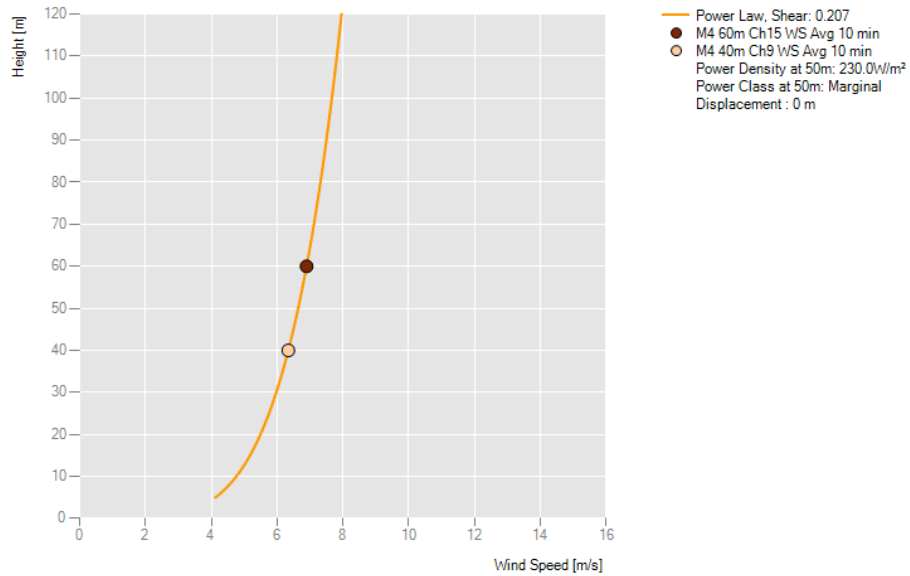


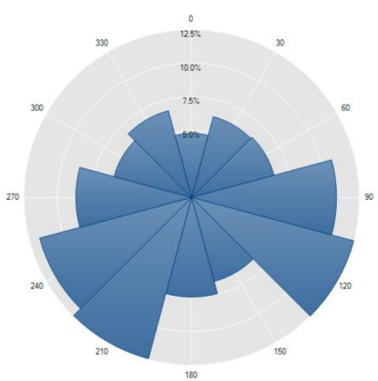


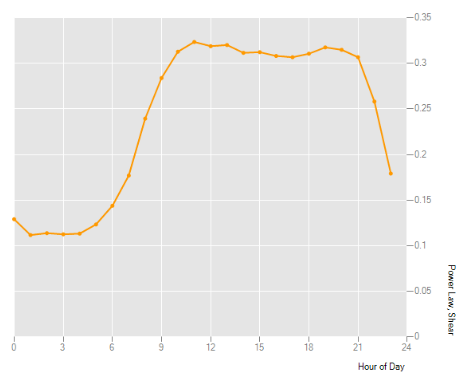
Wind. It means the world to us.™

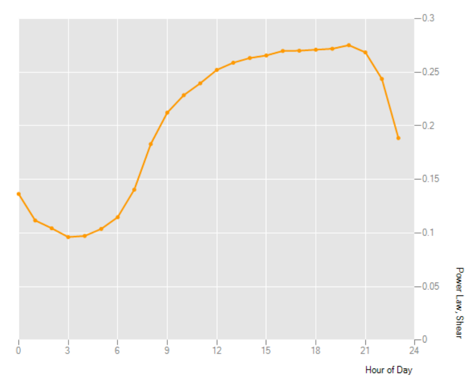
Australia 2

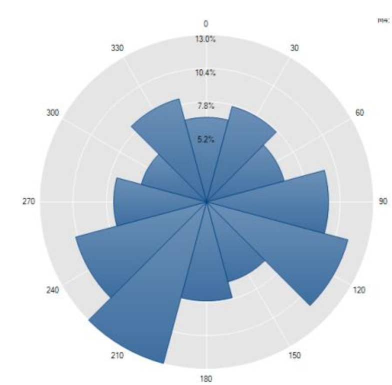

Power Law, Shear: 0.243
M1 60m Ch3 WS Avg 10 min
M1 40m Ch5 WS Avg 10 min
Power Density at 50m: 340.2W/m²
Power Class at 50m: Fair
Displacement : 0 m
Height [m]
Wind Speed [m/s]


Power Law, Shear: 0.207
M4 60m Ch15 WS Avg 10 min
M4 40m Ch9 WS Avg 10 min
Power Density at 50m: 230.0W/m²
Power Class at 50m: Marginal
Displacement : 0 m
Height [m]
Wind Speed [m/s]







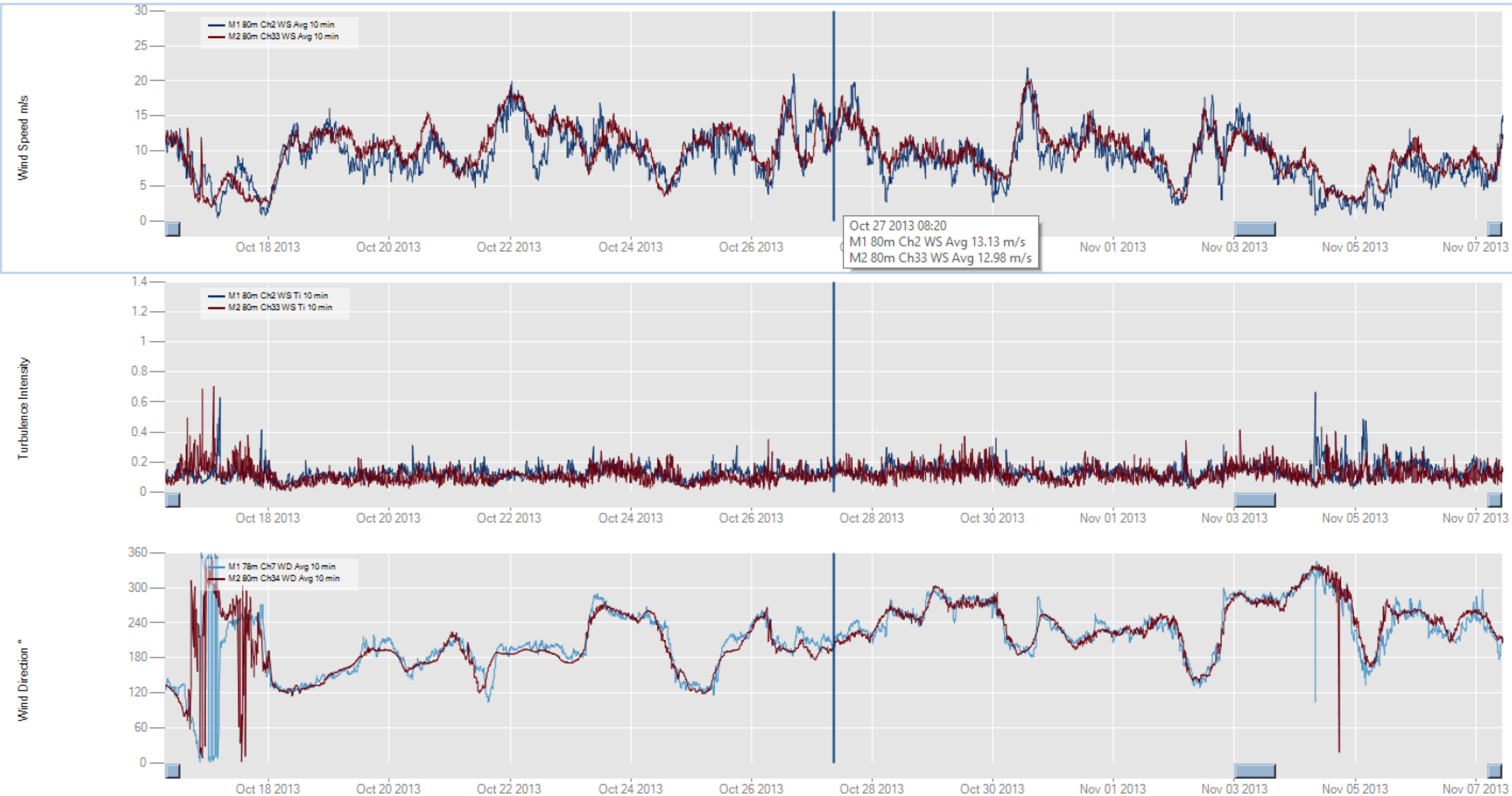


Scotland 1

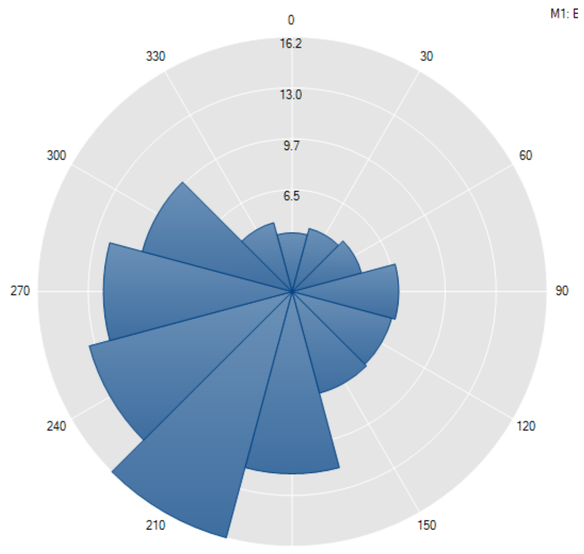
	avg(V)	σ(V)	A	k
Obs. data	8.1 m/s	4.3 m/s	9.1 m/s	2.0
Model	8.7 m/s	4.0 m/s	10.0 m/s	2.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	9.23	7.43	8.43	9.03	8.25	5.60	5.20	6.80	7.42	9.53	7.40	12.39	8.07
All	9.23	7.43	8.43	9.03	8.25	5.60	5.20	6.80	7.42	9.53	7.40	12.39	8.07

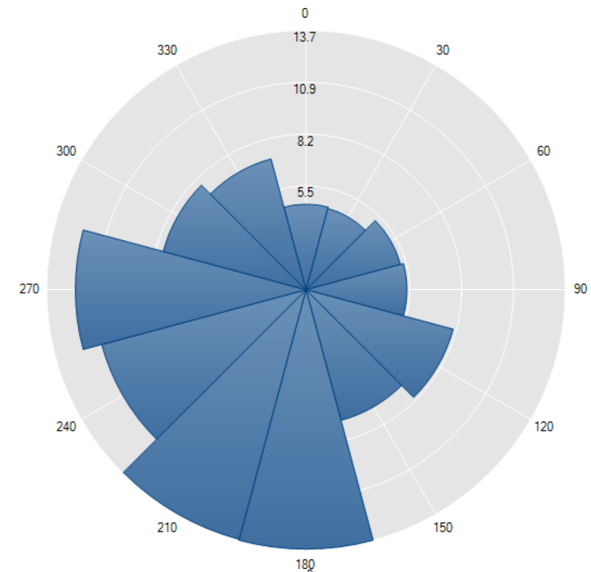
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	9.77	8.62	8.62	9.29	8.69	5.98	5.45	7.17	8.21	10.42	8.70	13.05	8.67
All	9.77	8.62	8.62	9.29	8.69	5.98	5.45	7.17	8.21	10.42	8.70	13.05	8.67

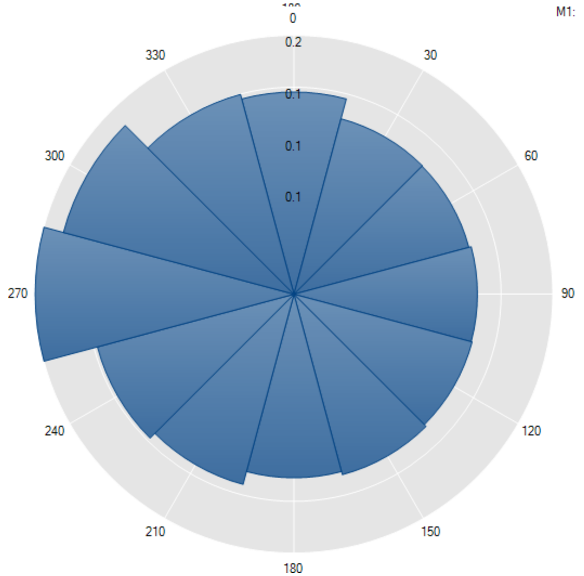


Scotland 1

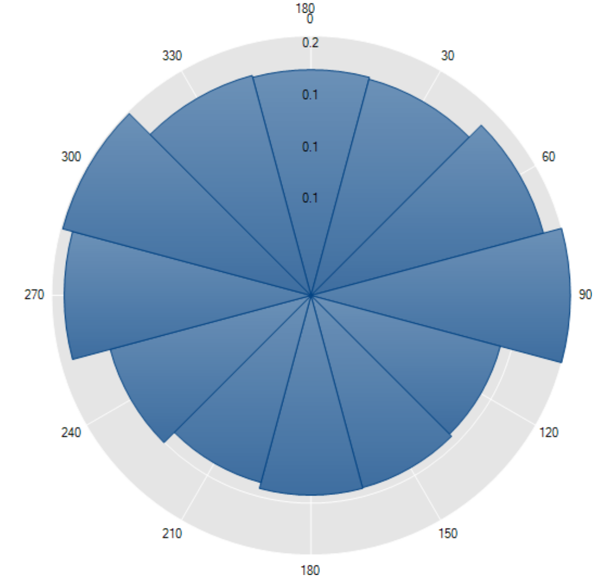


Wind Frequency Rose





Turbulence intensity Rose

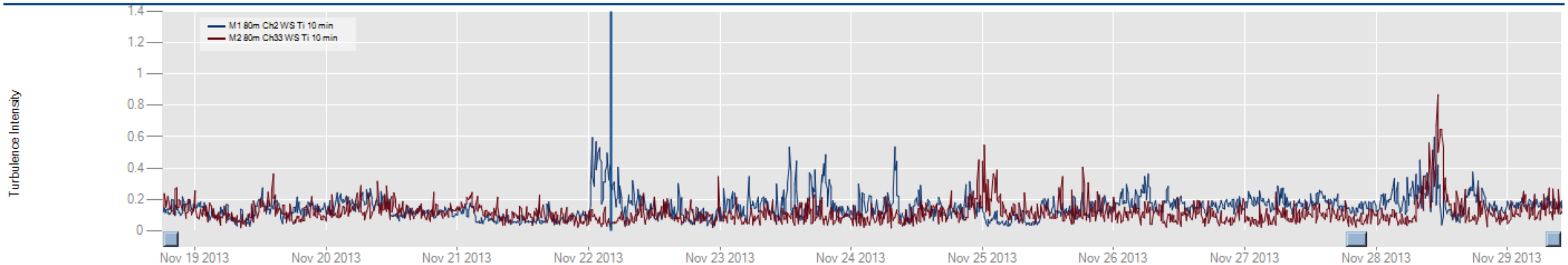


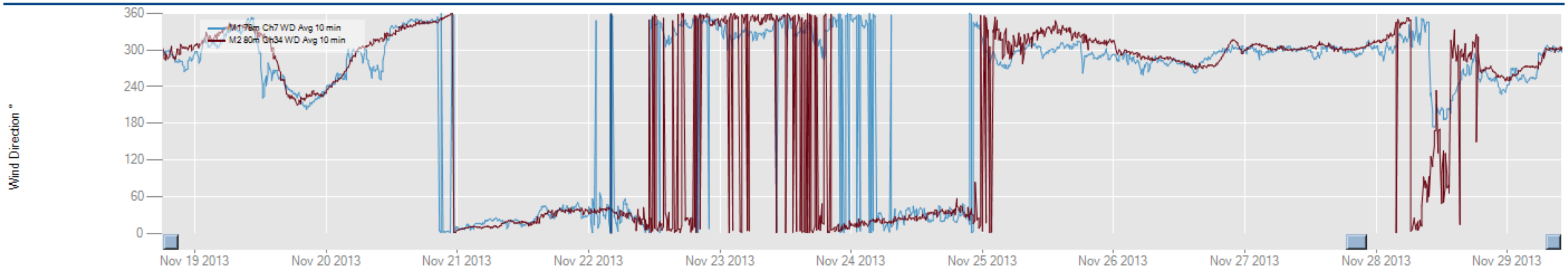
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	0.13	0.13	0.11	0.13	0.13	0.15	0.15	0.14	0.14	0.13	0.15	0.14	0.14
All	0.13	0.13	0.11	0.13	0.13	0.15	0.15	0.14	0.14	0.13	0.15	0.14	0.14

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	0.11	0.12	0.13	0.13	0.13	0.16	0.14	0.14	0.12	0.12	0.12	0.12	0.13
All	0.11	0.12	0.13	0.13	0.13	0.16	0.14	0.14	0.12	0.12	0.12	0.12	0.13

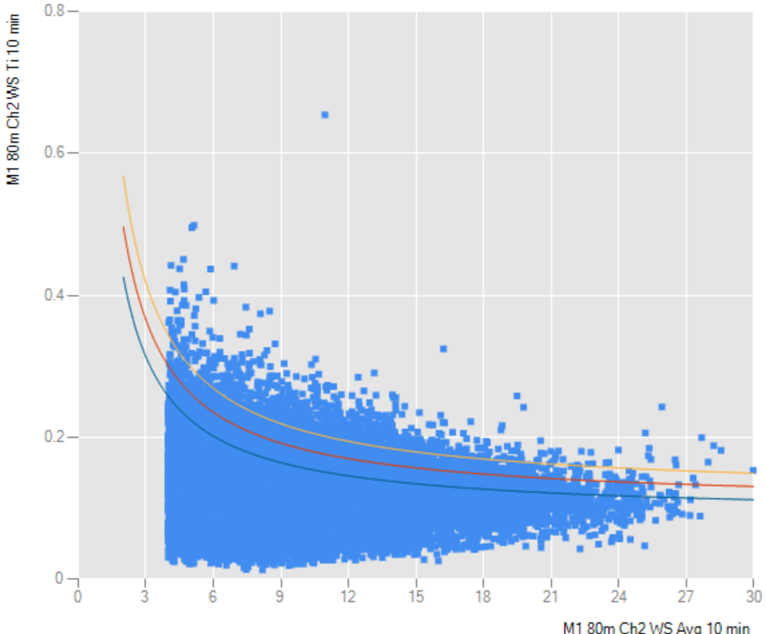
Scotland 1

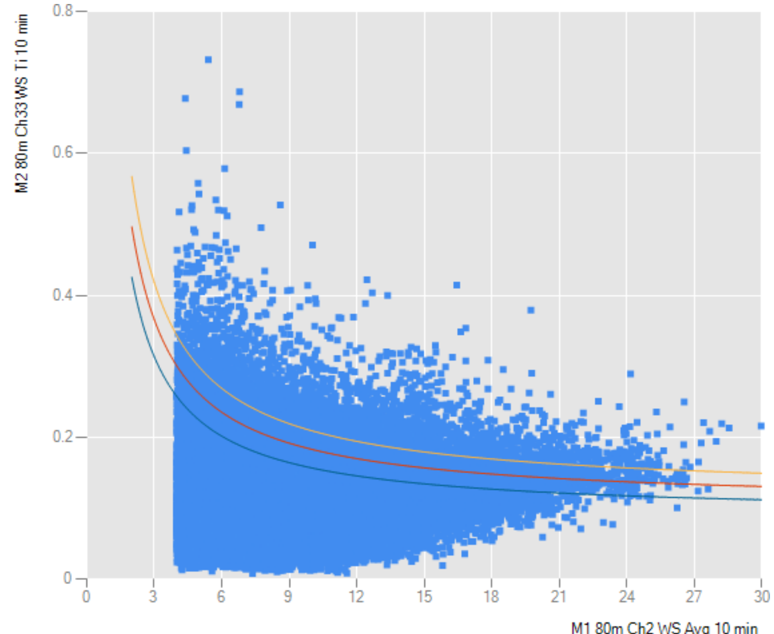
Period of low wind speed causing ”high” turbulence intensity

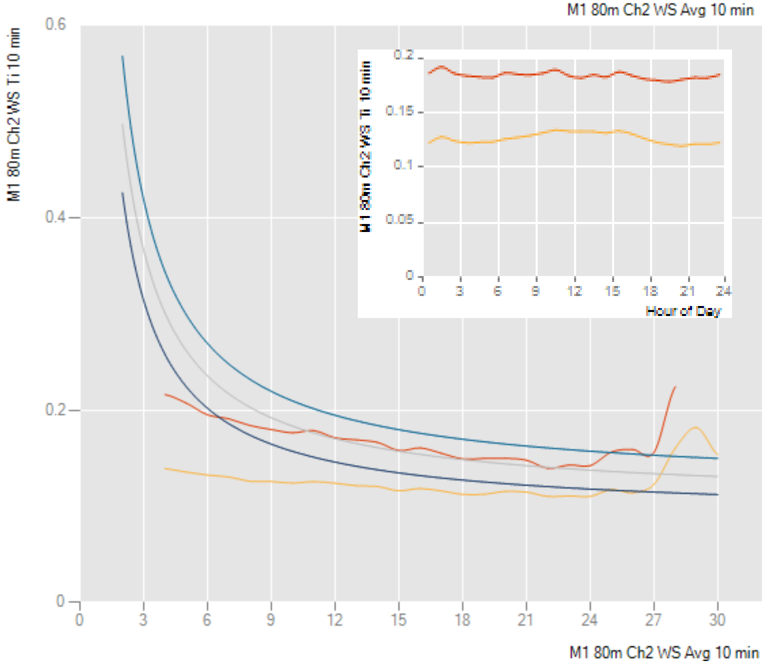


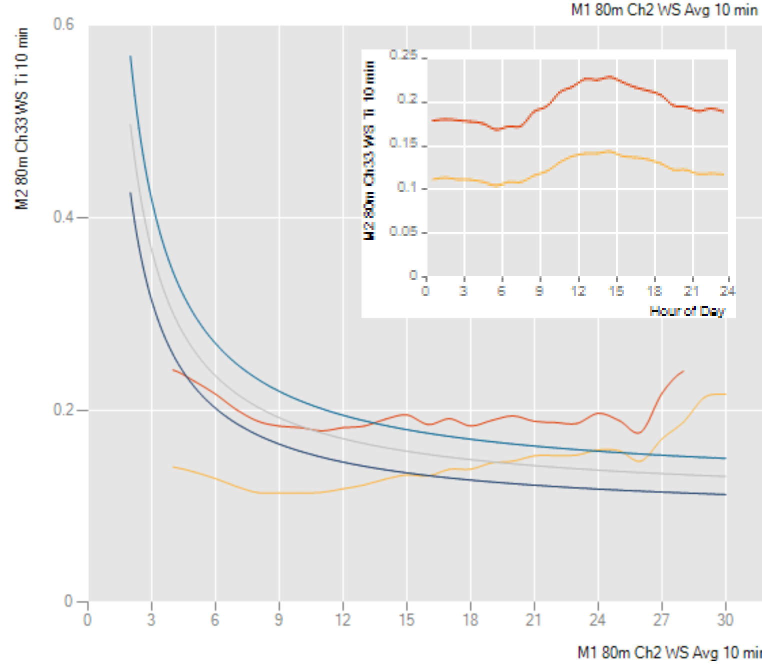


Scotland 1

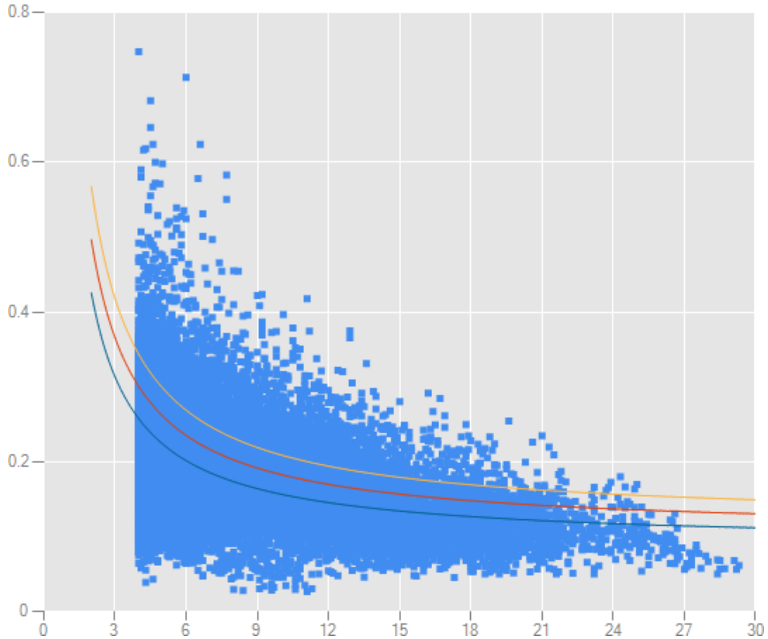

M1 80m Ch2 WS Ti 10 min
0.8
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30
M1 80m Ch2 WS Avg 10 min

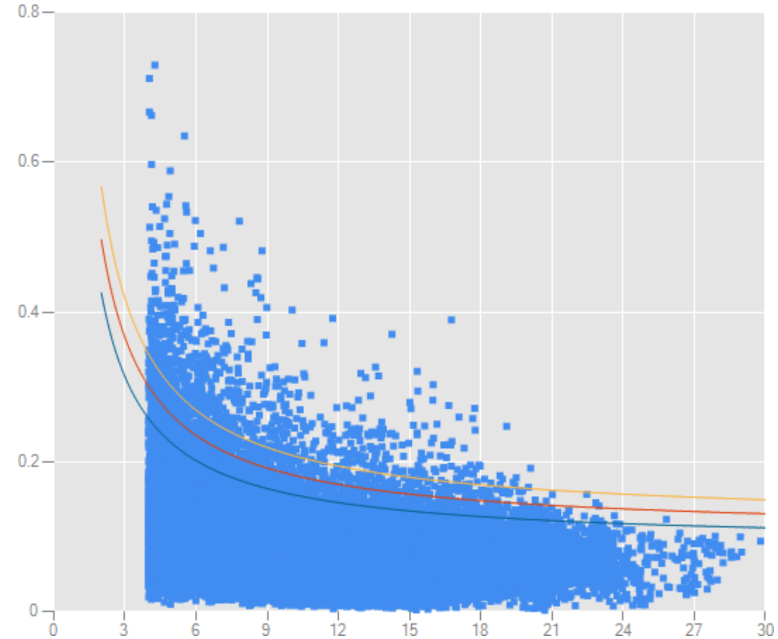

M2 80m Ch33 WS Ti 10 min
0.8
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30
M1 80m Ch2 WS Avg 10 min

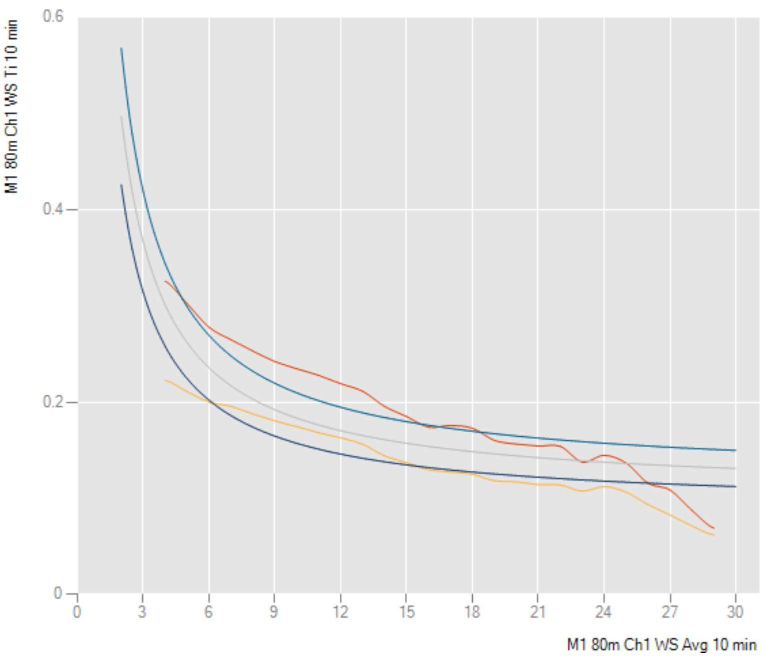

M1 80m Ch2 WS Ti 10 min
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30
M1 80m Ch2 WS Avg 10 min
M1 80m Ch2 WS Ti 10 min
0.2
0.15
0.1
0.05
0
0 3 6 9 12 15 18 21 24
Hour of Day

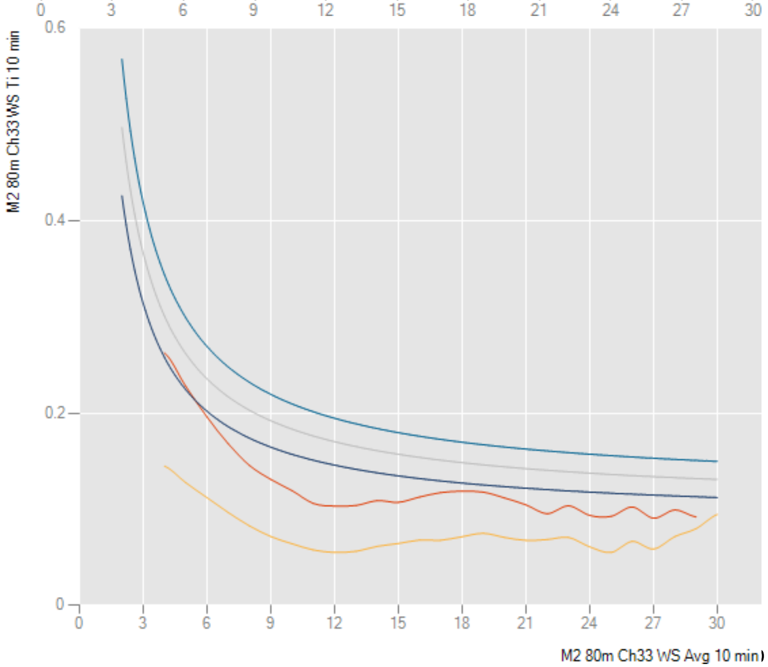

M2 80m Ch33 WS Ti 10 min
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30
M1 80m Ch2 WS Avg 10 min
M2 80m Ch33 WS Ti 10 min
0.25
0.2
0.15
0.1
0.05
0
0 3 6 9 12 15 18 21 24
Hour of Day

USA 1


0.8
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30


0.8
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30

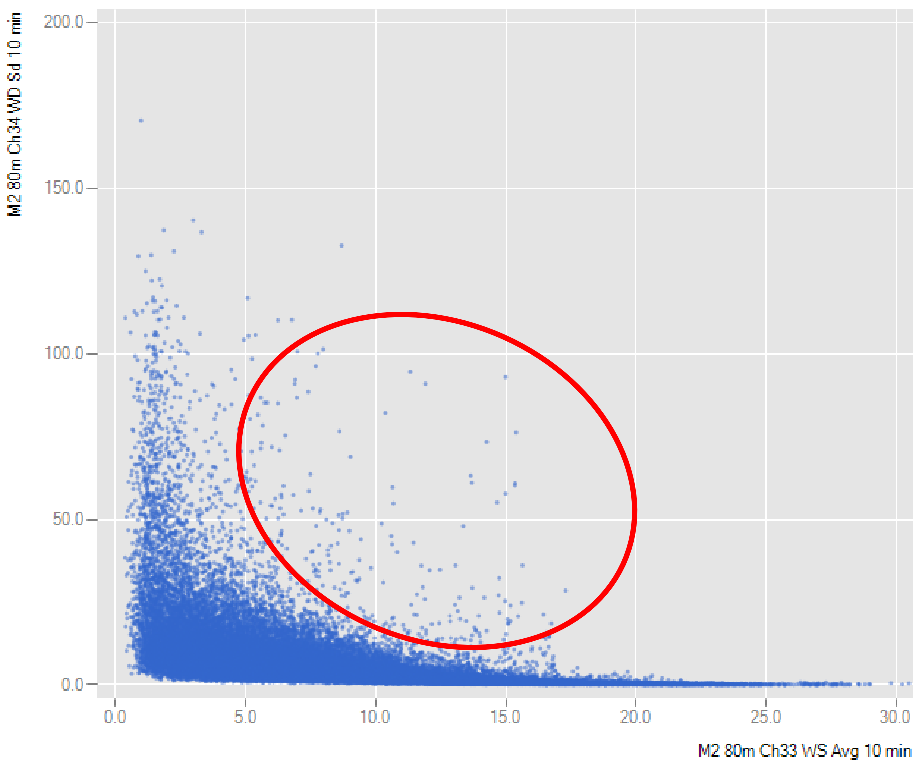

M1 80m Ch1 WS Ti 10 min
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30
M1 80m Ch1 WS Avg 10 min


M2 80m Ch33 WS Ti 10 min
0.6
0.4
0.2
0
0 3 6 9 12 15 18 21 24 27 30
M2 80m Ch33 WS Avg 10 min)

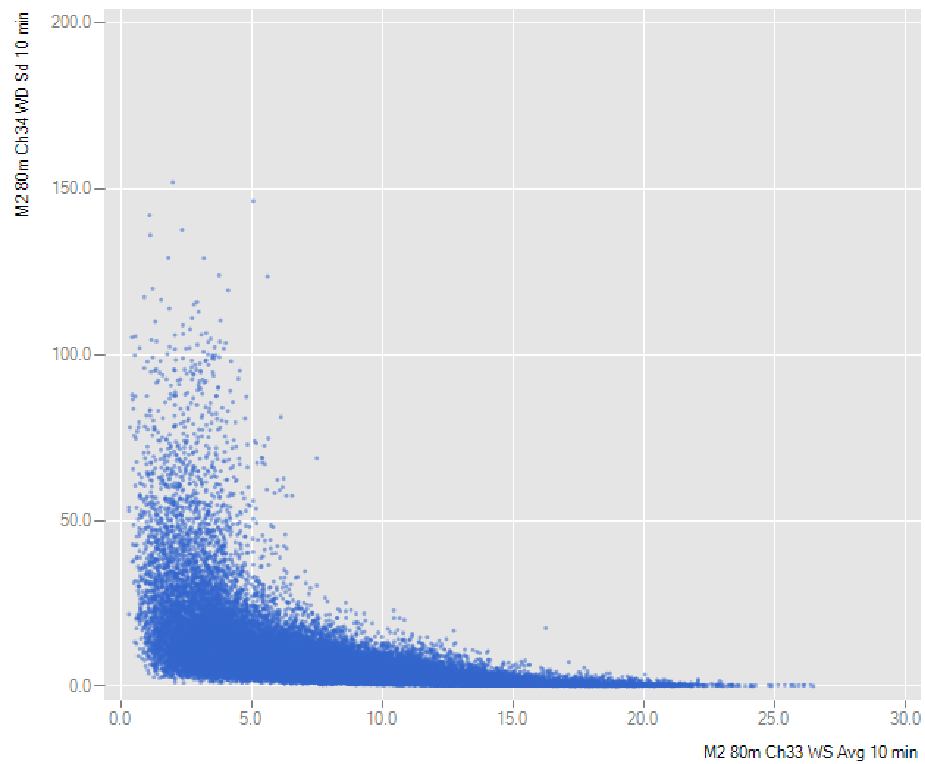
US.™

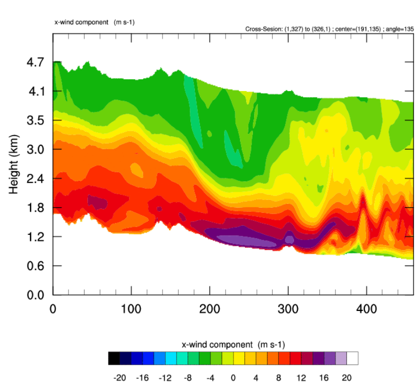
Vestas

USA 1



Scotland 1



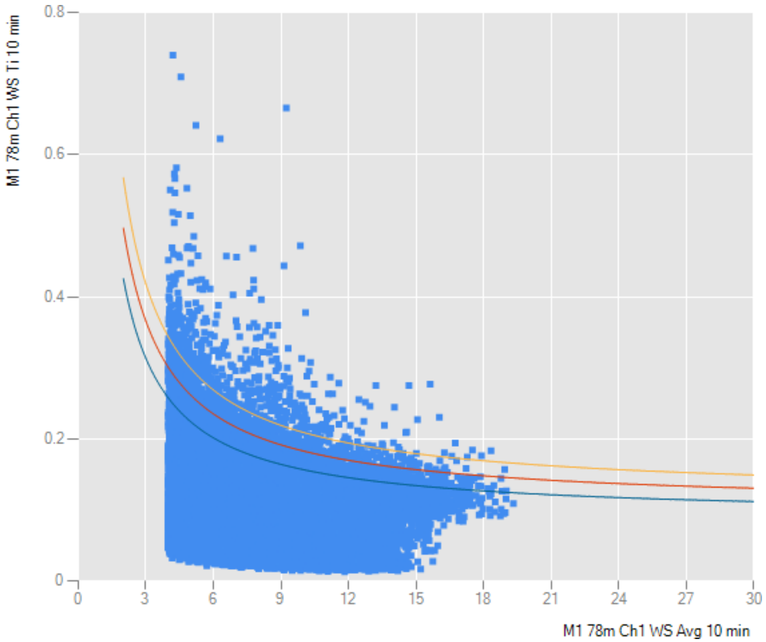


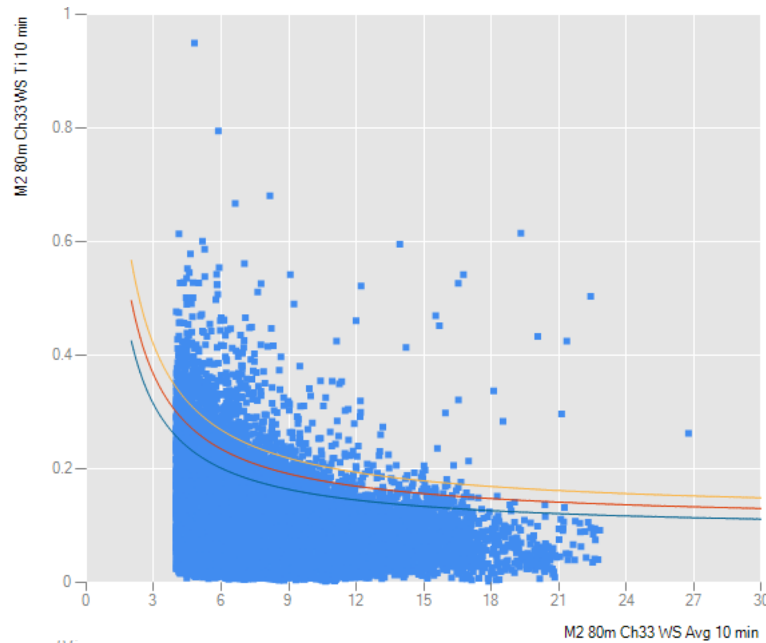
σ(WDir) vs. Wspeed

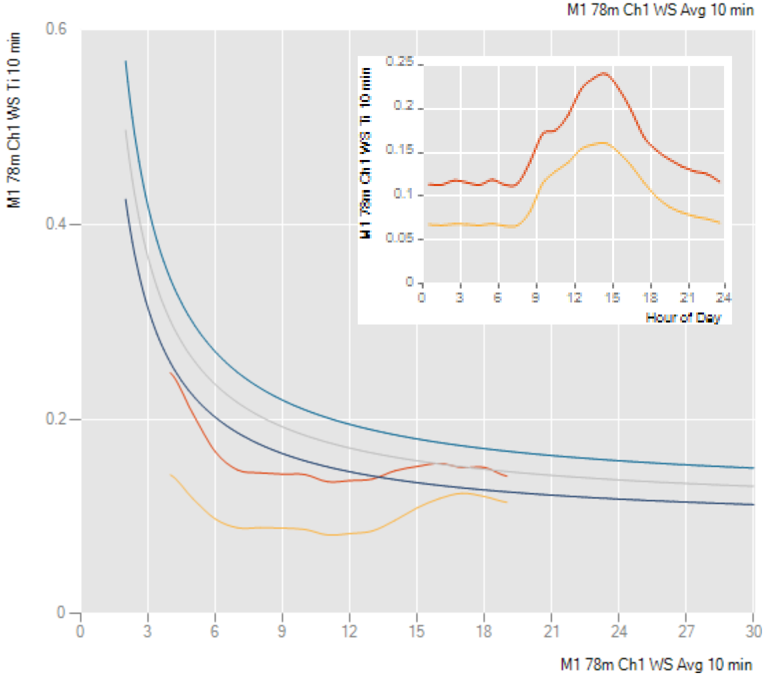
Indicates rapid direction changes

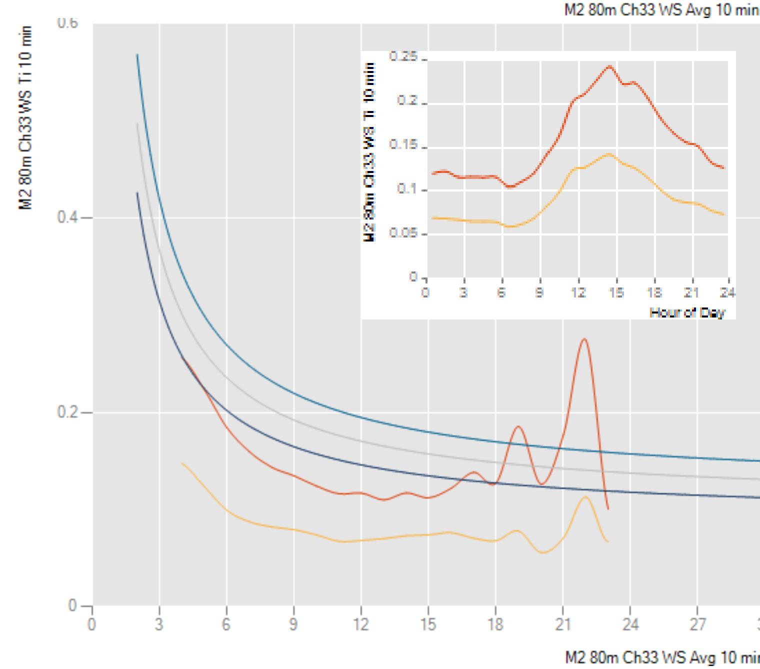
Available in Vortex WRF-LES output

India 1



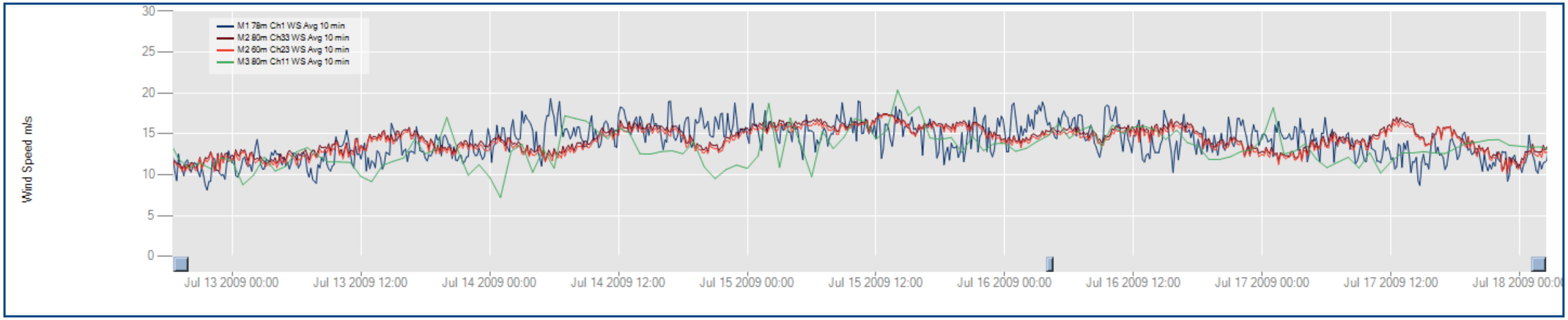






l to us.™

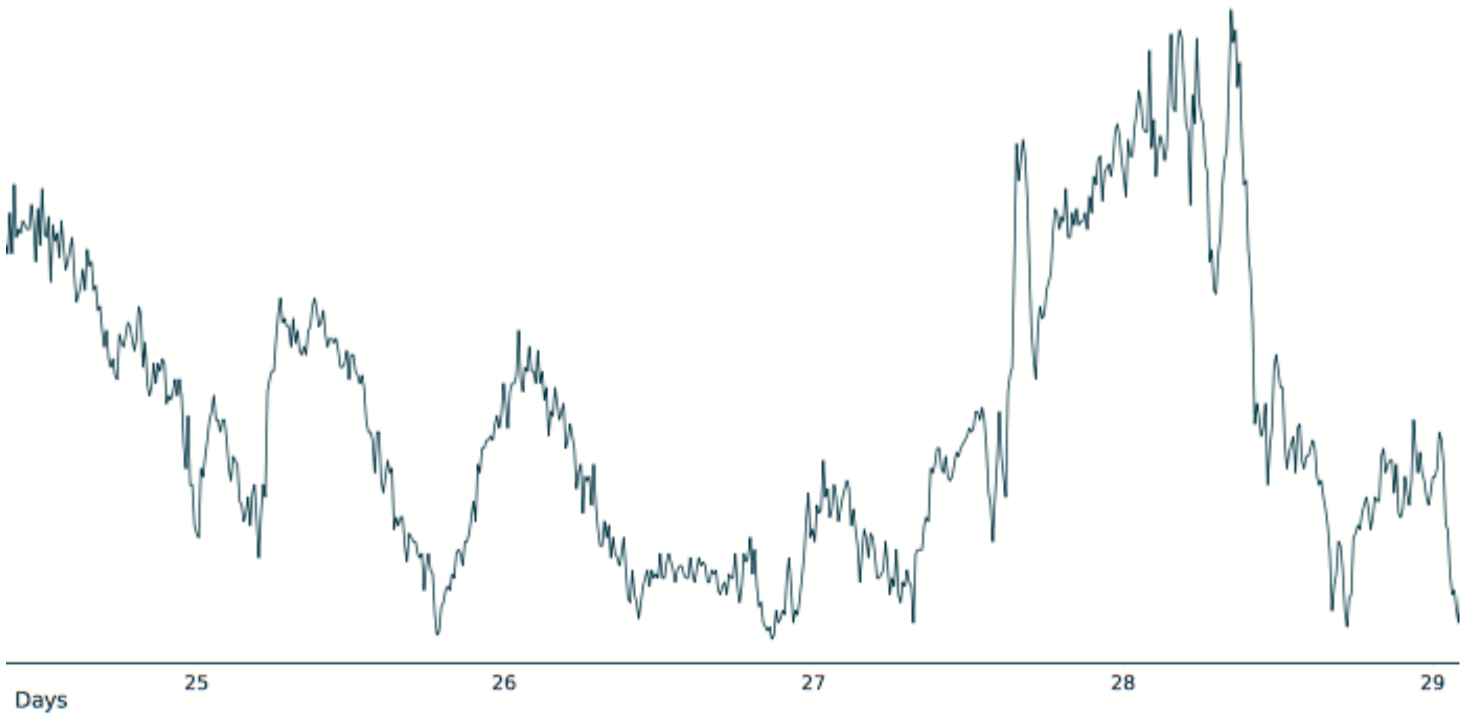
India 1



Observed at met-mast
Vestas WRF 3km
Vortex WRF-LES

- Not whole weather is simulated accurately
- But the statistics of wind speed, turbulence, ... is very comparable
- Future development?

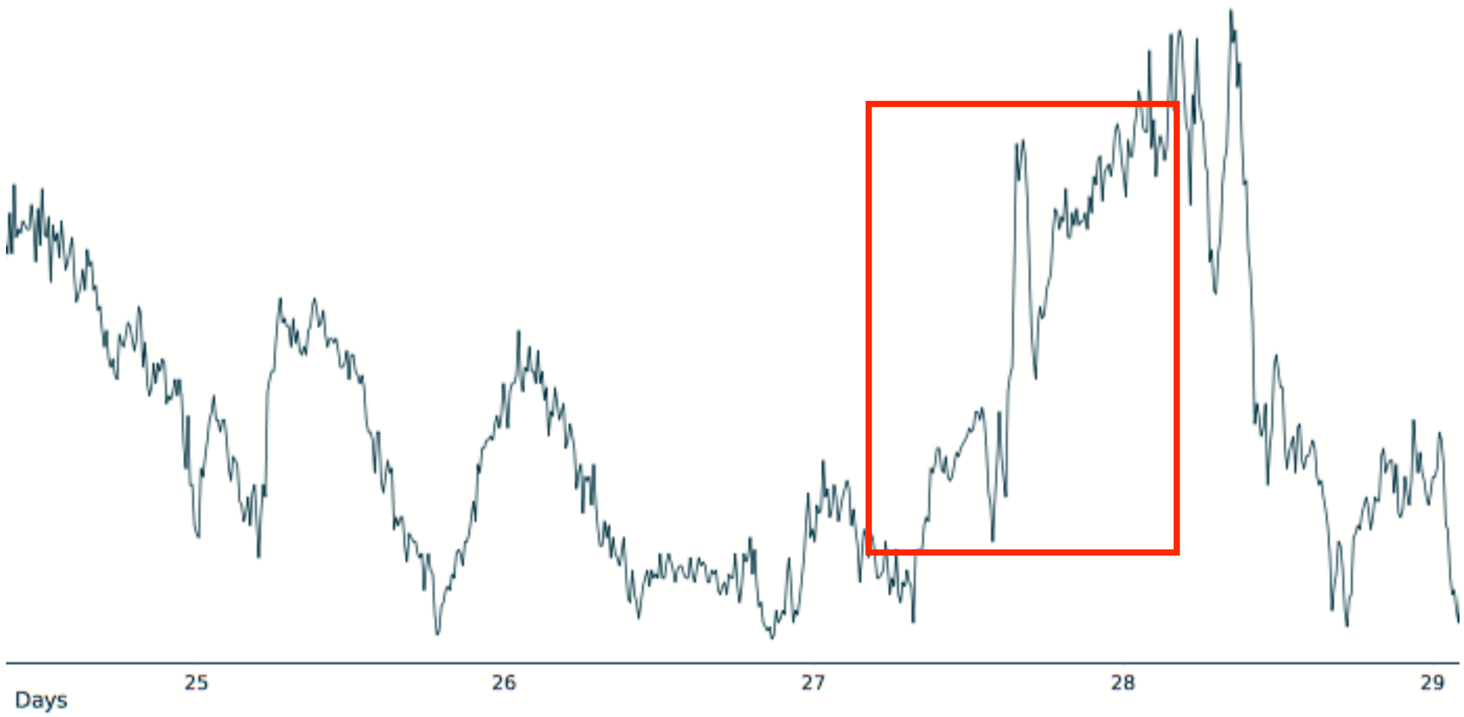
Guess which are the measurements…



…and which are the model results

LES IS MORE!

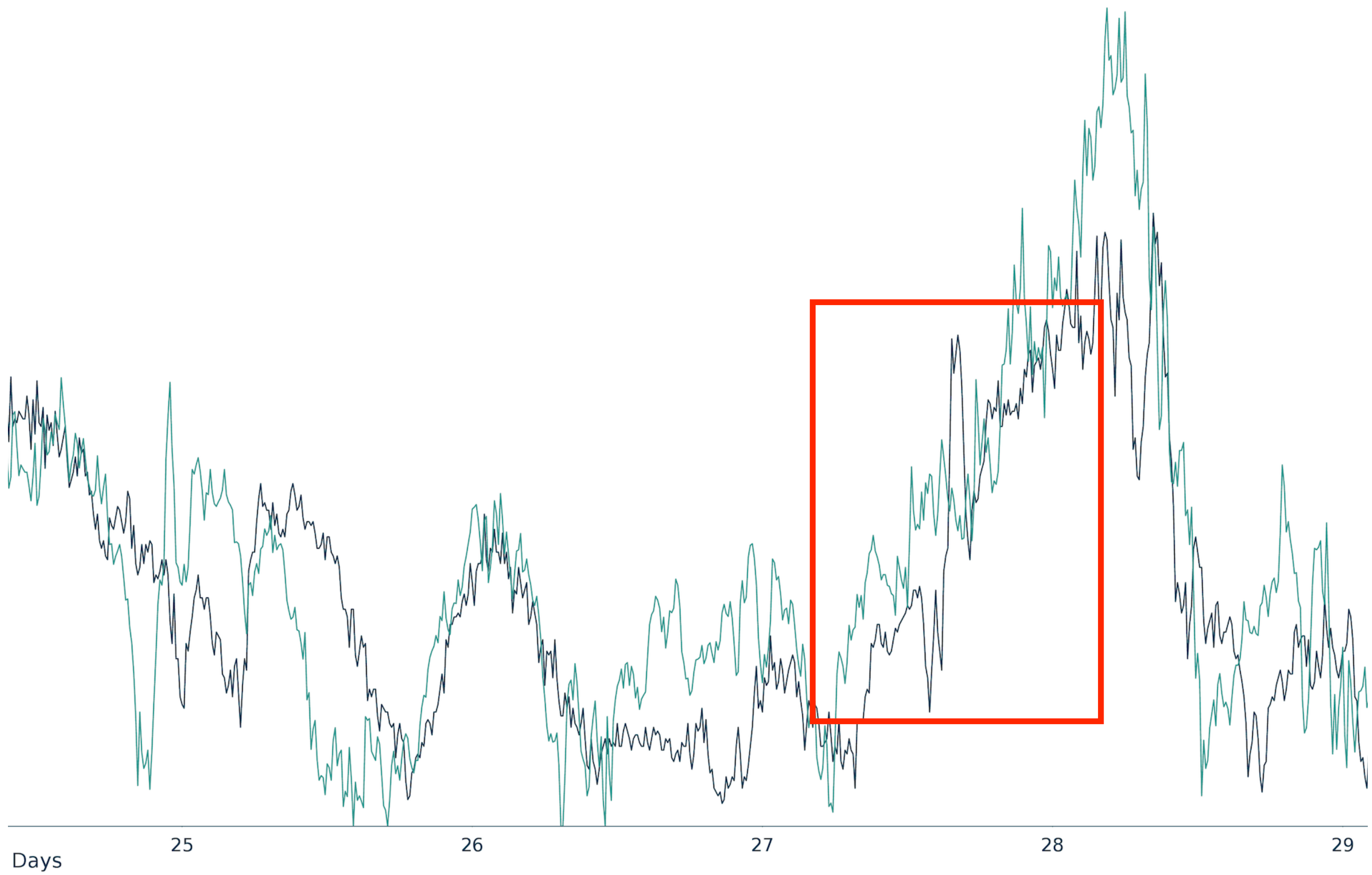
Guess which are the measurements…



…and which are the model results

LES IS MORE!

Guess which are the measurements…



…and which are the model results

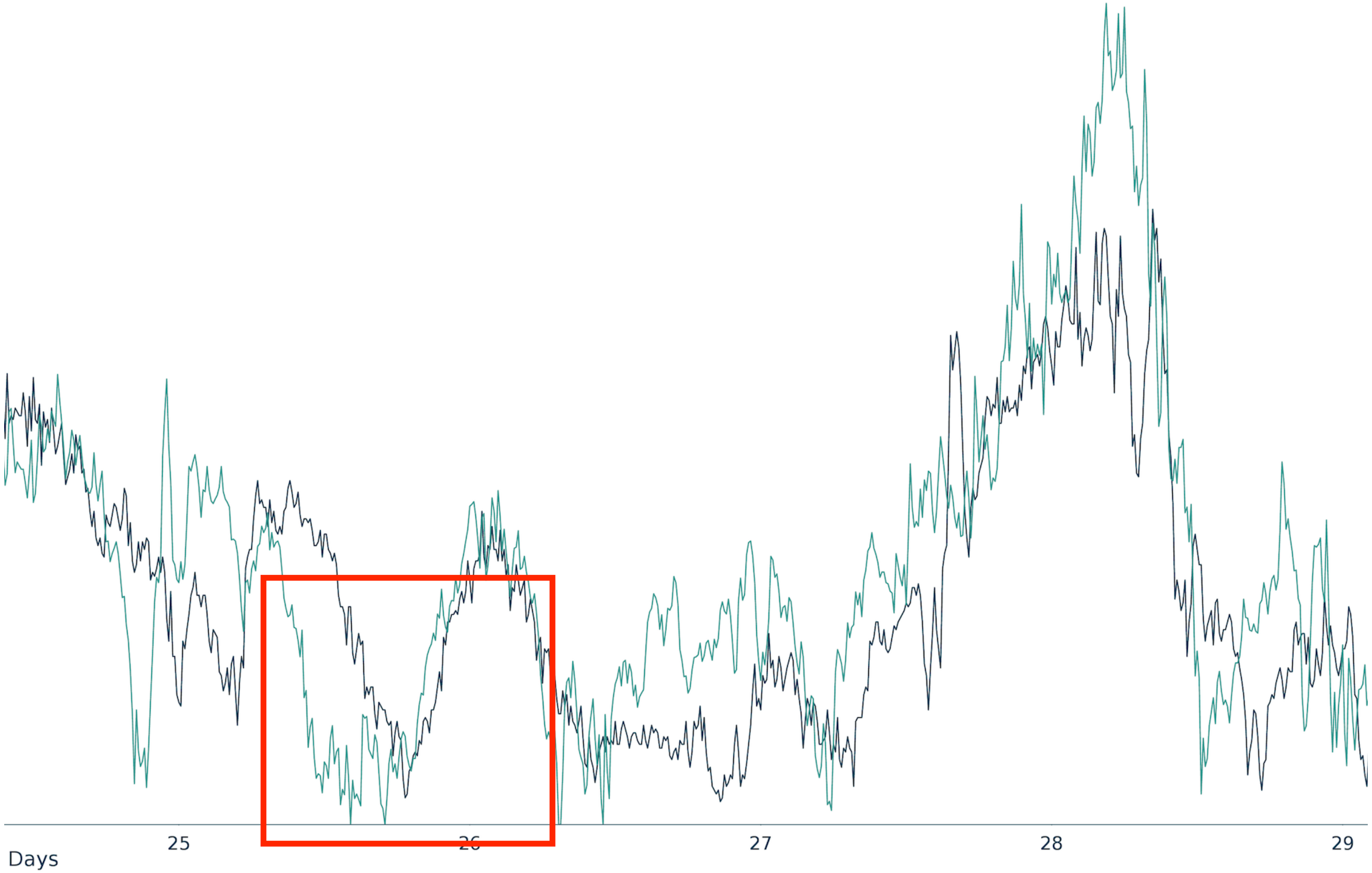
LES IS MORE!

Guess which are the measurements…

…and which are the model results

LES IS MORE!

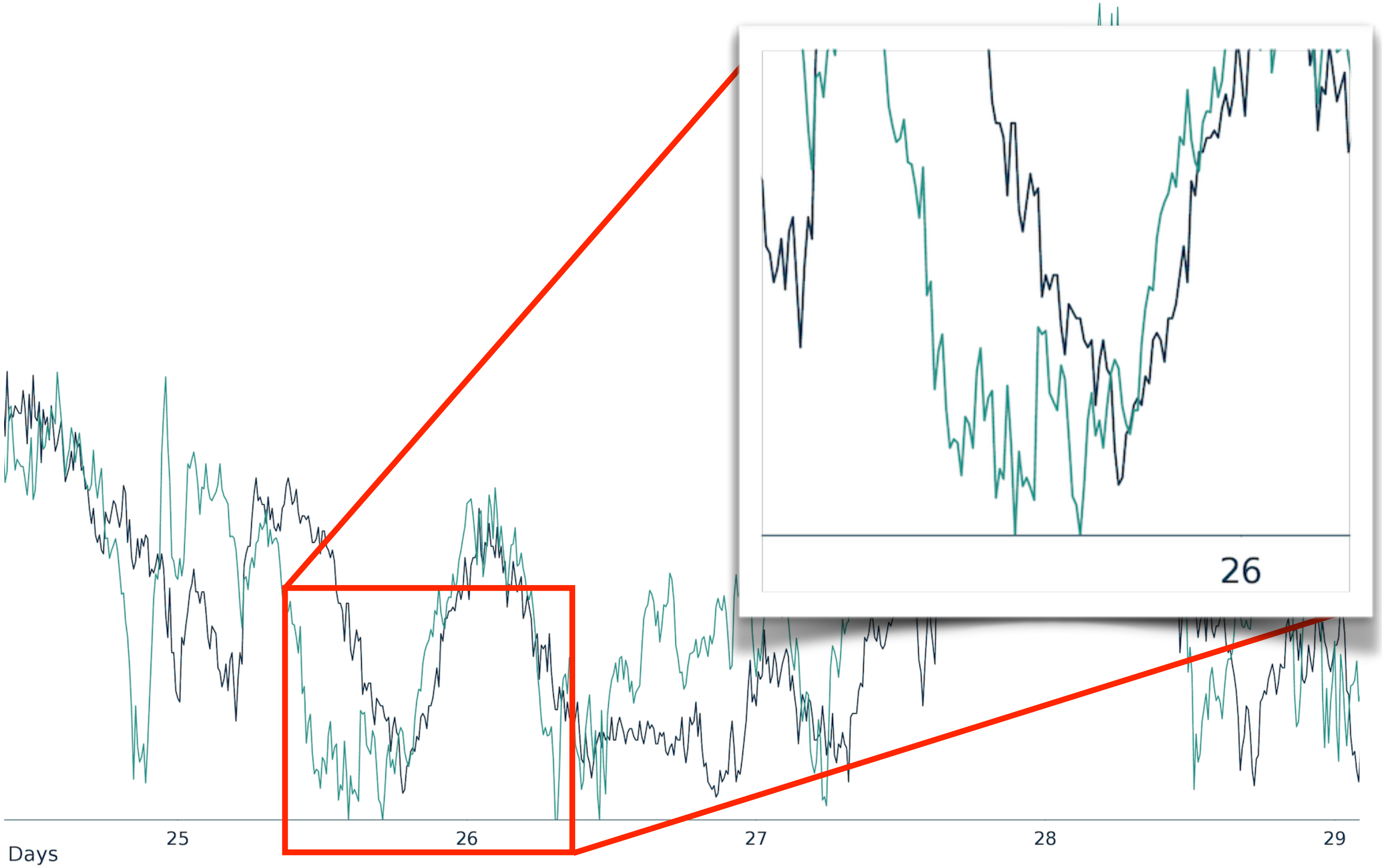
Guess which are the measurements…



…and which are the model results

LES IS MORE!

Guess which are the measurements…

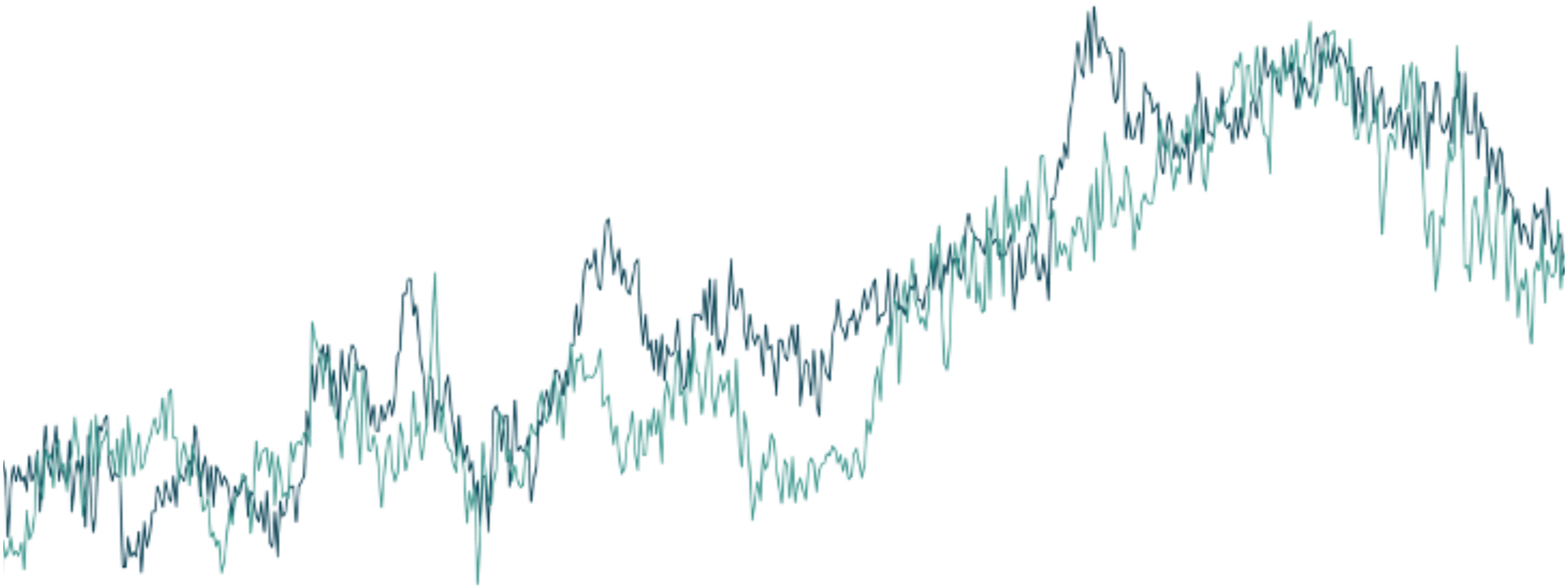


…and which are the model results

LES IS MORE!

LES* IS MORE!

*LARGE EDDY SIMULATIONS BY VORTEX



WindEnergy Hamburg 2016