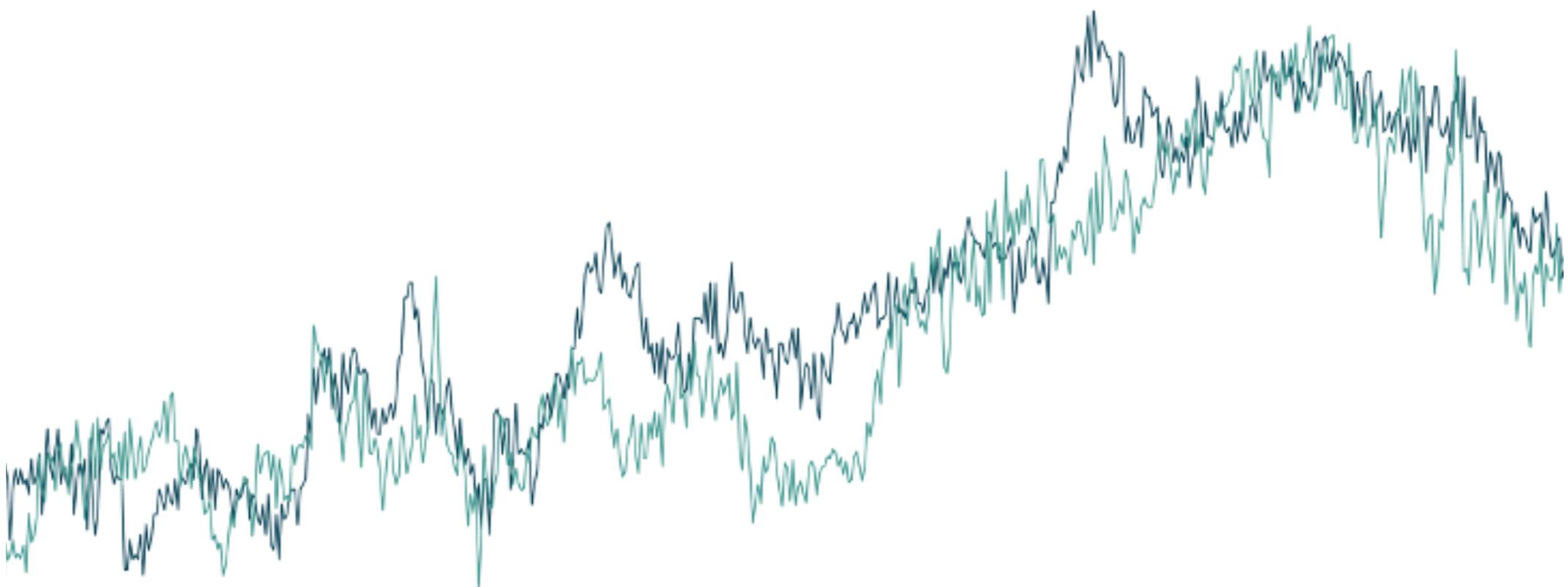




# LES\* IS MORE!

\*LARGE EDDY SIMULATIONS BY VORTEX



WindEnergy Hamburg 2016

# OUTLINE

**MOTIVATION** Pep Moreno. CEO, Vortex

**BASIS** Alex Montornés. *Modelling Specialist, Vortex*

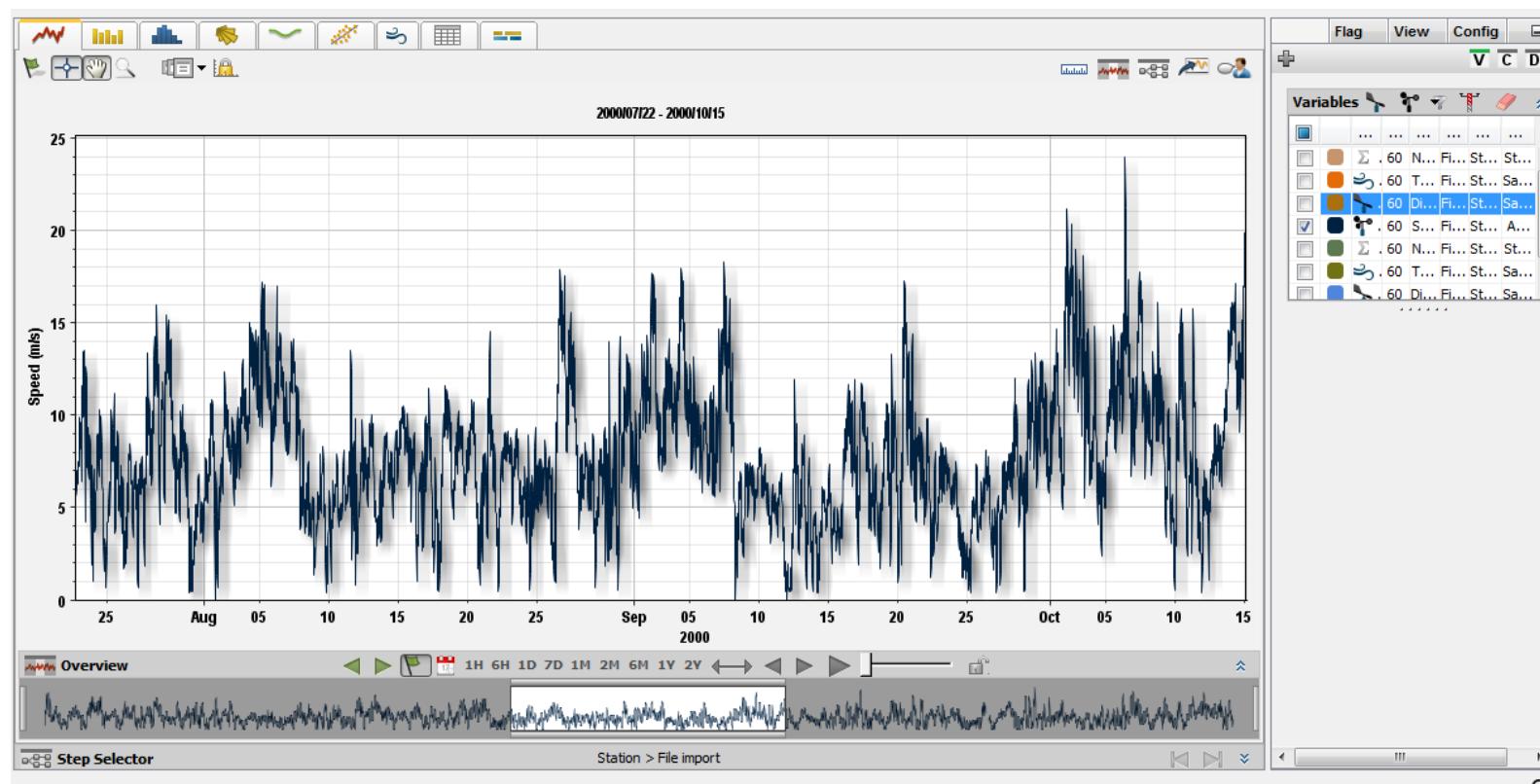
**VALIDATION** Mark Žagar. *Modelling Specialist, Vestas*

Q & A



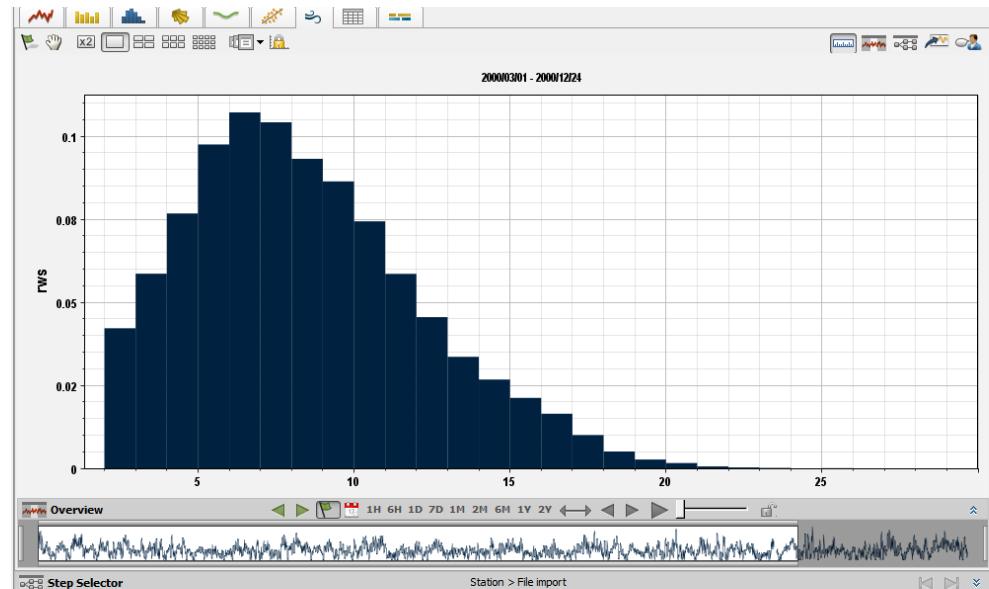
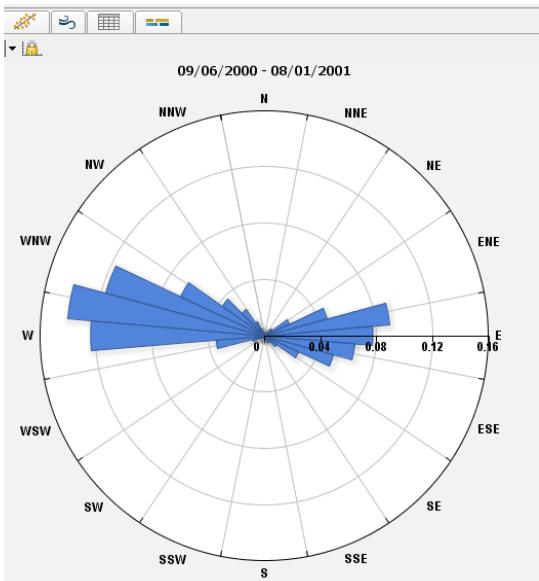
LES IS MORE!

# Time series, why?



LES IS MORE!

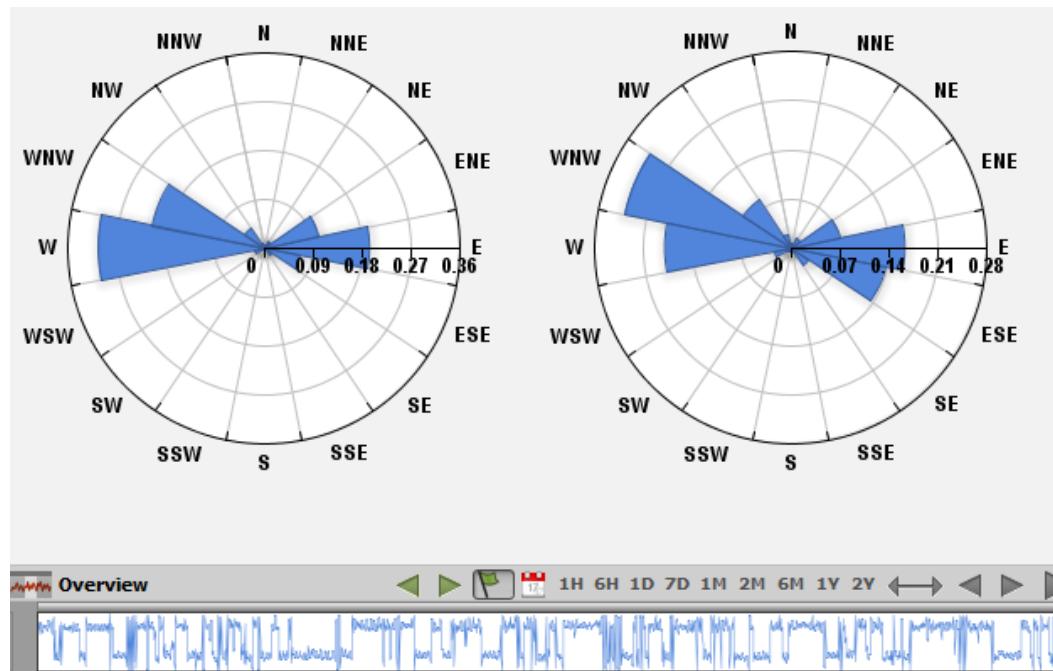
# Time series, why?



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

# Time series, why?

If full time series were available, you could...



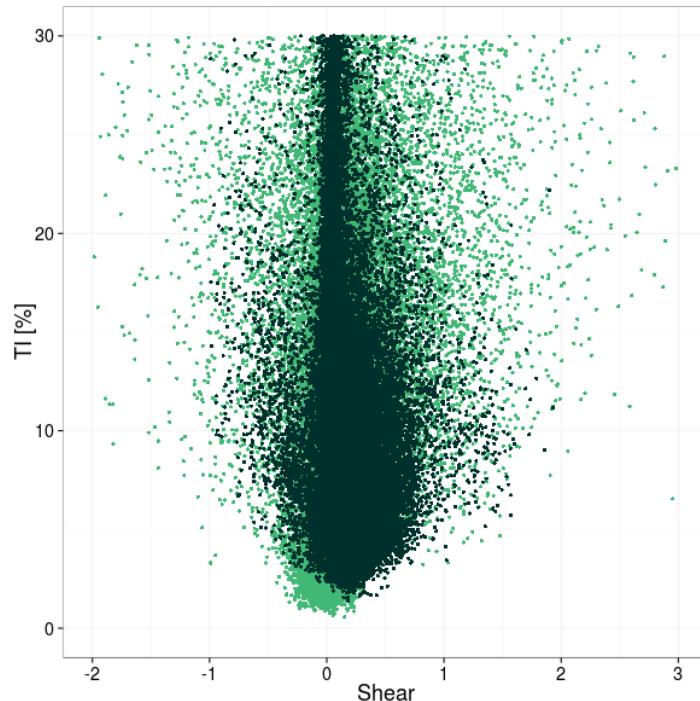
...discriminate (day/night)...



LES IS MORE!

# Time series, why?

If full time series were available, you could...



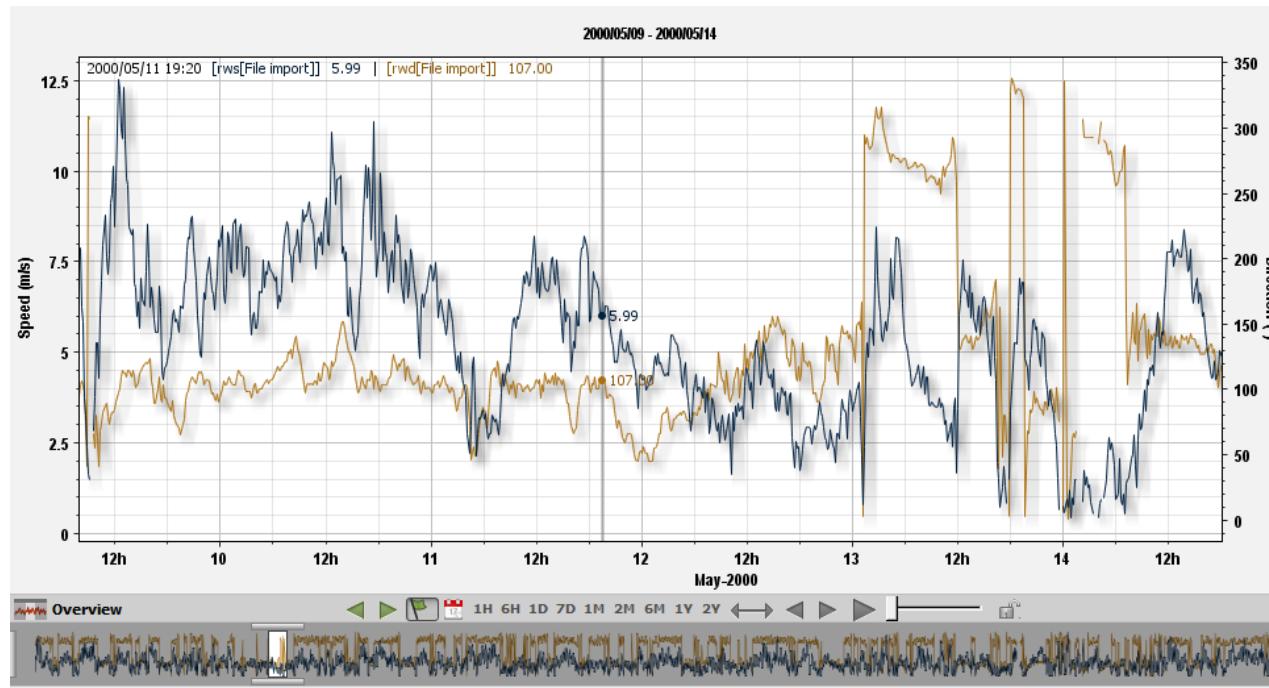
...cross-relate variables (TI vs. shear)



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!



LES IS MORE!

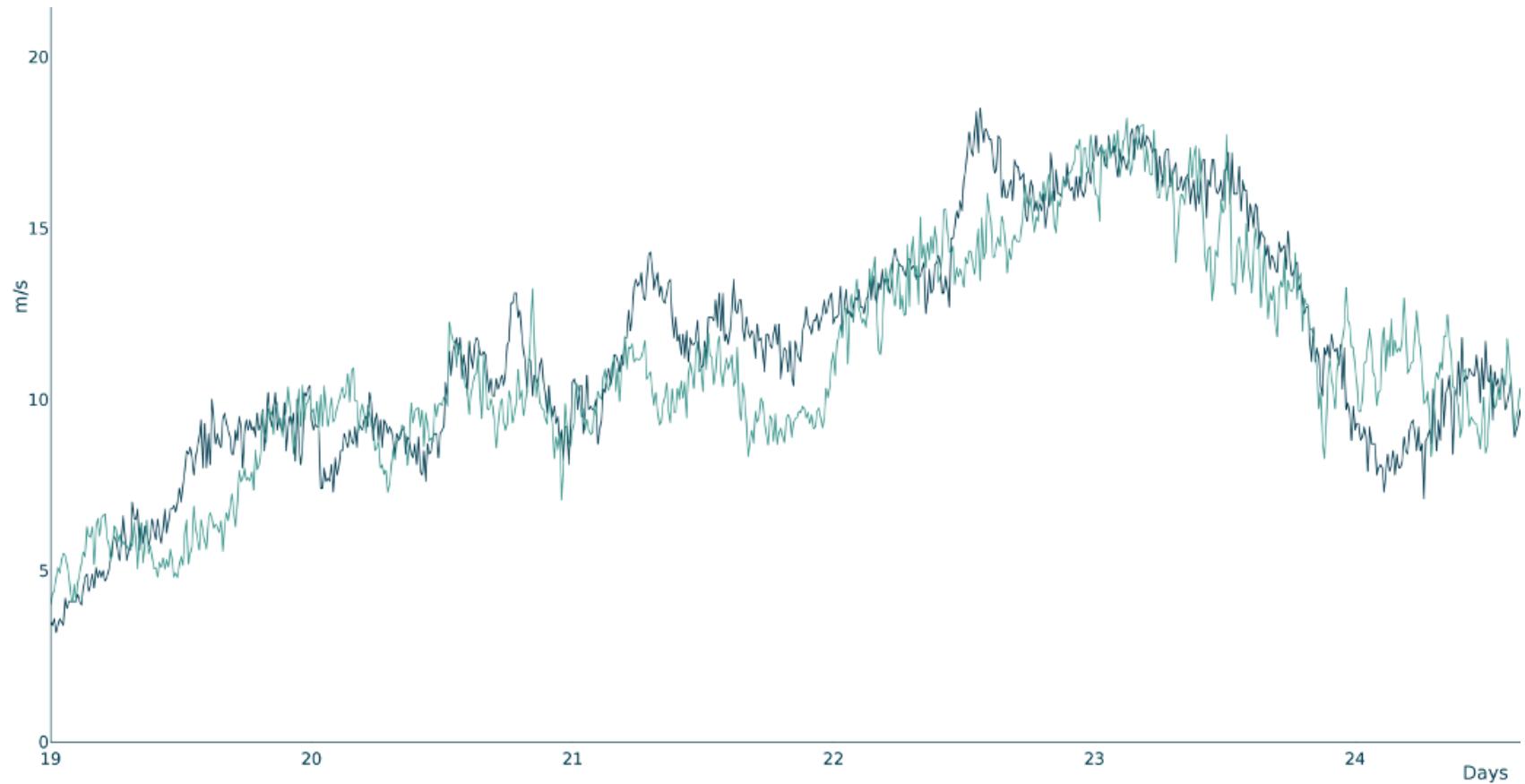
Have you ever wished to have a time series of measurements at each turbine position of your planned or existing wind farm?

Large Eddy Simulations (LES) produces something outstandingly similar!



LES IS MORE!

Guess which are the measurements...



...and which are the model results



LES IS MORE!

Measured time series are scarce (expensive)

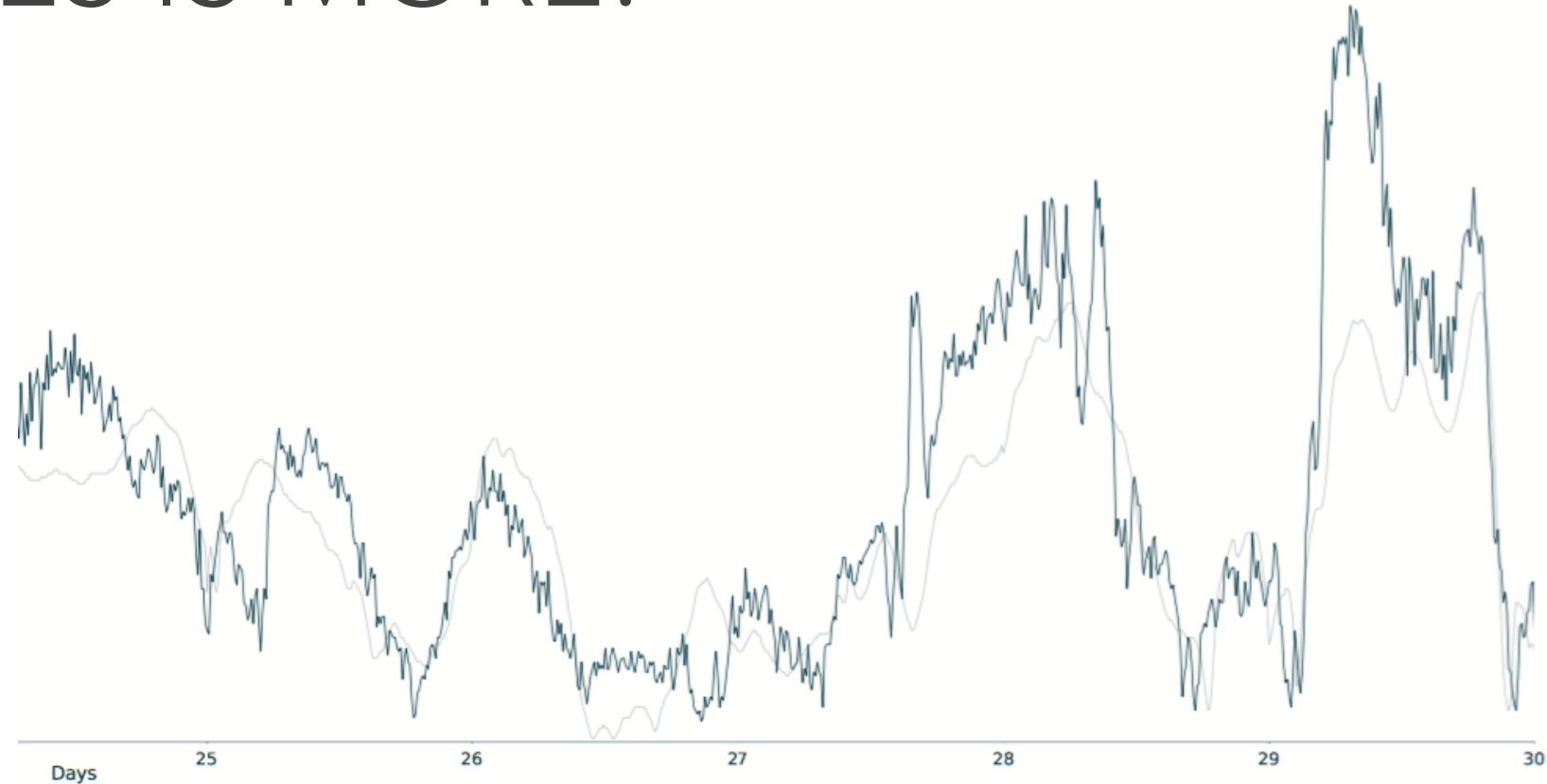
Distributions come mainly from windfield extrapolation (modeling): WAsP, CFD...

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



LES IS MORE!

# LES IS MORE!

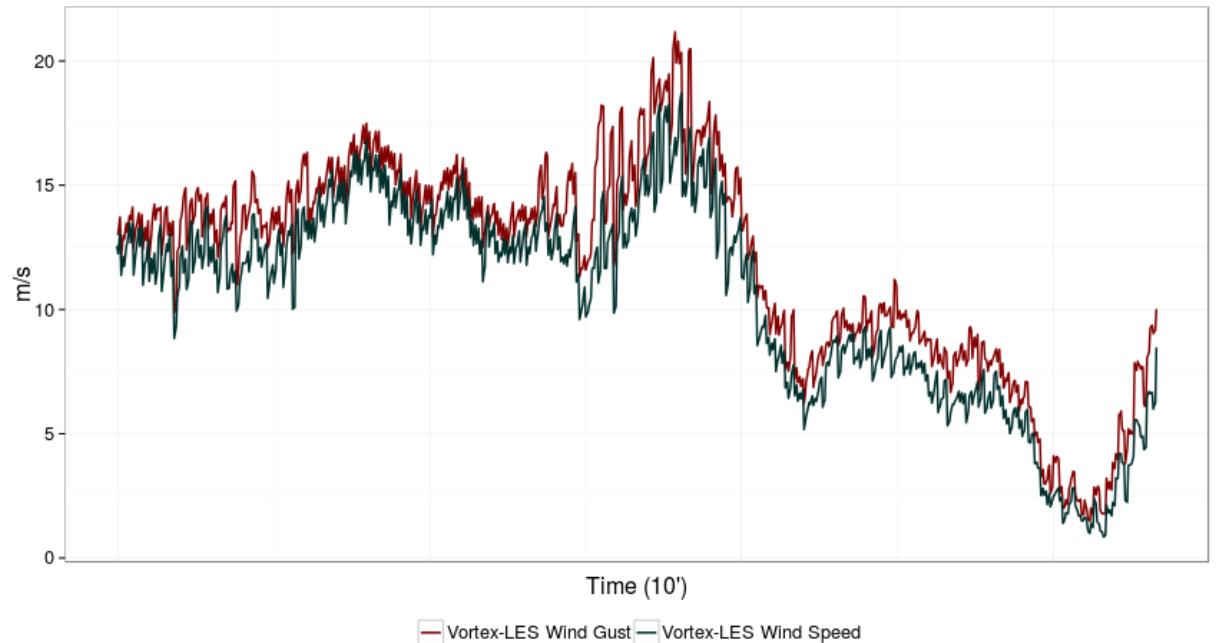
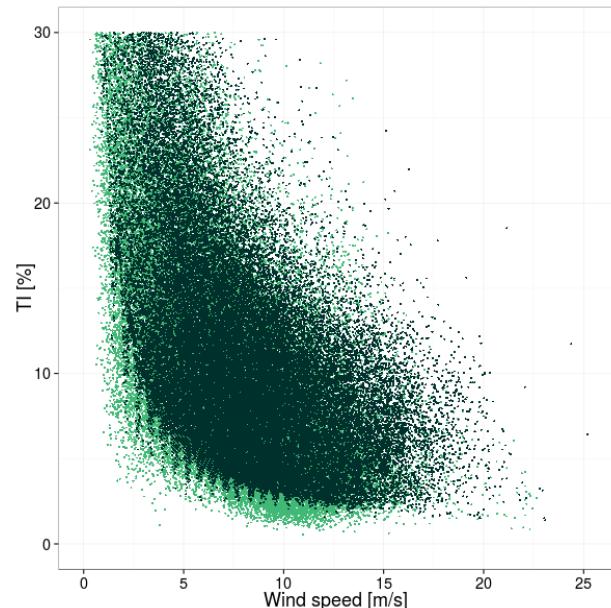


LES produces real (physical) 10' averages



LES IS MORE!

# LES IS MORE!

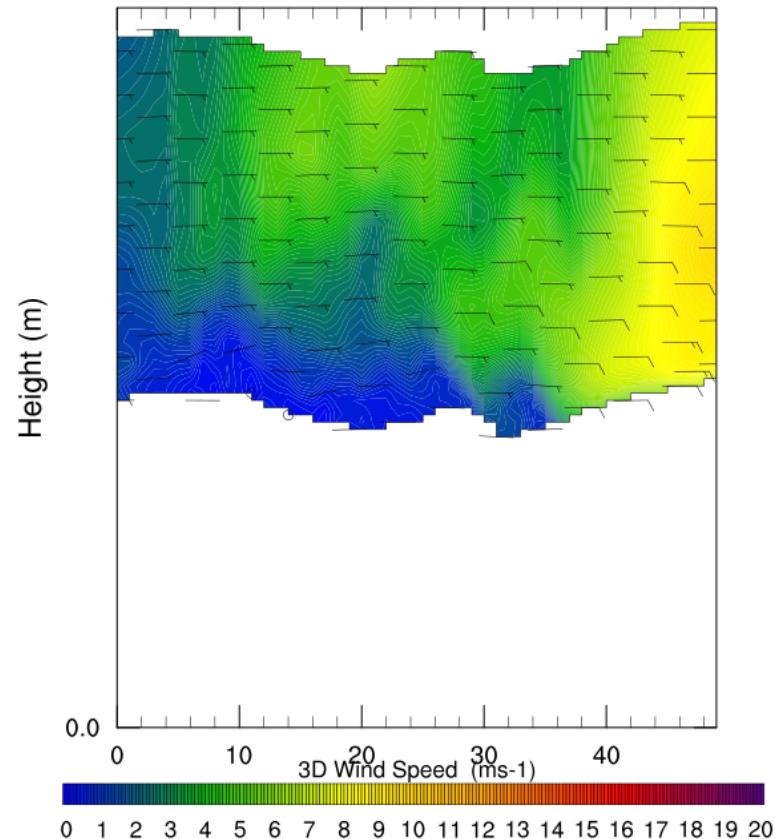


LES produces 3" samples (TI, gust...)



LES IS MORE!

# LES IS MORE!



LES produces 3D results (shear and veer)



LES IS MORE!



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

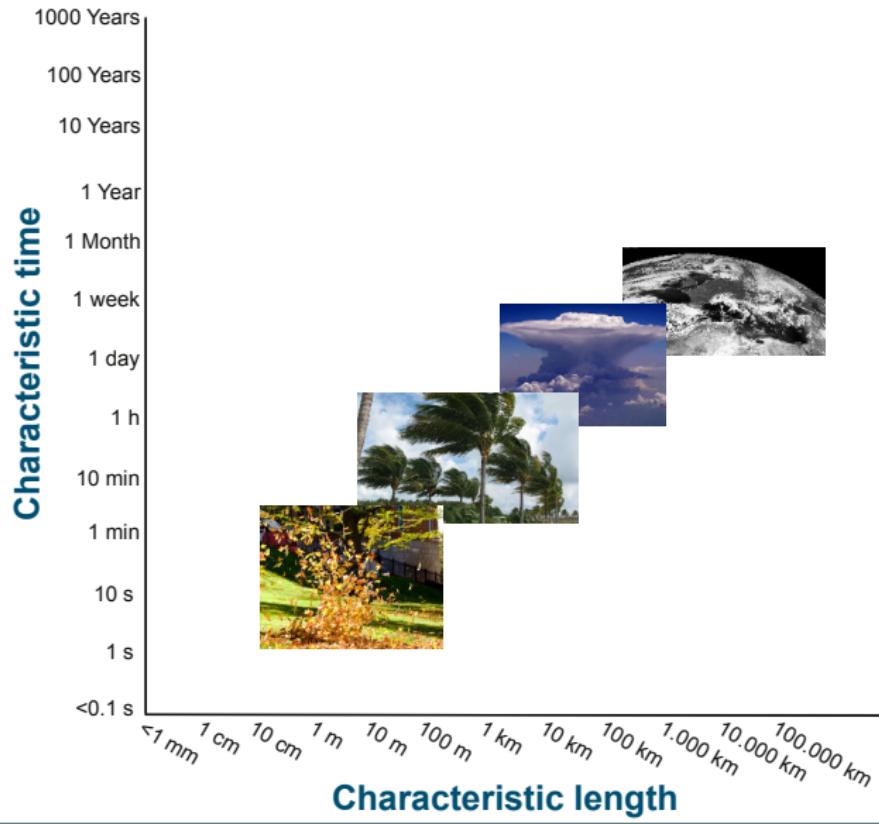


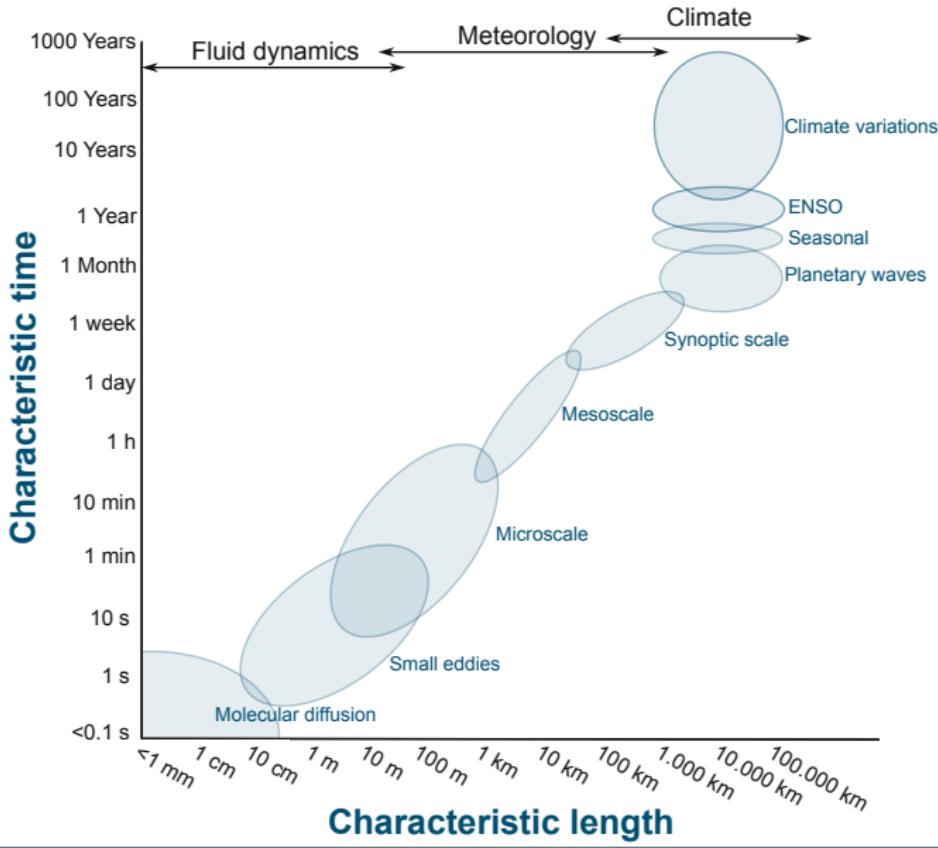


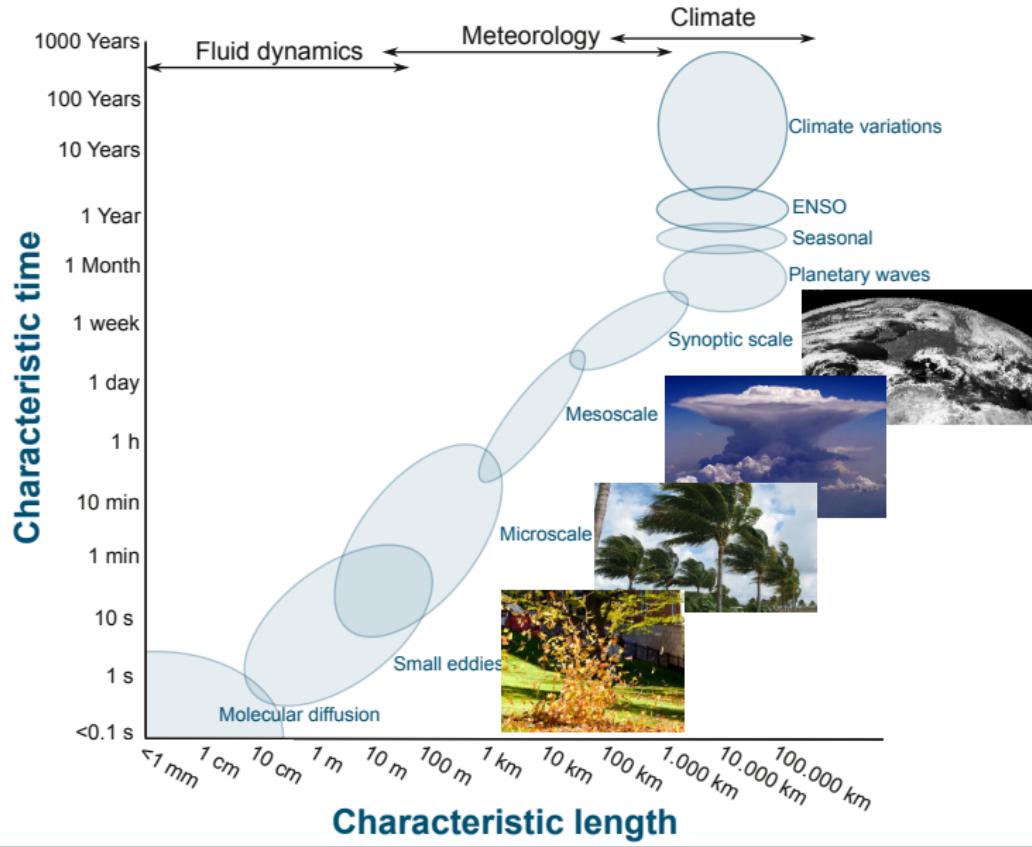
**Characteristic time**

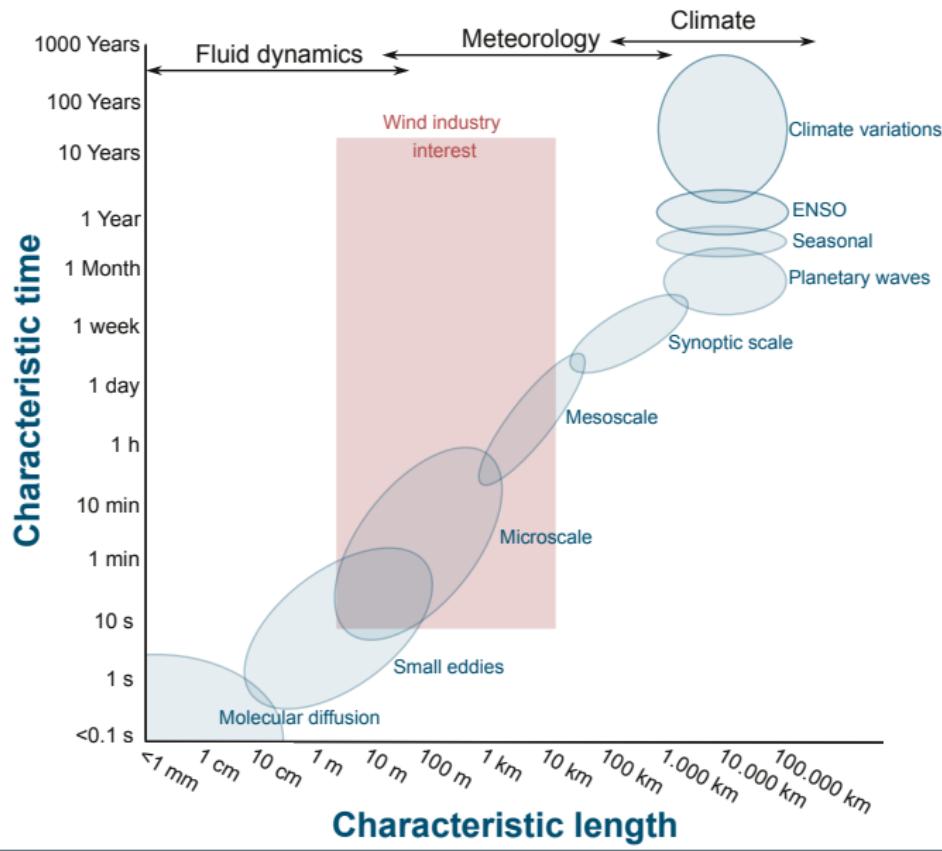


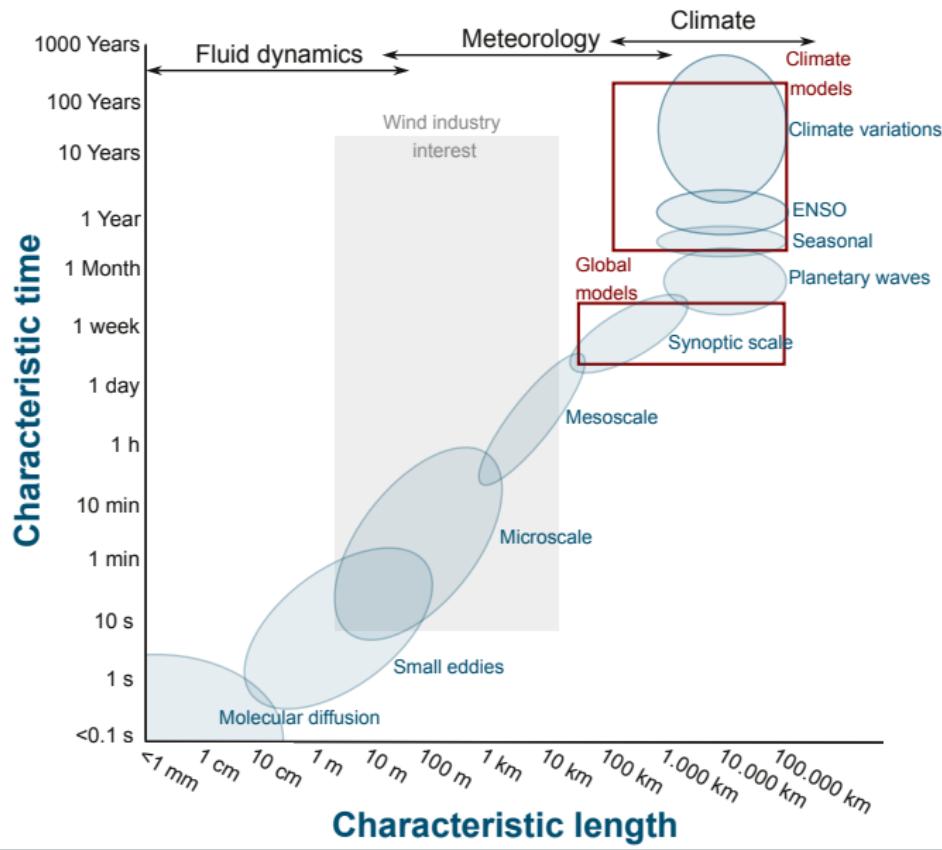
**Characteristic length**

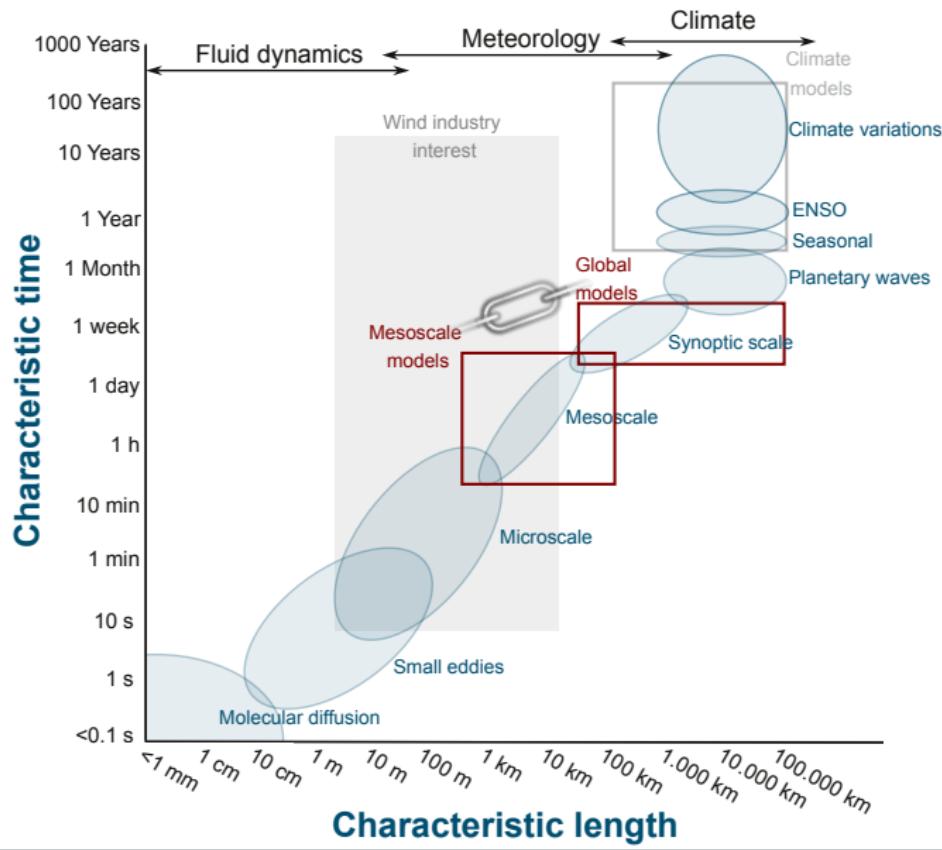


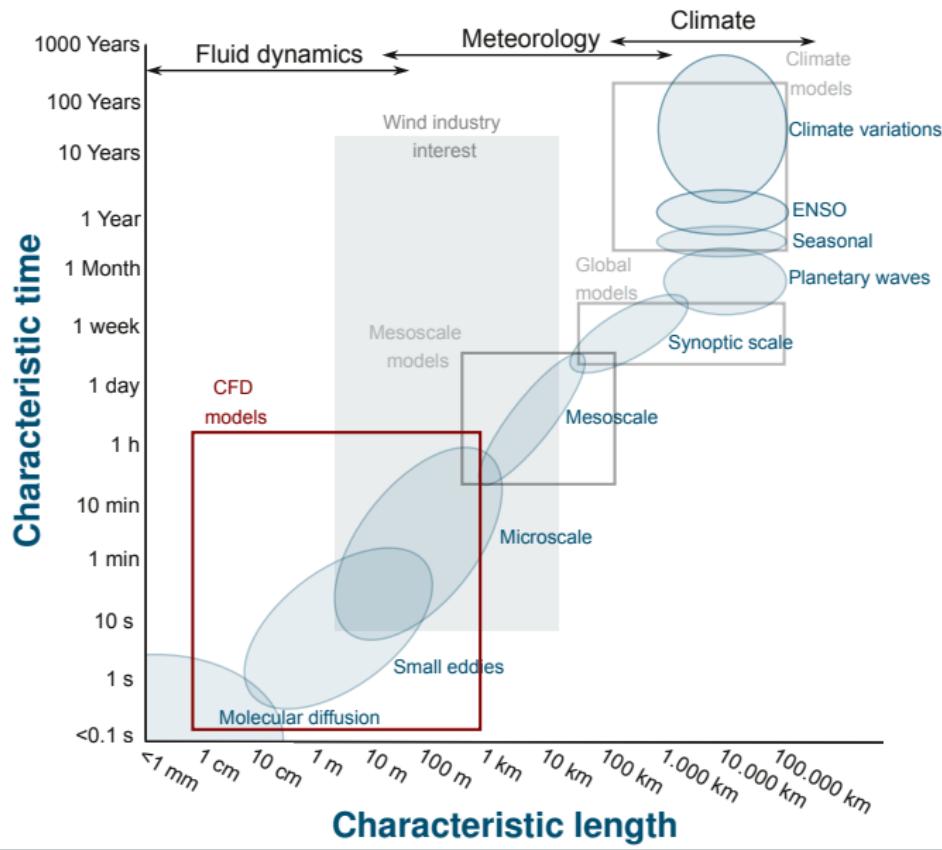


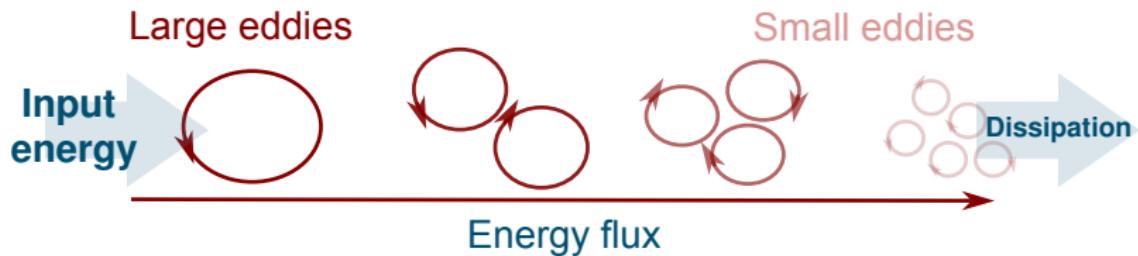


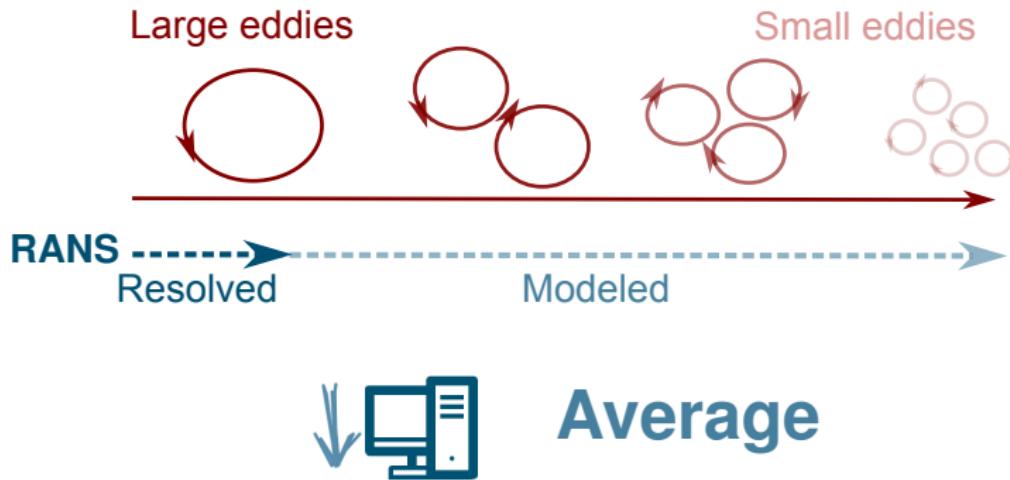


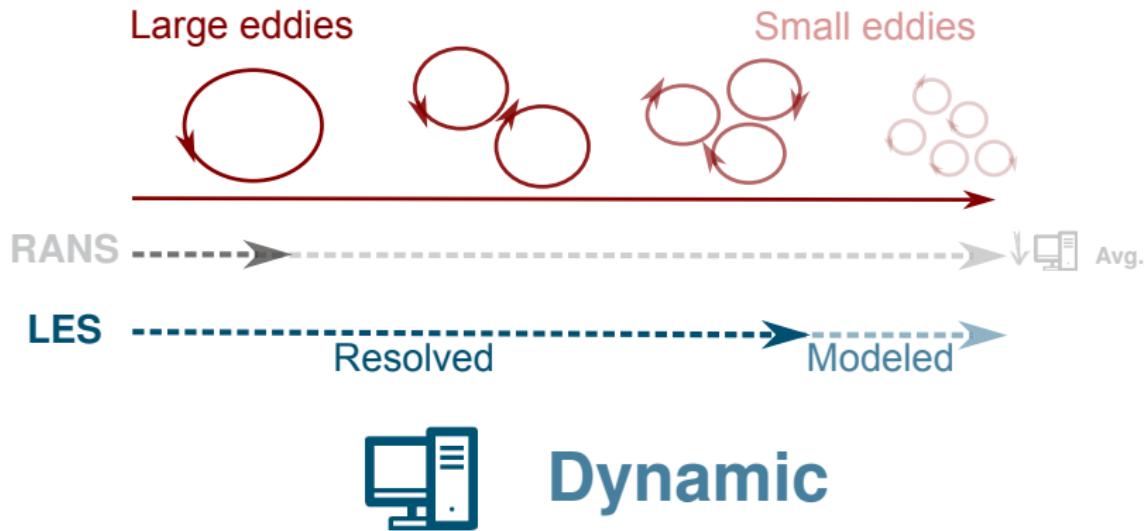


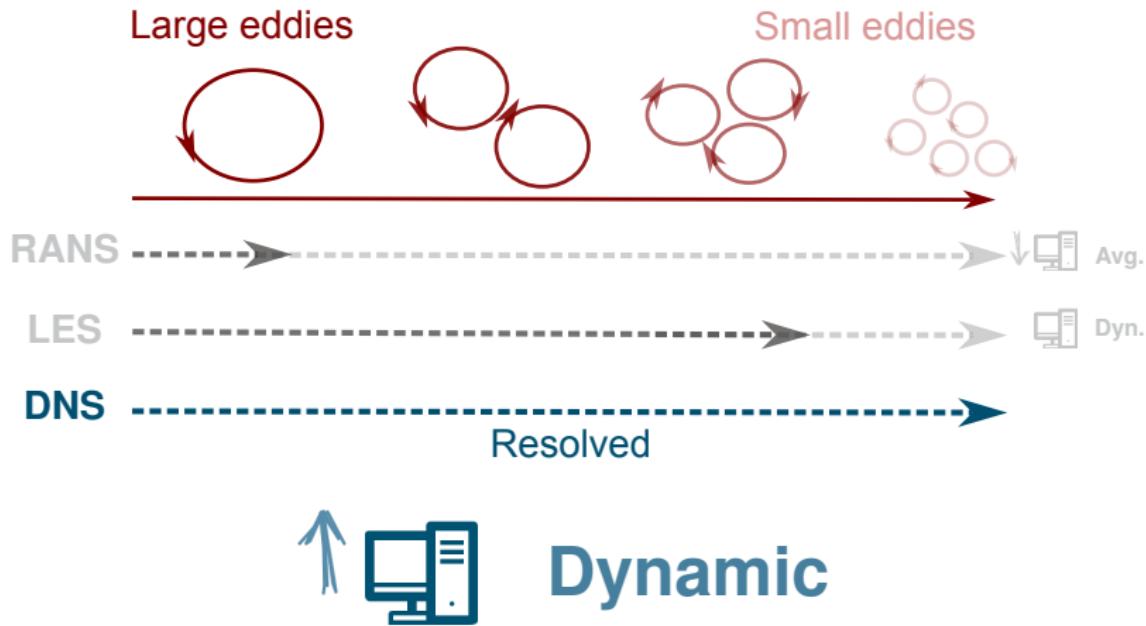


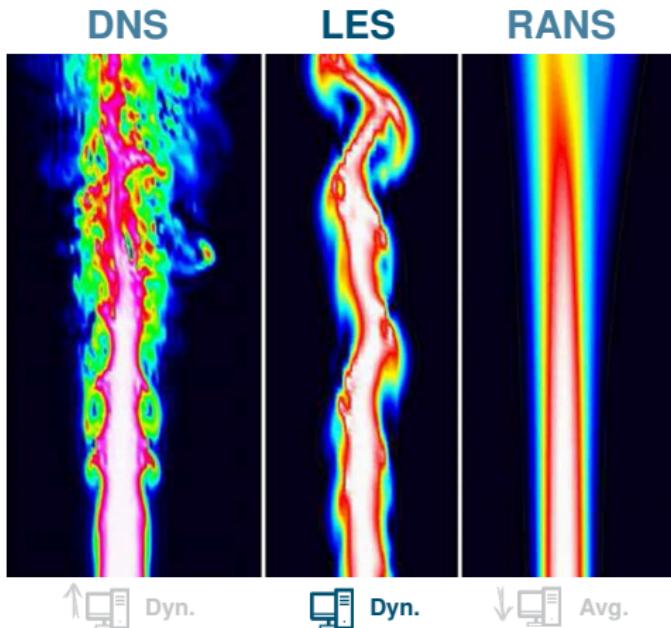




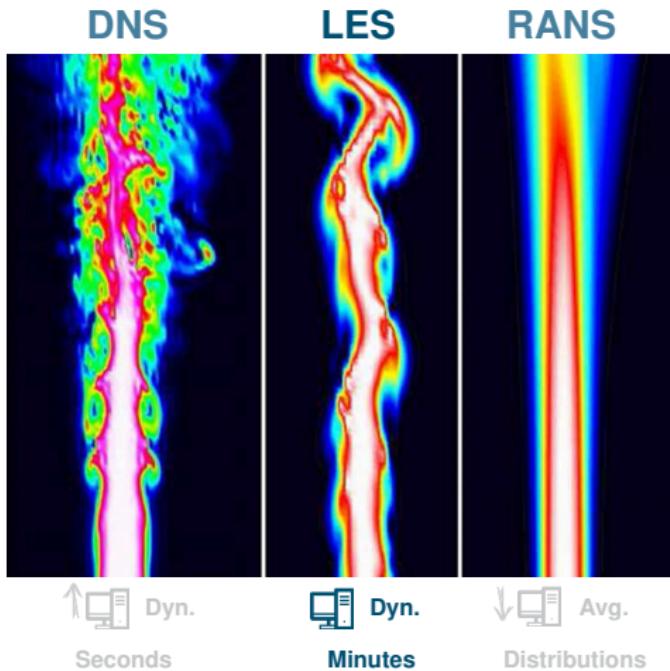




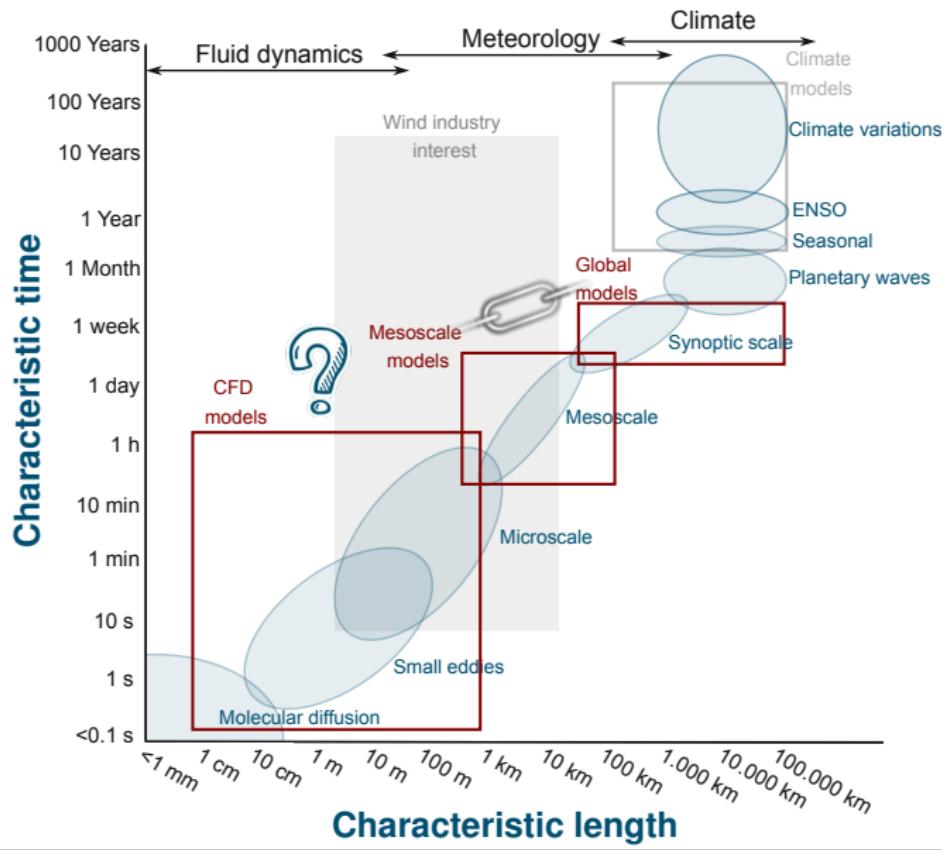


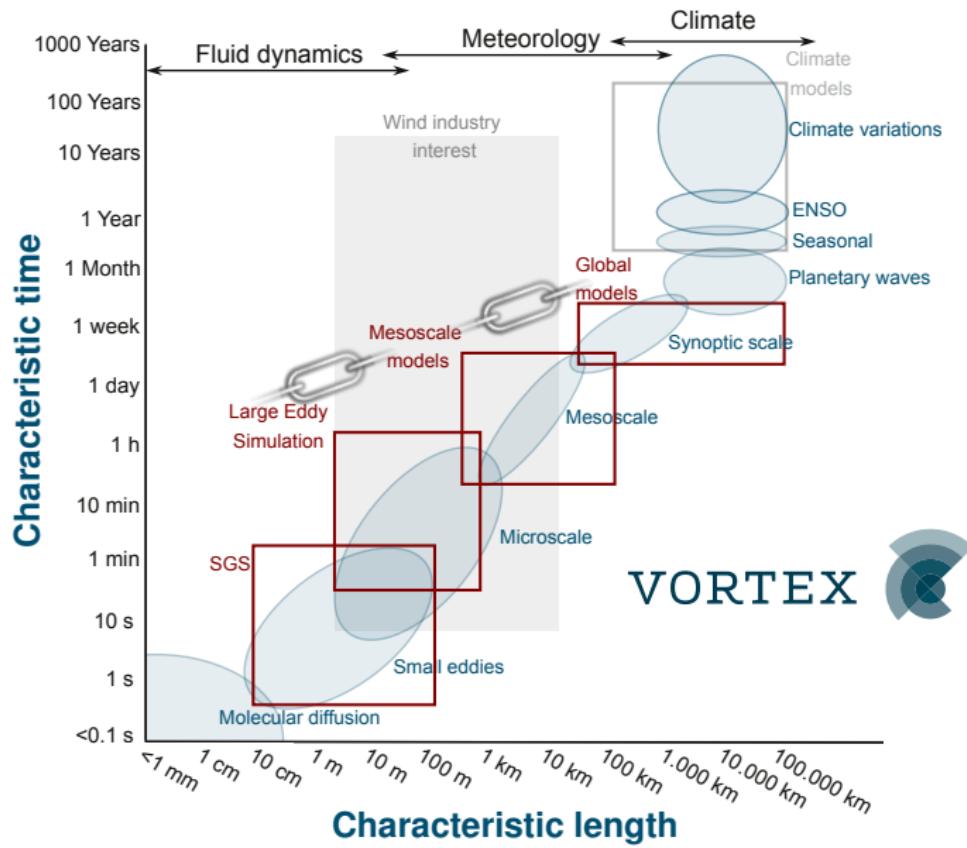


Adapted from Maries, A., Haque, M. A., Yilmaz, S. L., Nik, M. B., Marai, G. E.: New Developments in the Visualization and Processing of Tensor Fields, Springer, pp. 137-156, D. Laidlaw, A. Villanova. 2012



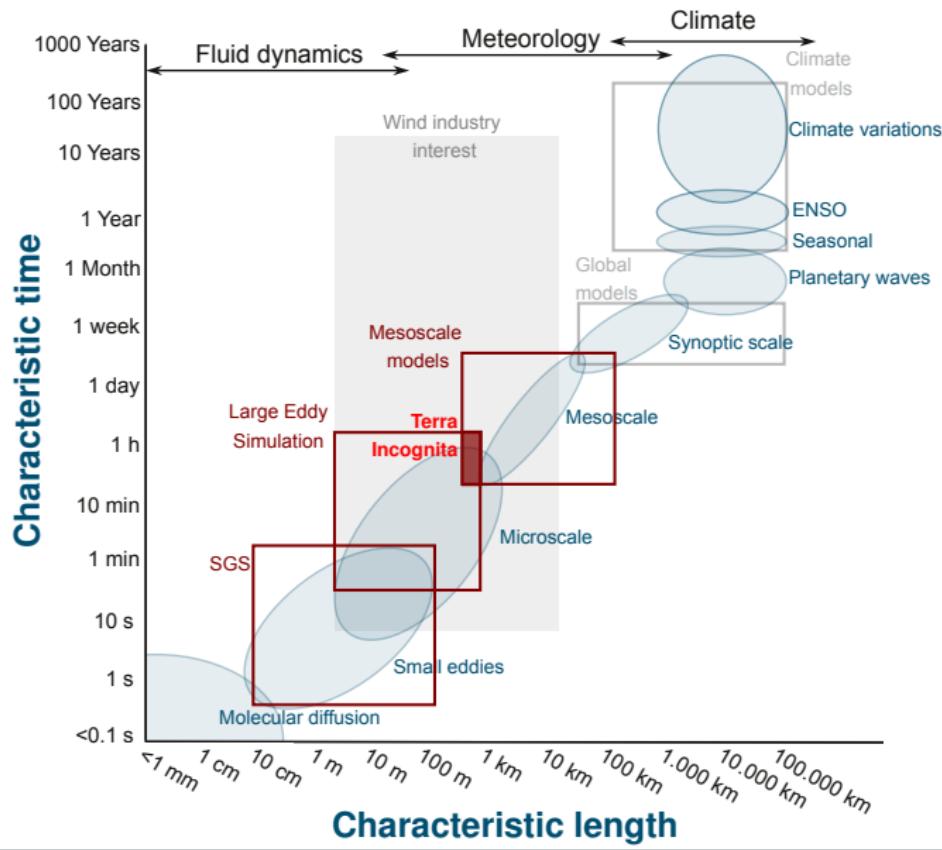
**Different tools for different applications**





# Coupling mesoscale-LES: Challenges

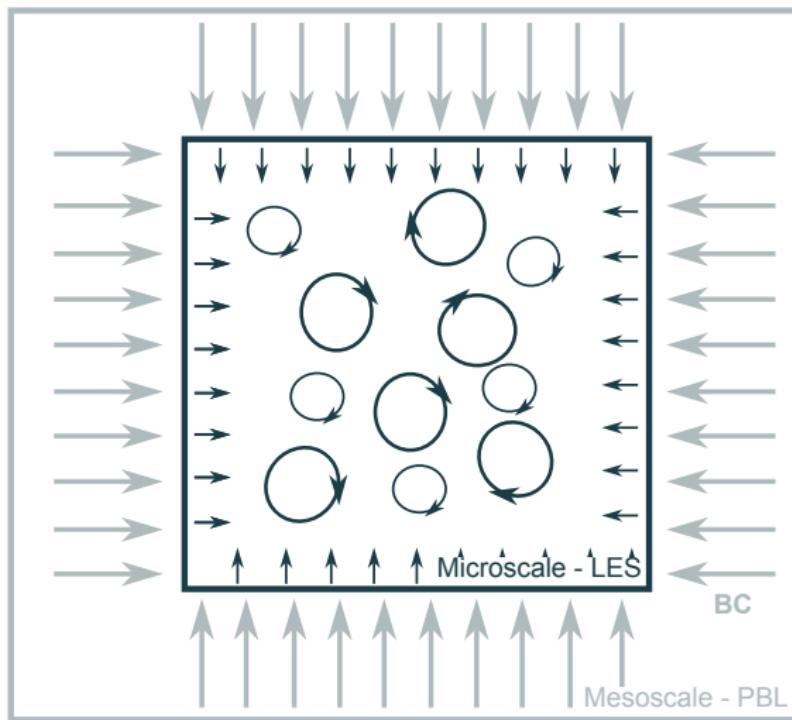
- ▶ Lateral boundary conditions
- ▶ Surface layer and Land Surface Model
- ▶ Terra-Incognita



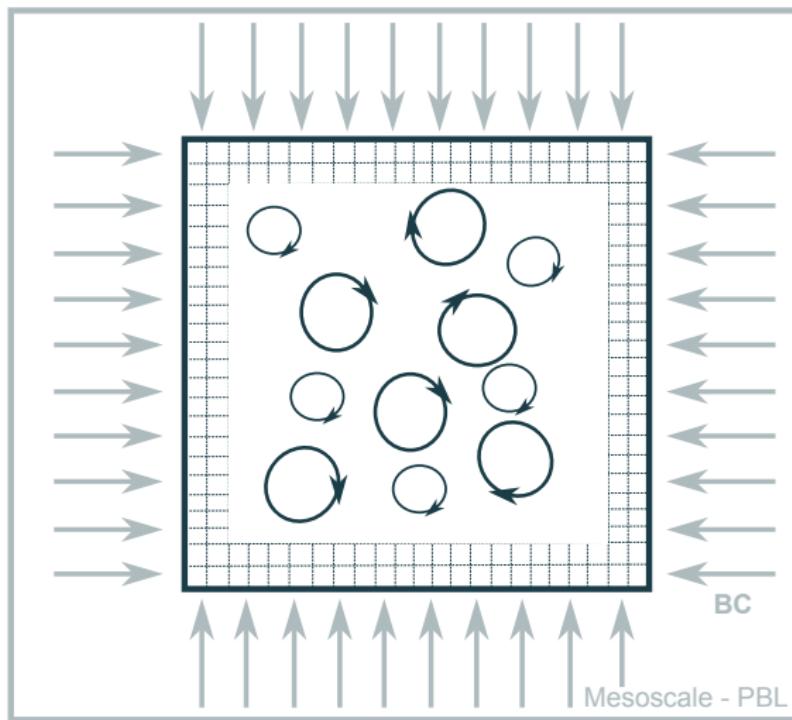
# Coupling mesoscale-LES: Challenges

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

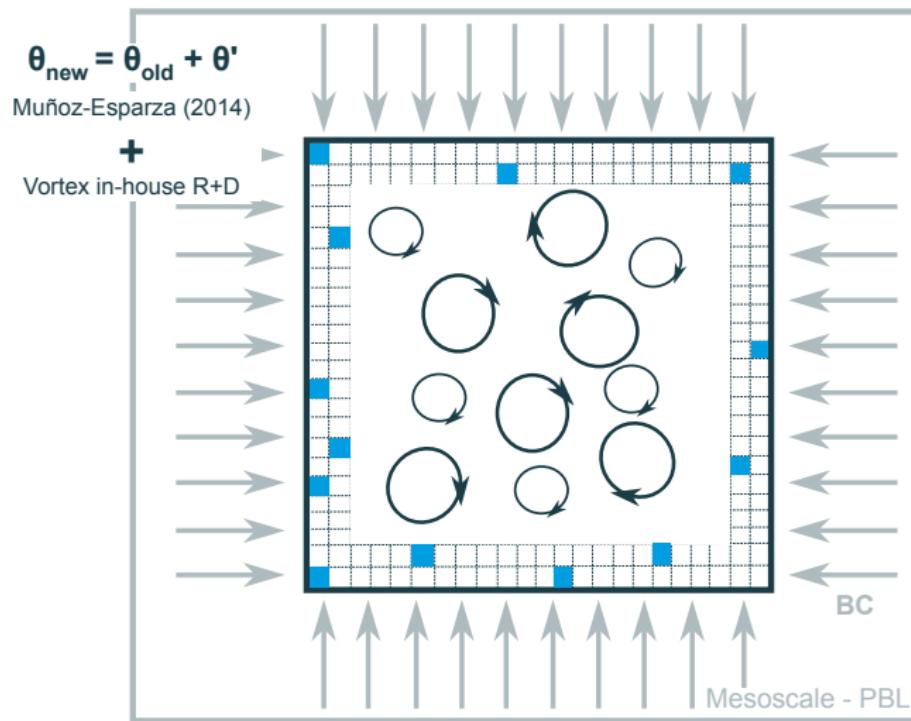
# Lateral boundary conditions



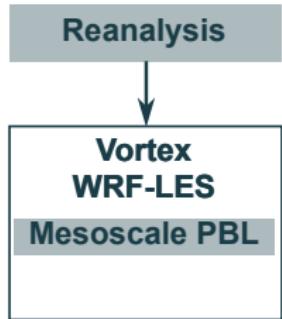
# Lateral boundary conditions



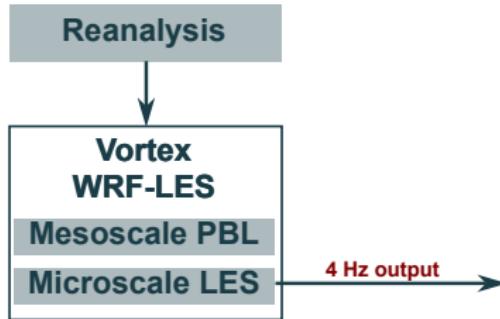
# Lateral boundary conditions



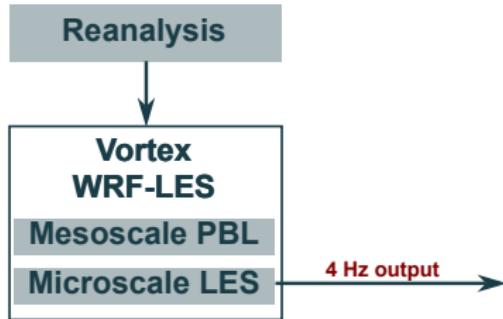
# Vortex approach



# Vortex approach

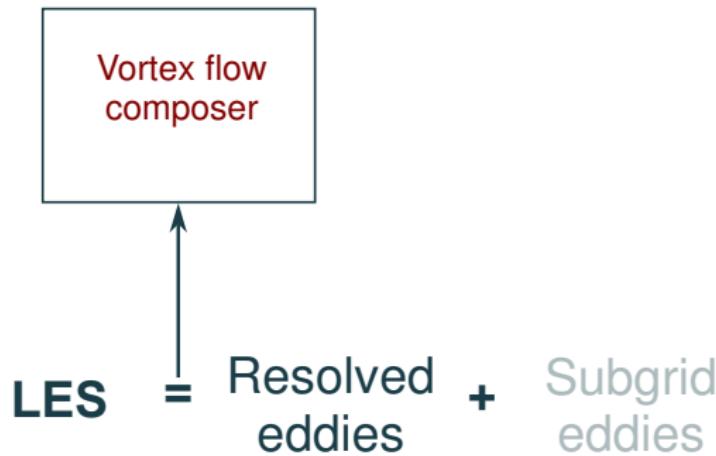


# Vortex approach

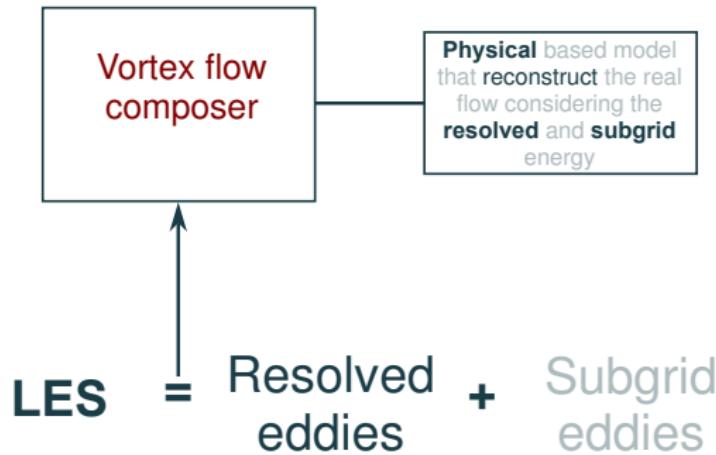


$$\text{LES} = \text{Resolved eddies} + \text{Subgrid eddies}$$

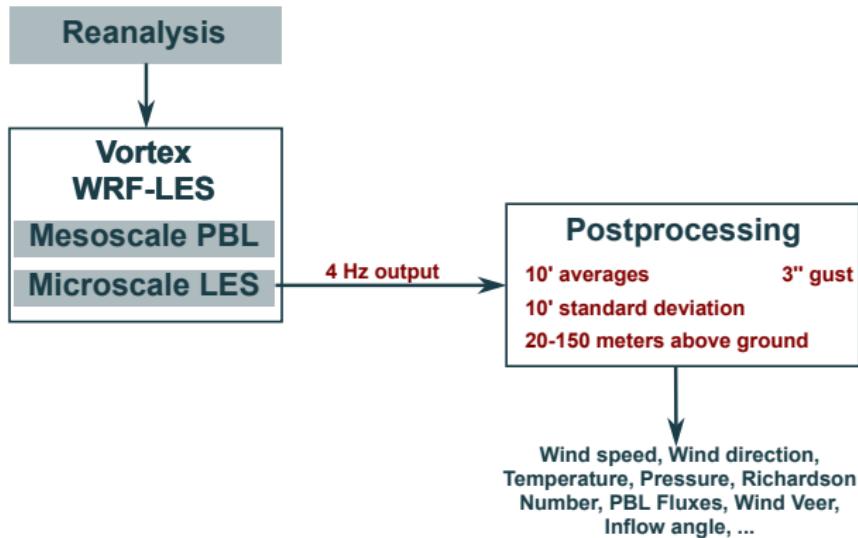
# Vortex approach



# Vortex approach

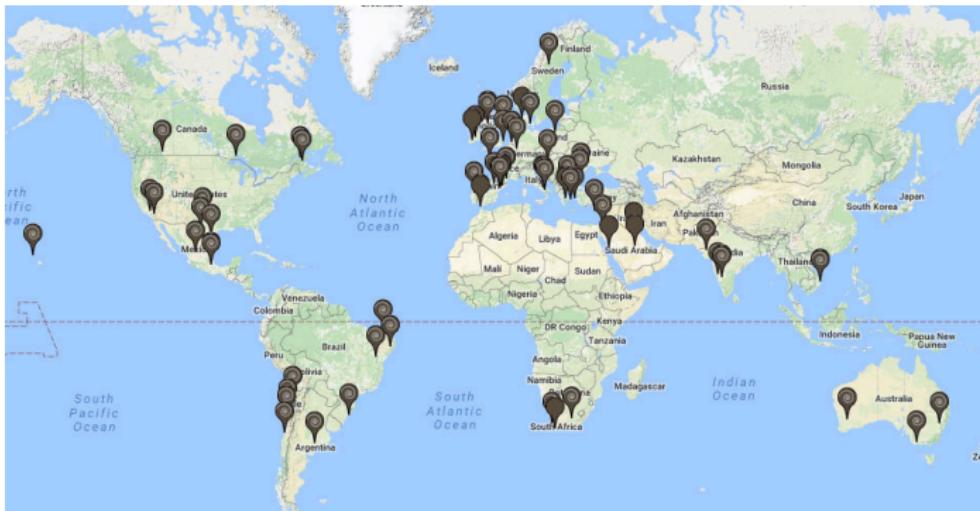


# Vortex approach

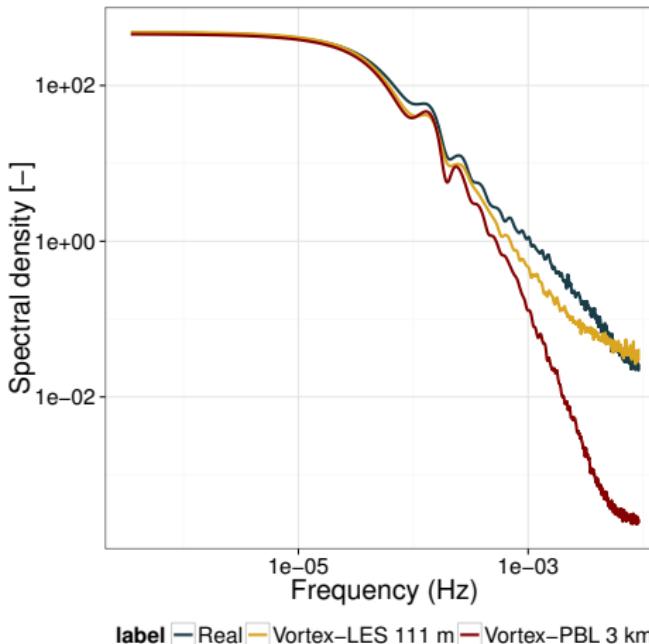


# Vortex-LES validation exercise

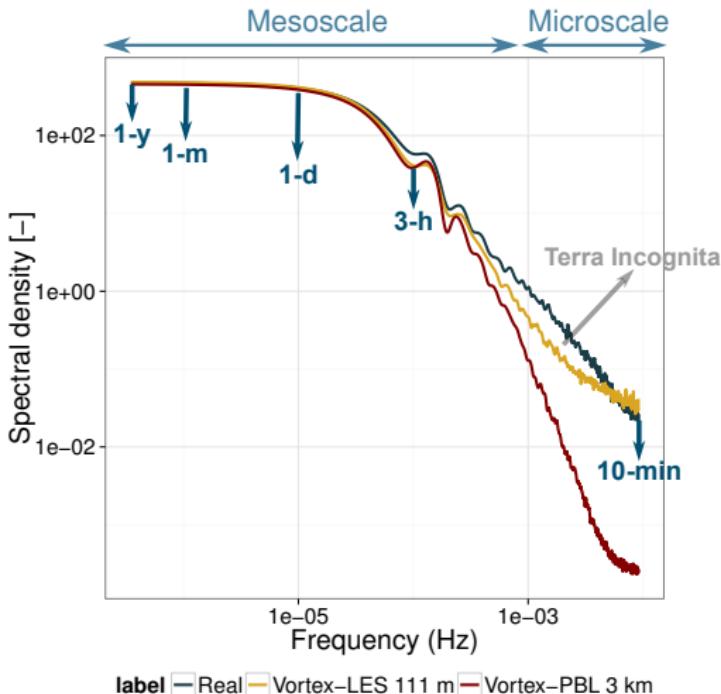
- ▶ Wind metrics validated for **93 sites**
- ▶ Turbulence Intensity validated for **51 sites**



# 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 <sup>2</sup> 10-min	0.59	0.09
R <sup>2</sup> hourly	0.62	0.09
R <sup>2</sup> daily	0.80	0.09

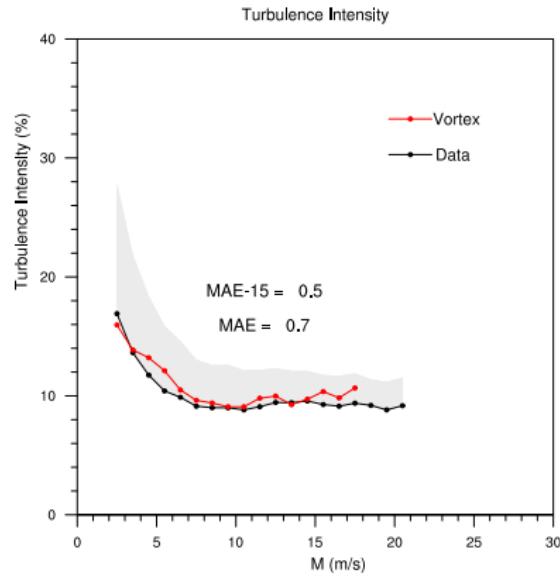
# Vortex-LES validation exercise

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

Which metric to use?

1. MAE between TI-model against TI-obs weighted by bin-occurrence
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





# **Applications and validation of meso- $\gamma$ and microscale (WRF / WRF-LES) meteorological modeling in wind energy**

Mark Žagar

Specialist, Plant Siting & Forecasting

Vestas Technology & Service Solutions

PUBLIC

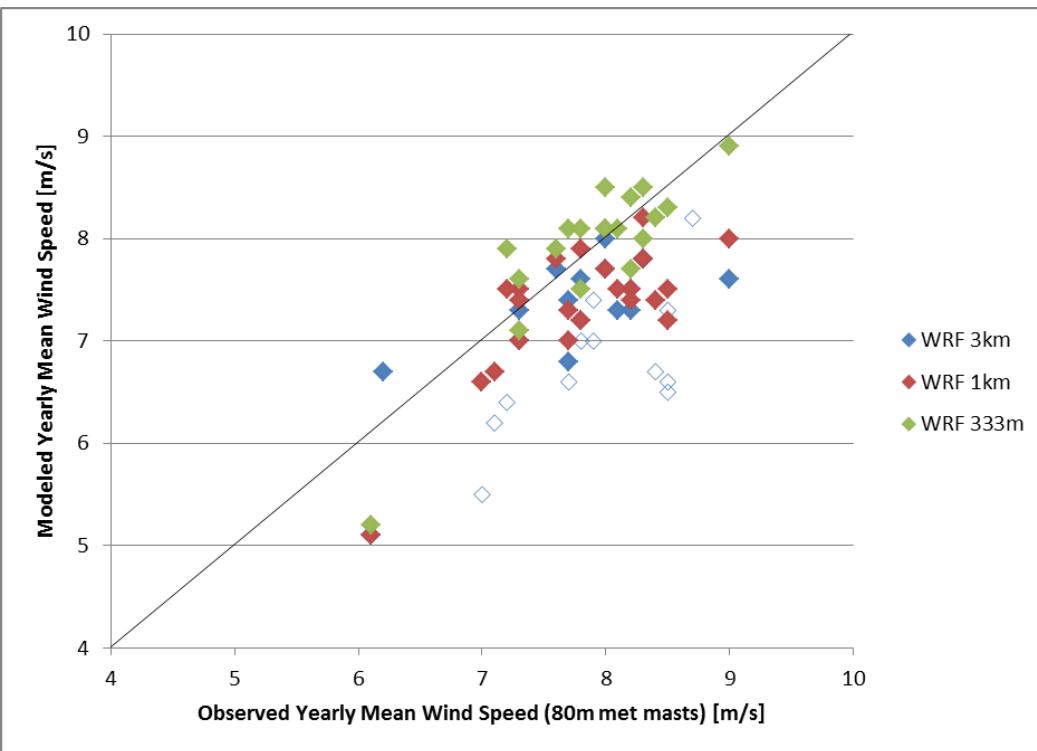
How we are doing at microscale meteorological modeling?

# Achievable 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.**

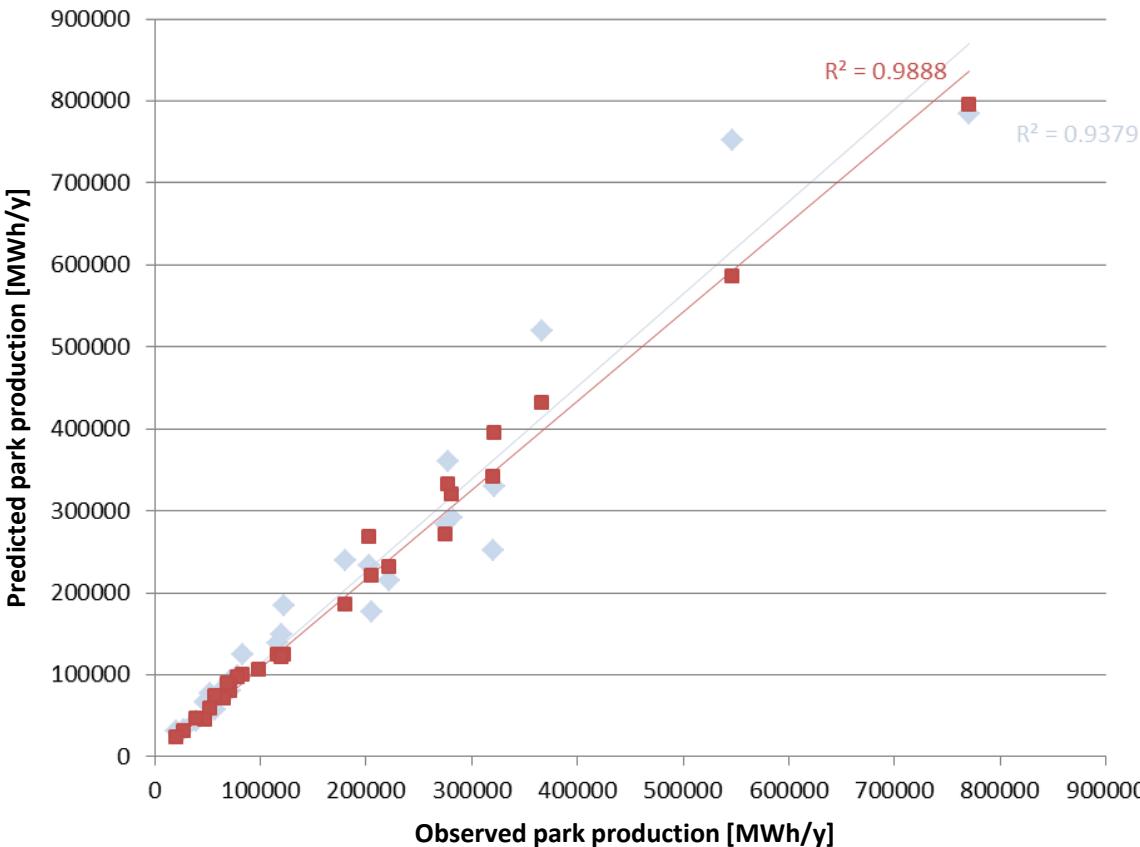
	BIAS [m/s]	MAE [m/s]	STDE [m/s]
3 km	-0.72	0.75	0.54
1 km	-0.44	0.53	0.36
1/3 km	+0.01	0.32	0.22

# Achievable 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

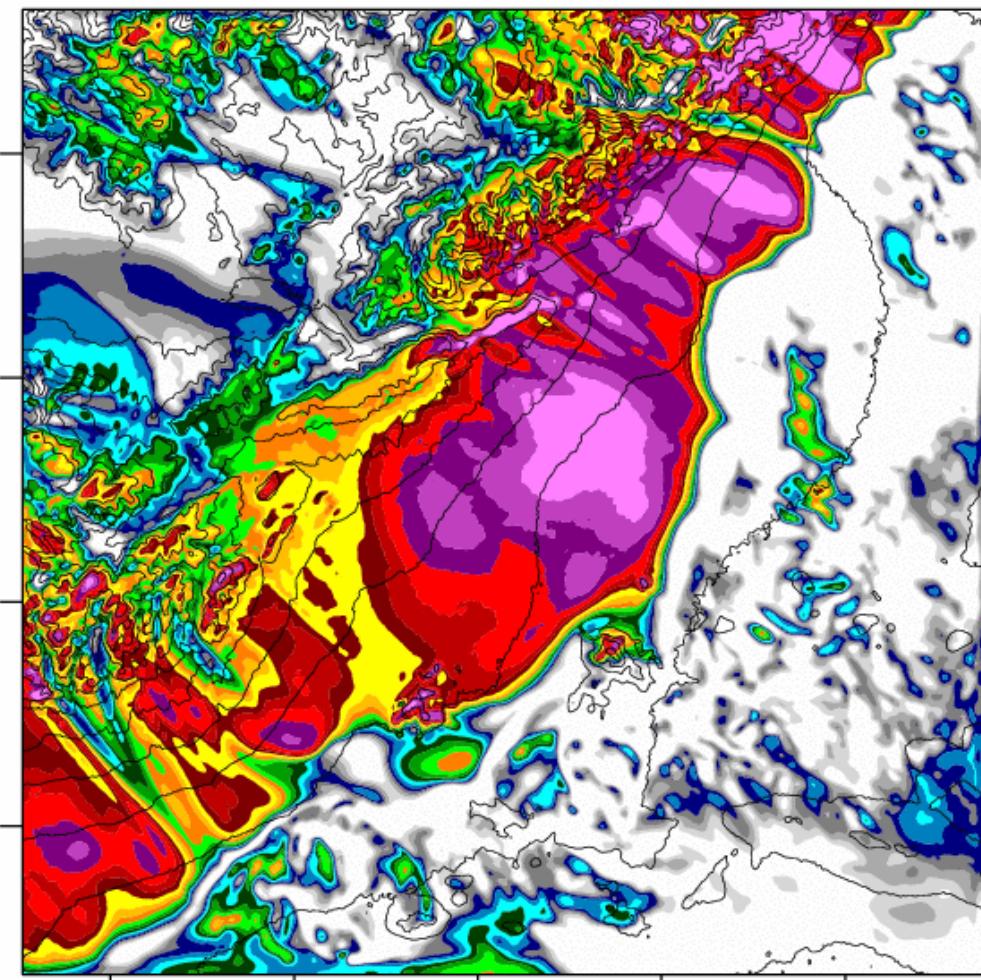
	MAE	STDE	EtotP
WRF raw	16.2%	18.2%	4.7%
WRF corr	8.0%	9.4%	2.7%

# Purely downscaling $1^\circ$ analyses

WRF-LES 100m

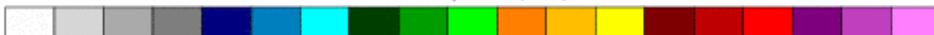
Init: 2008-07-11\_06:00:00  
Valid: 2008-07-11\_07:00:00

Wind Speed (m/s)  
Terrain Height (m)



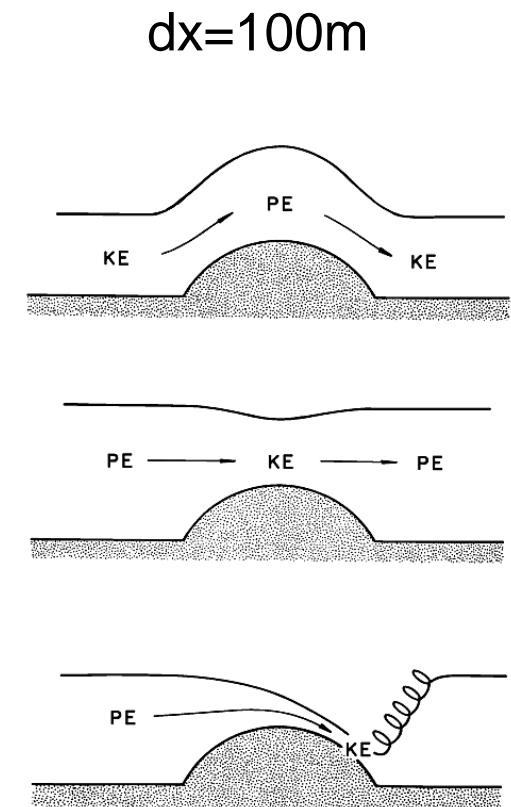
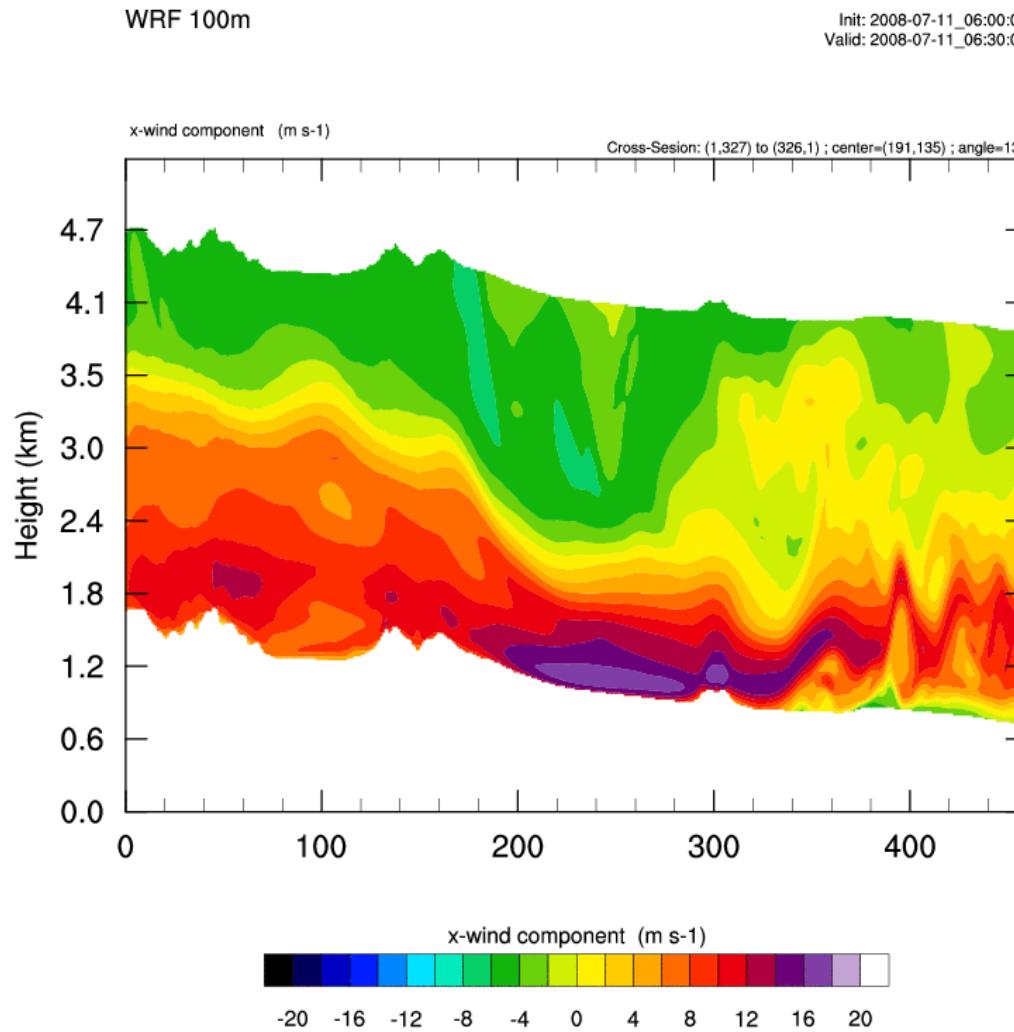
Terrain Height Contours: 600 to 1800 by 100

Wind Speed (m/s)



6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

# Downslope storm, hydraulic jump

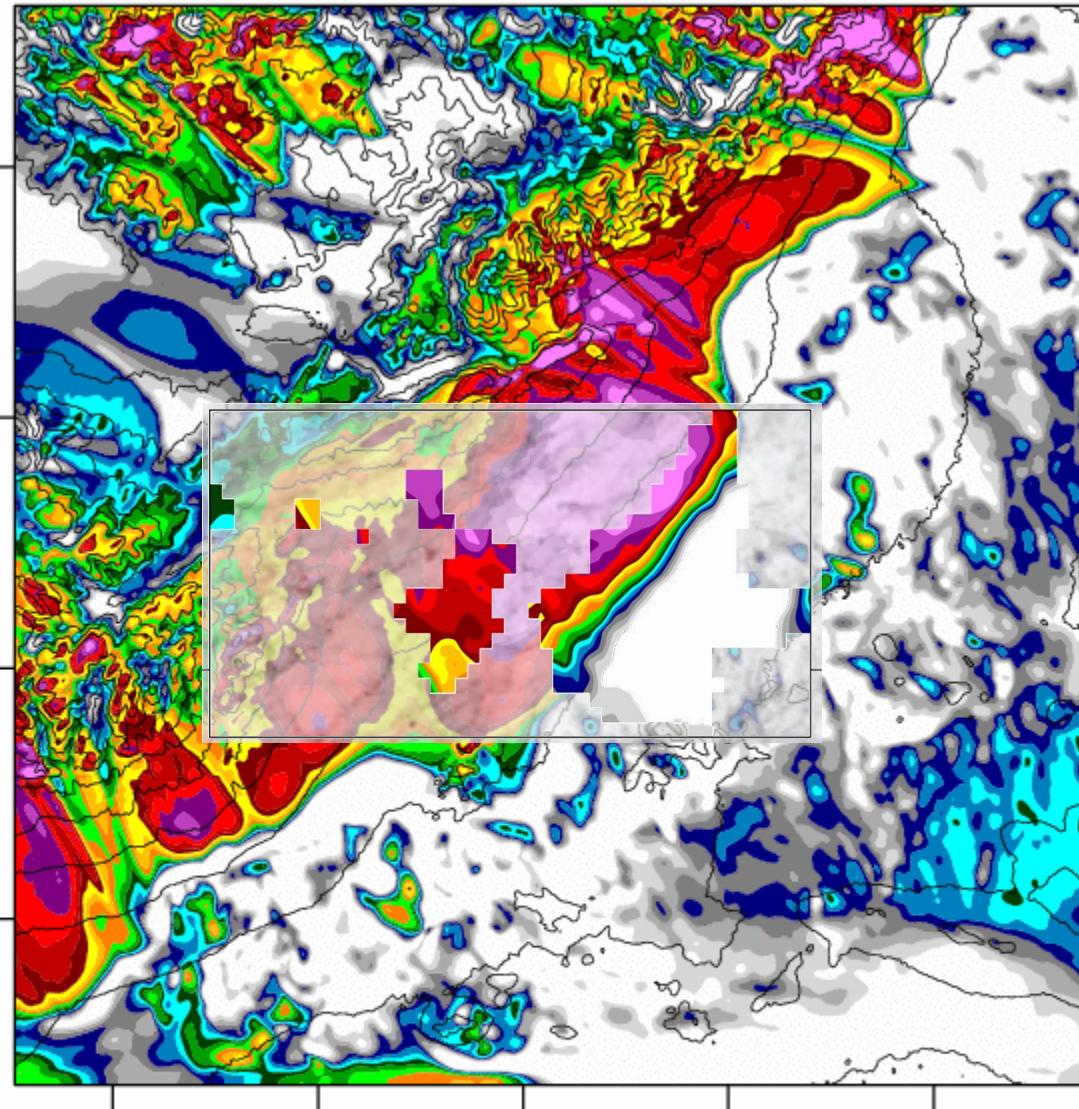


Holton, 1992

## Downslope storm, hydraulic jump

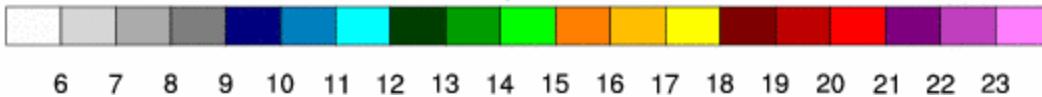
$dx=100m$

Data from nacelle  
anemometers overlaid



Terrain Height Contours: 600 to 1800 by 100

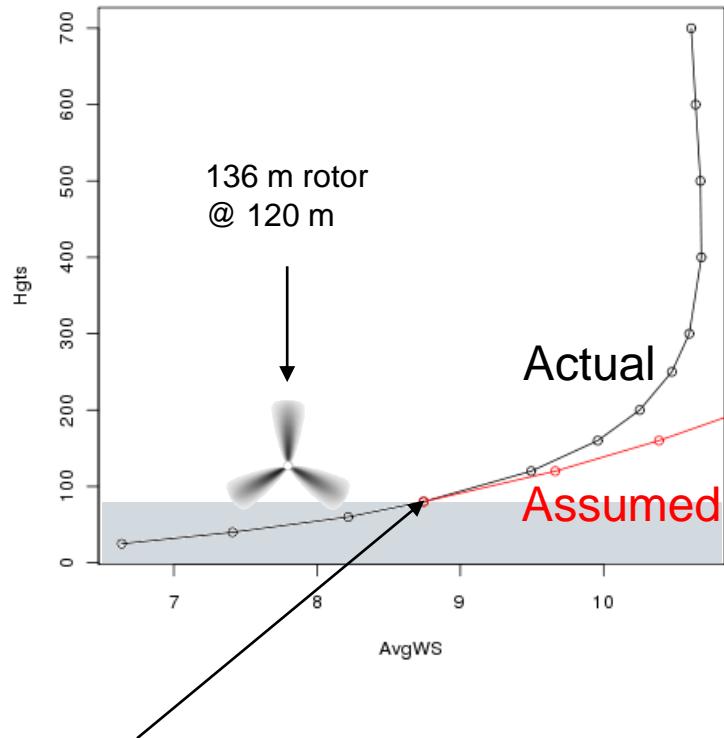
Wind Speed (m/s)



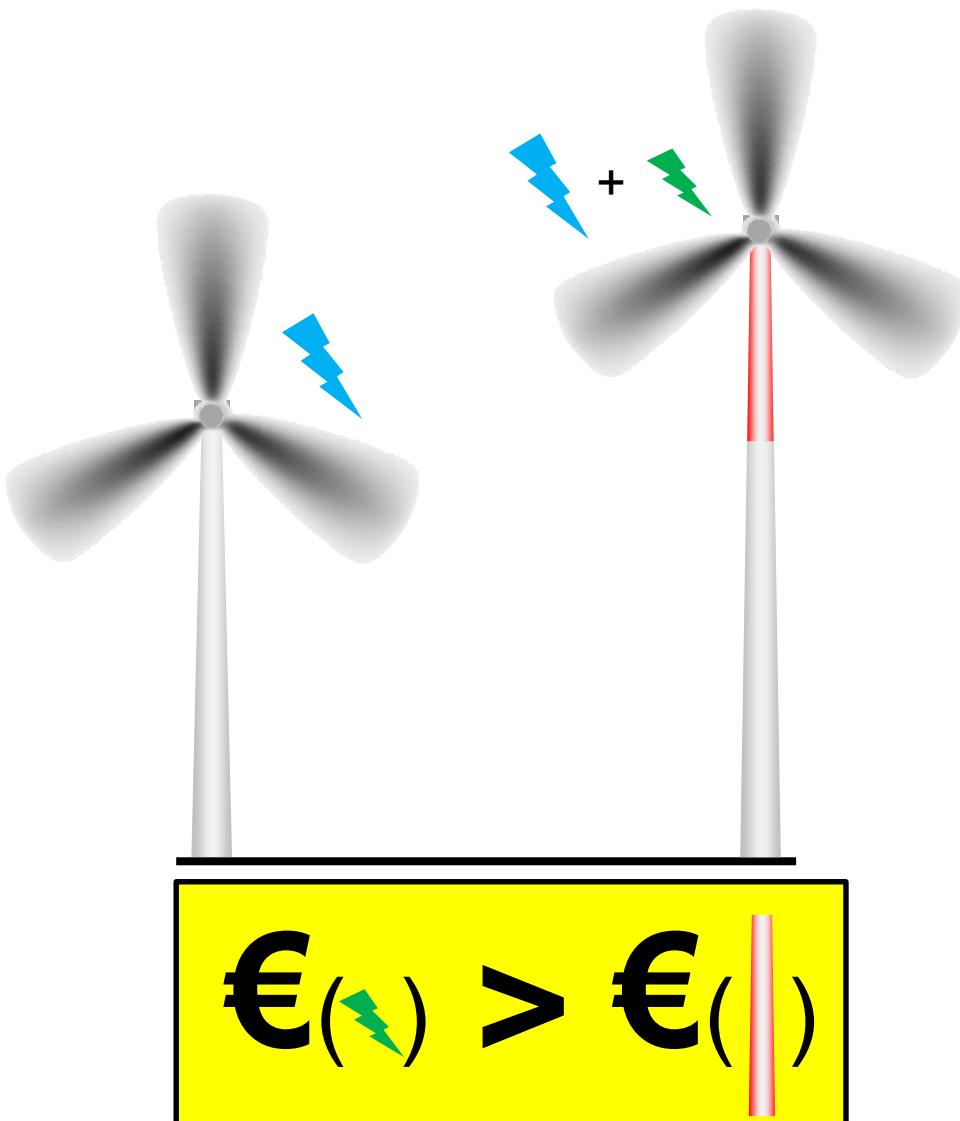
**Wind.** It means the world to us.™

An example of sensitivity to the "unknown"

# Important to know the wind profile

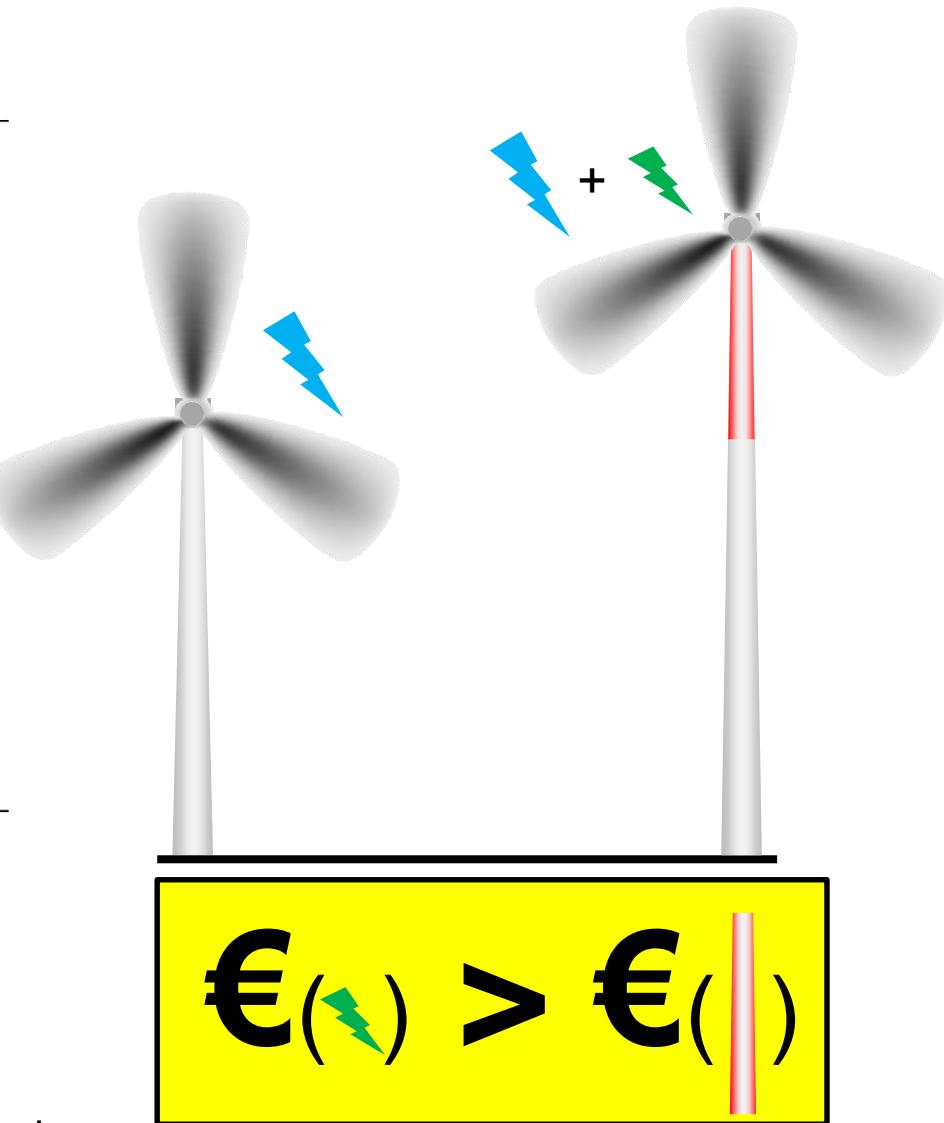
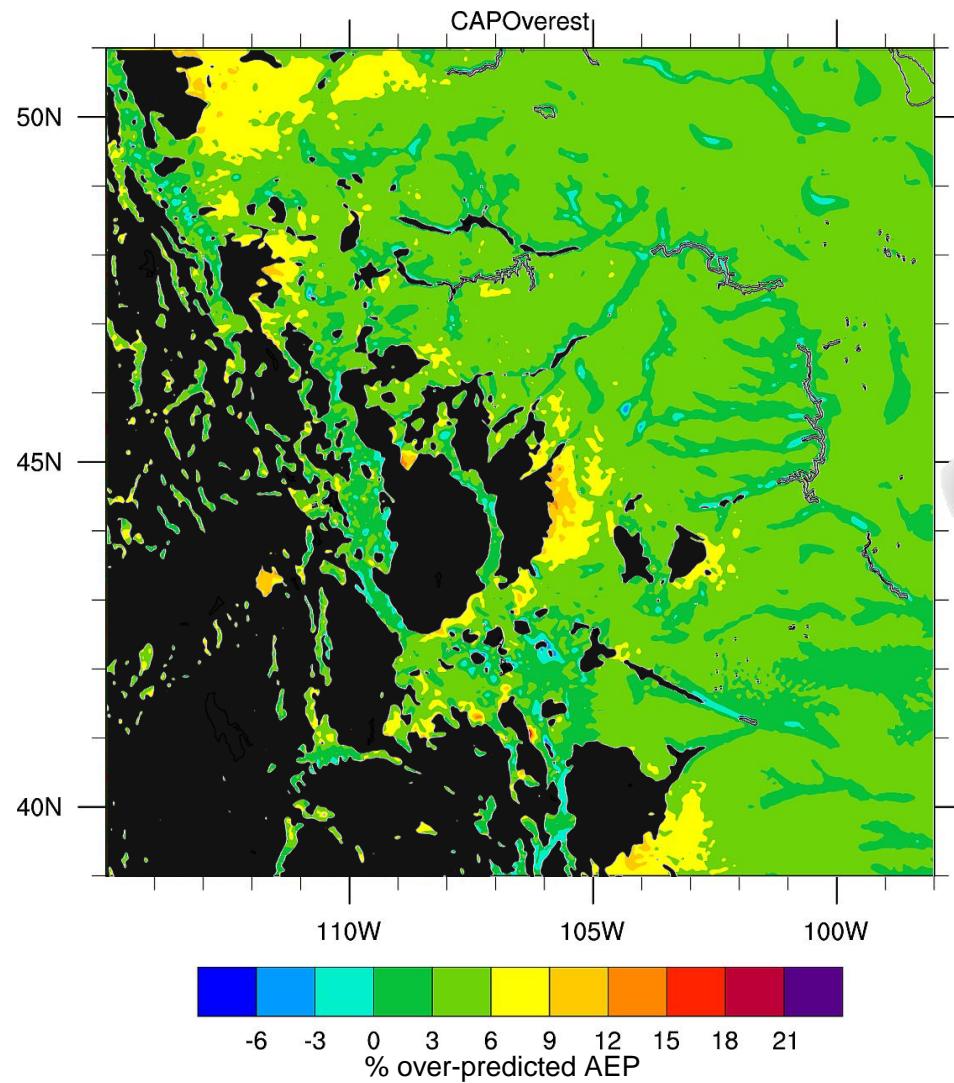


Typical met-mast  
height



2% wind speed error → 5% AEP error

# Important to know the wind profile



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

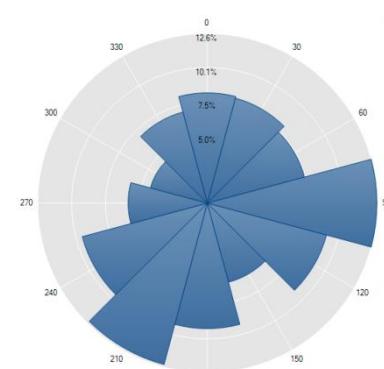
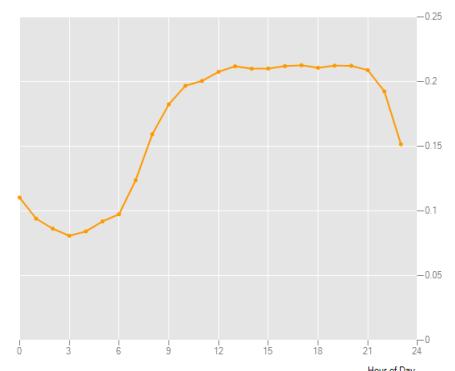
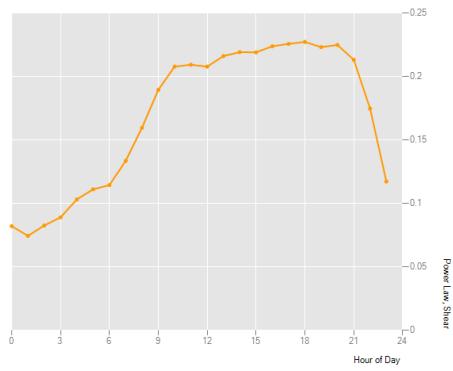
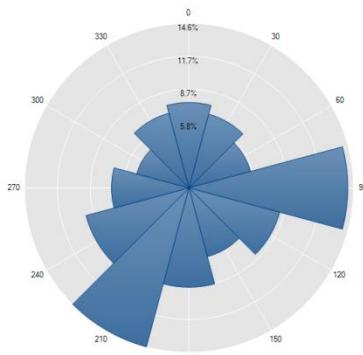
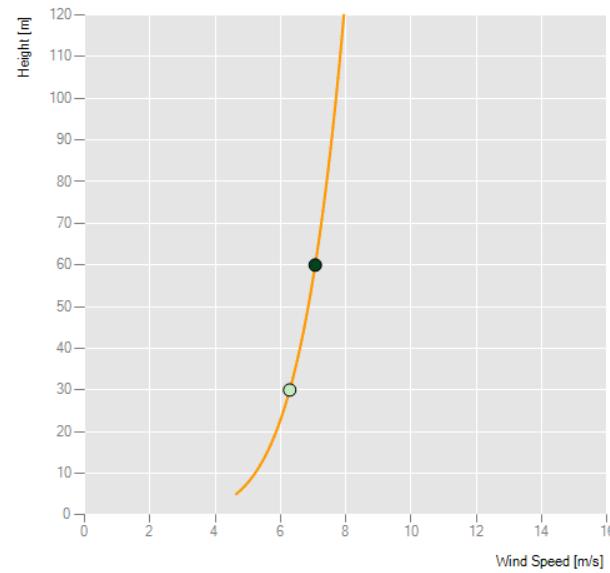
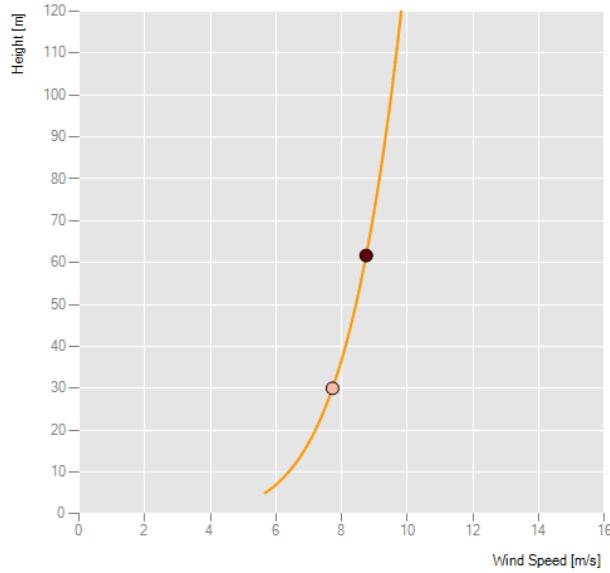
2% wind speed error → 5% AEP error

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

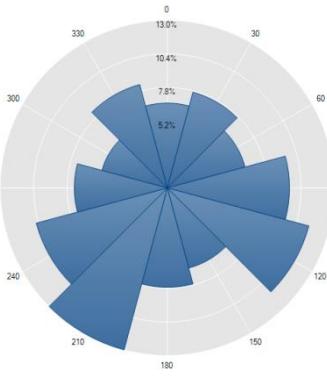
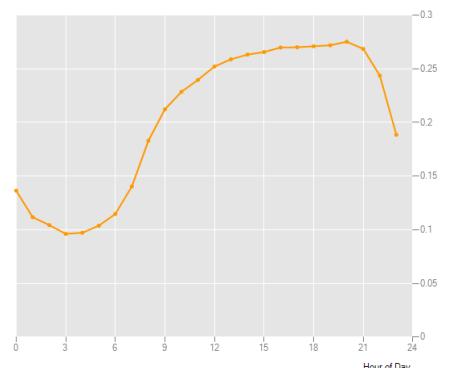
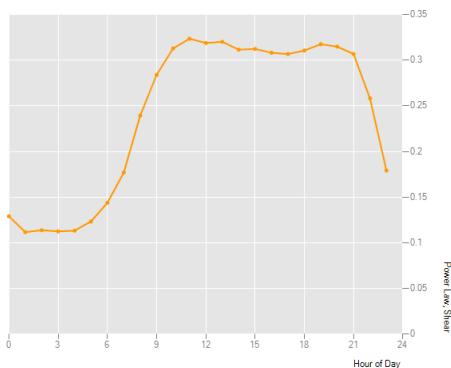
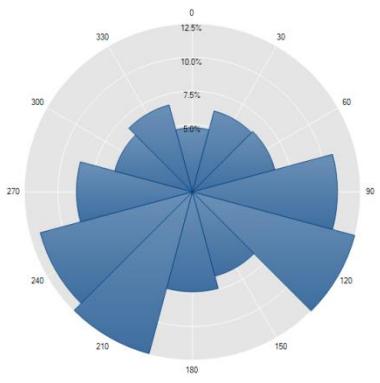
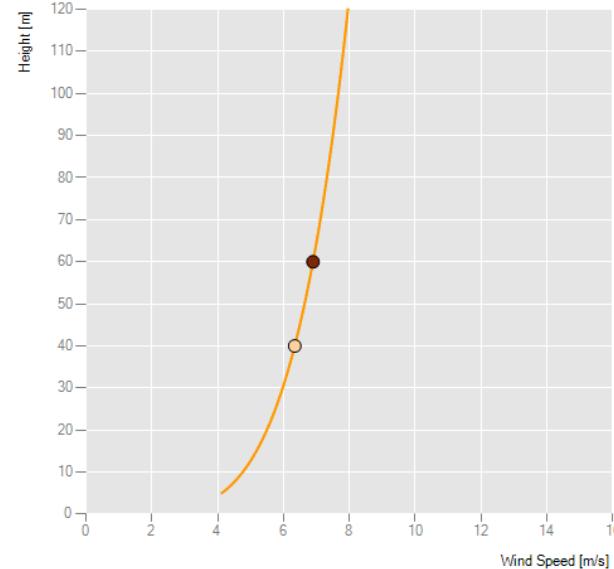
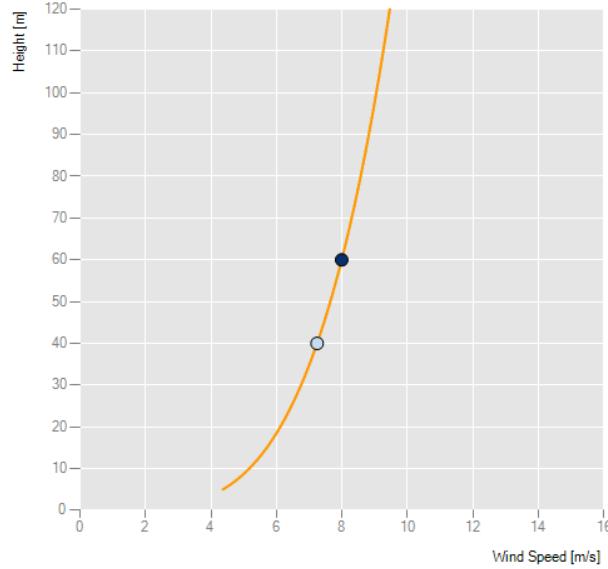
Wind. It means the world to us.™

# How does WRF-LES by Vortex do?

## Australia 1



# Australia 2

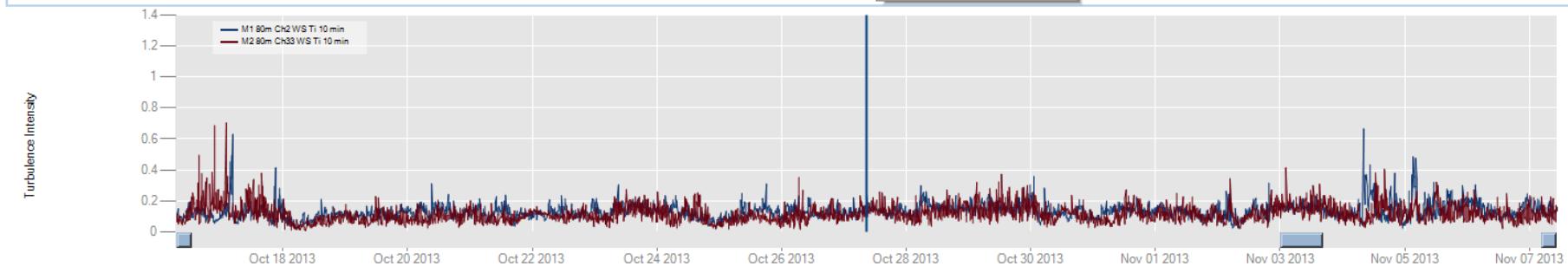
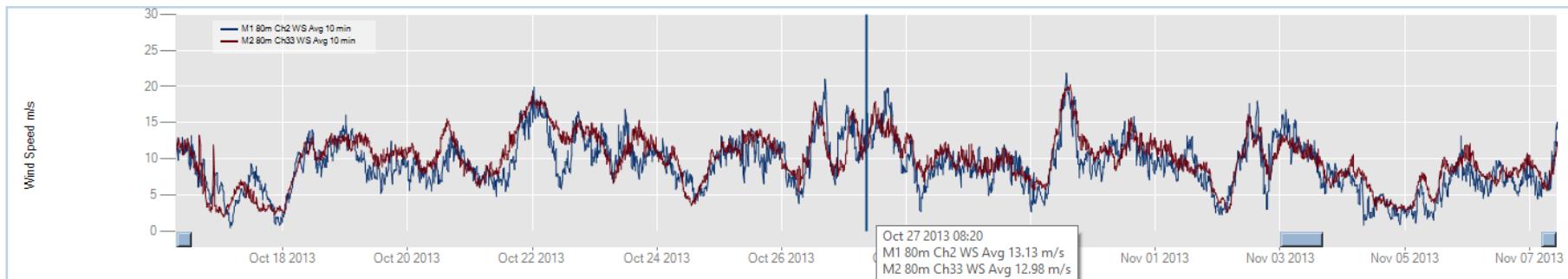


# Scotland 1

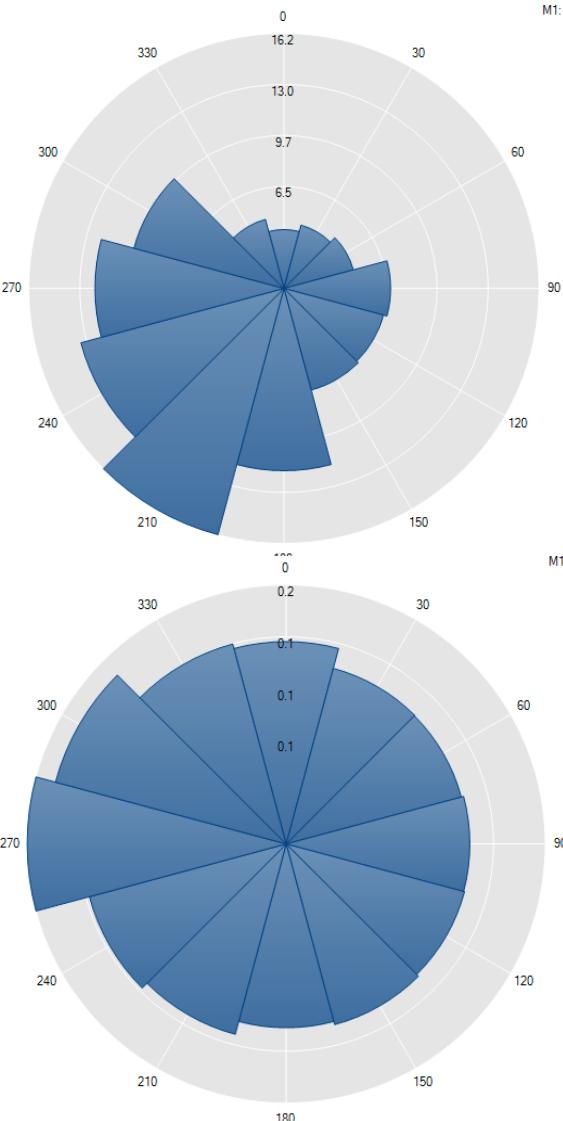
Vestas®

	avg(V)	$\sigma(V)$	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

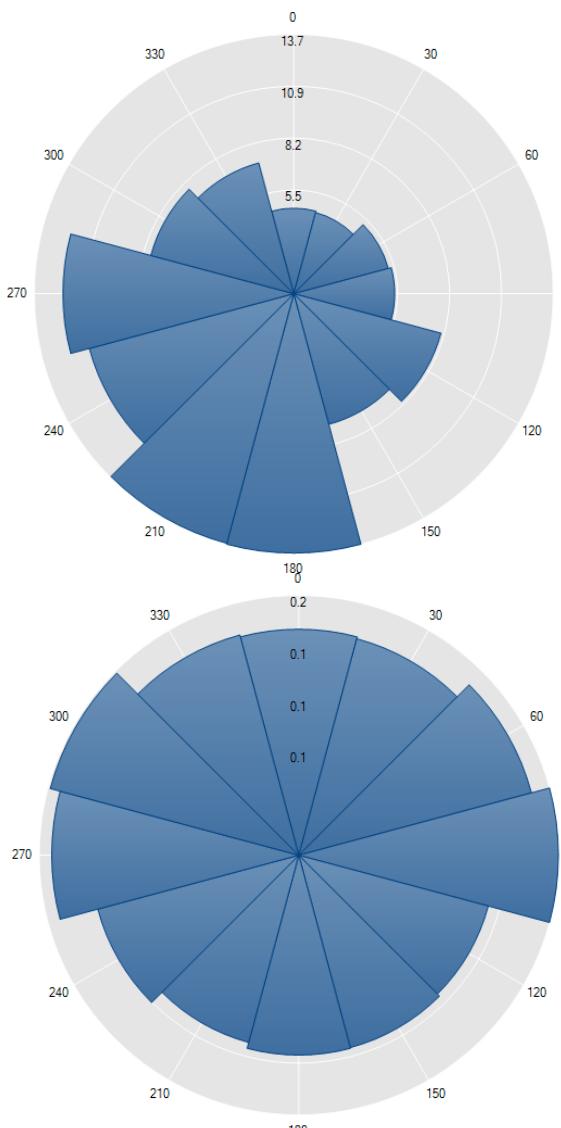
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	9.23	7.43	8.43	9.03	8.25	5.60	5.20	6.80	7.42	9.53	7.40	12.39	8.07
All	9.23	7.43	8.43	9.03	8.25	5.60	5.20	6.80	7.42	9.53	7.40	12.39	8.07
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	9.77	8.62	8.62	9.29	8.69	5.98	5.45	7.17	8.21	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



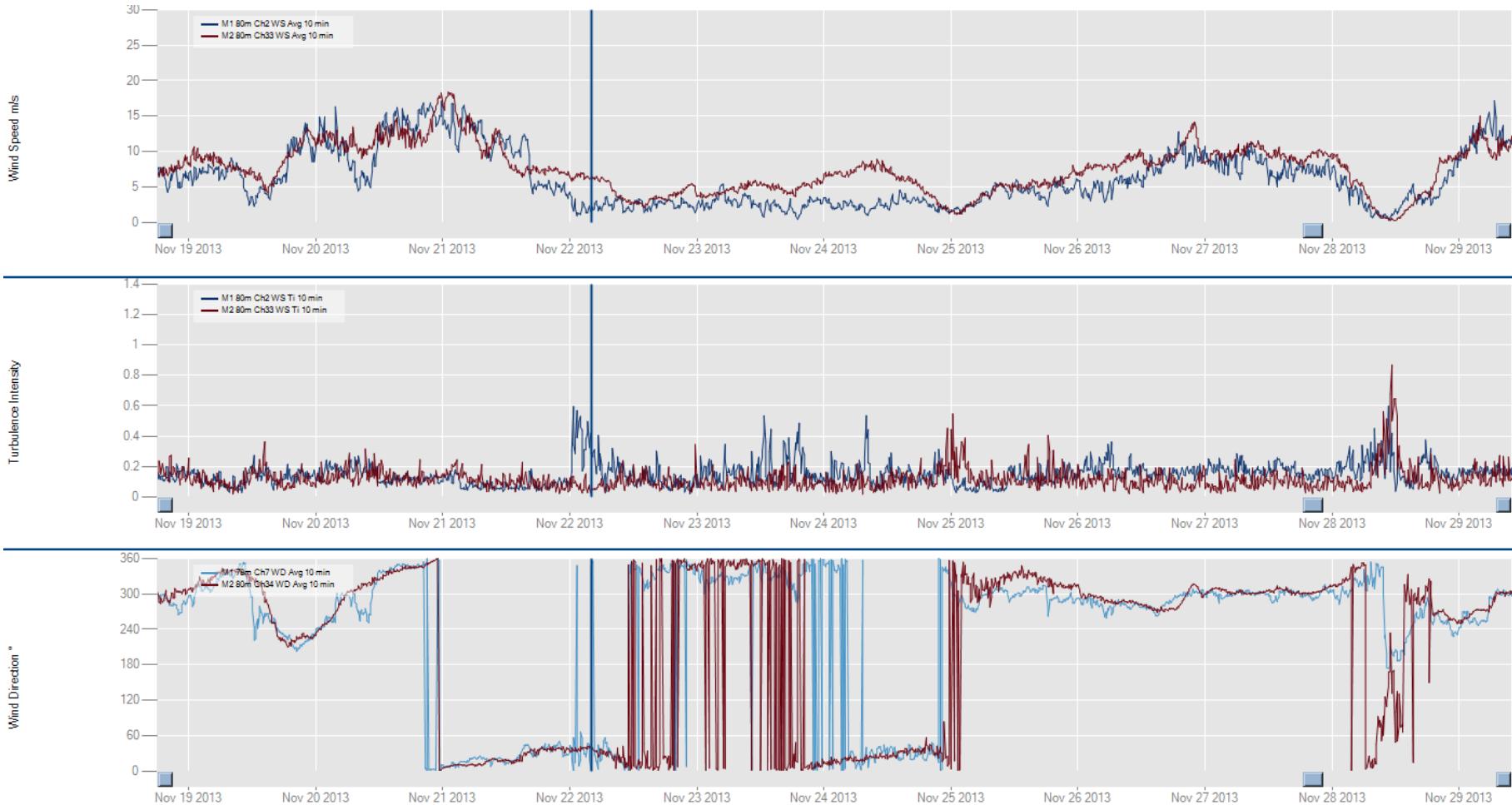
## Turbulence intensity Rose

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

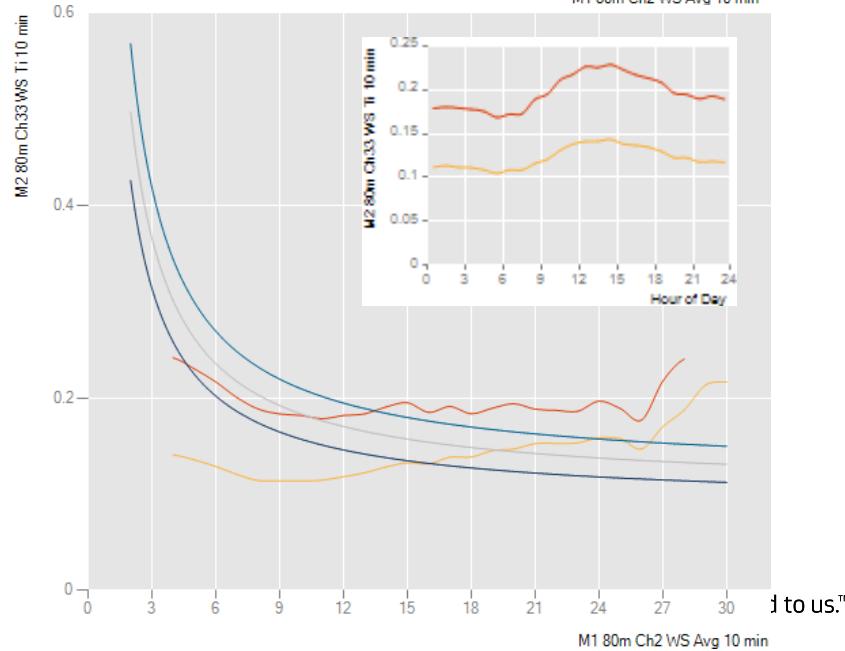
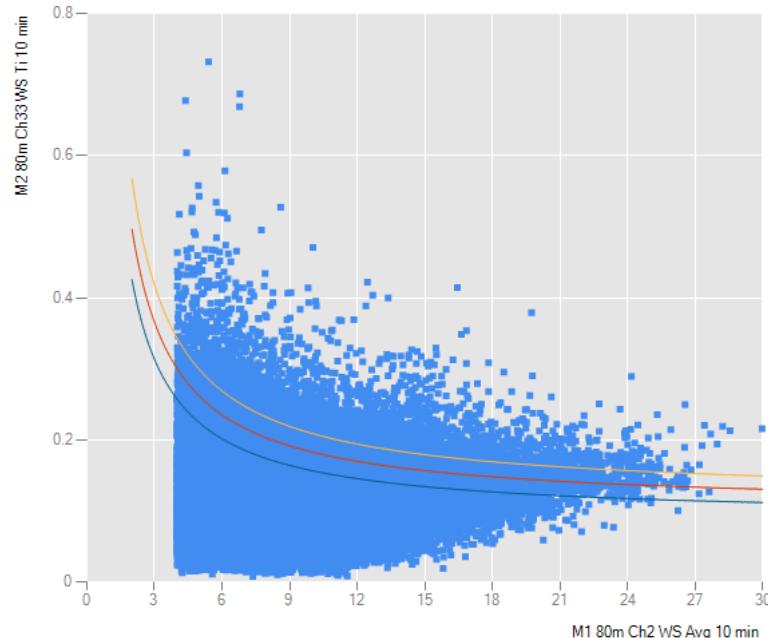
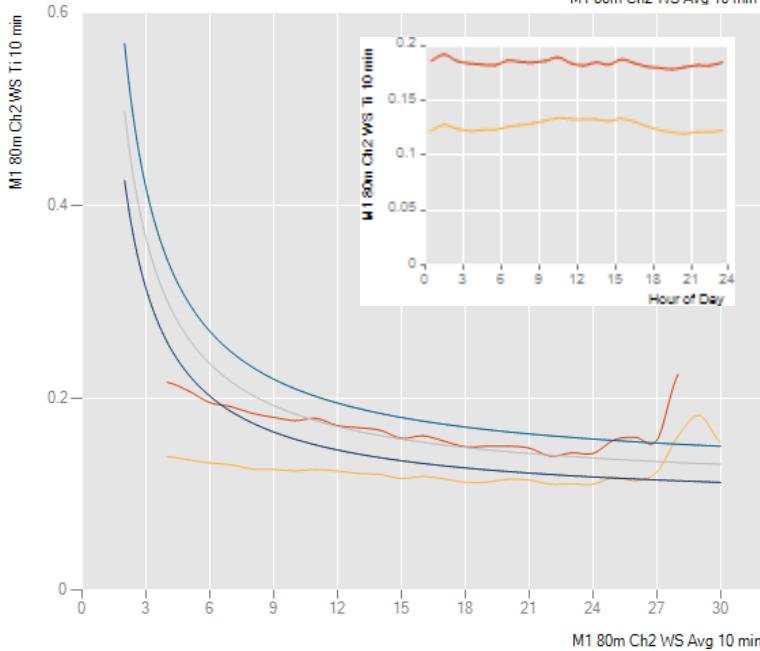
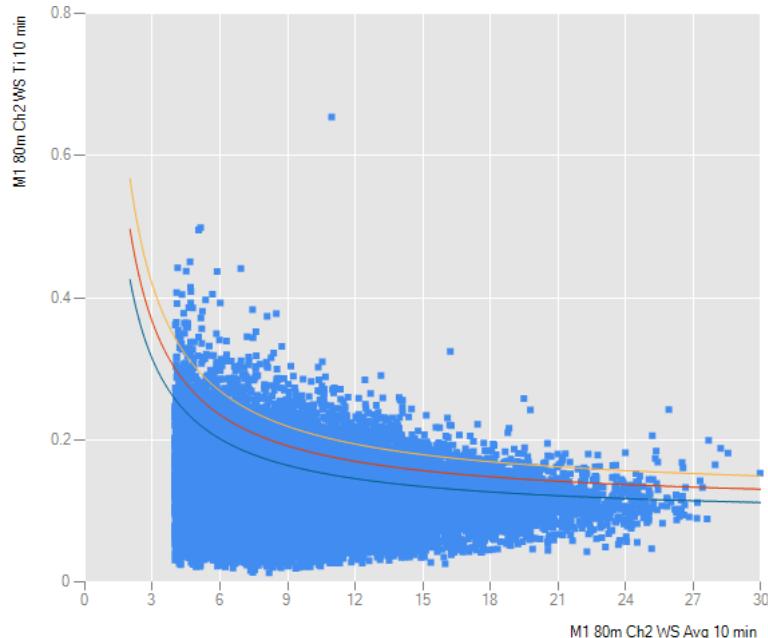
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
2013	0.11	0.12	0.13	0.13	0.13	0.16	0.14	0.14	0.12	0.12	0.12	0.12	0.13
All	0.11	0.12	0.13	0.13	0.13	0.16	0.14	0.14	0.12	0.12	0.12	0.12	0.13

**Wind.** It means the world to us.™

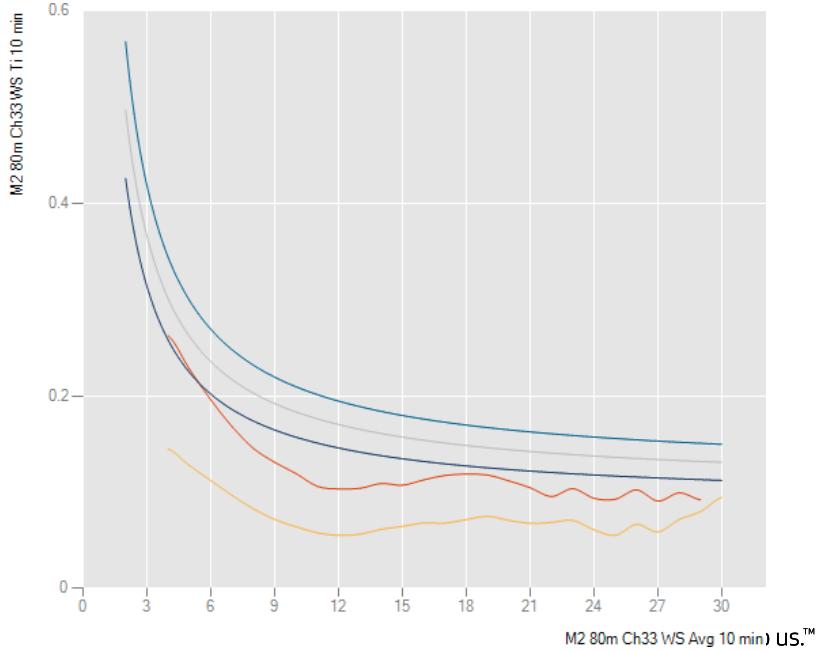
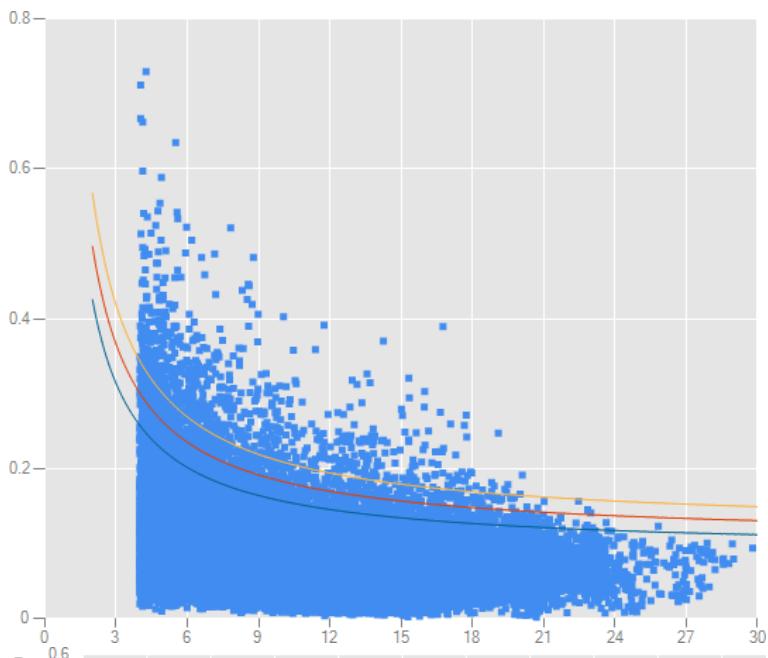
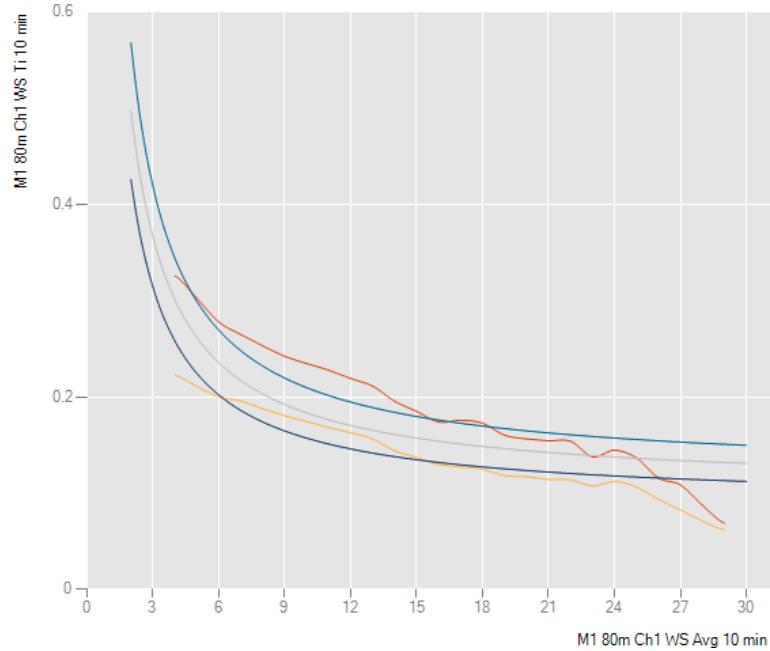
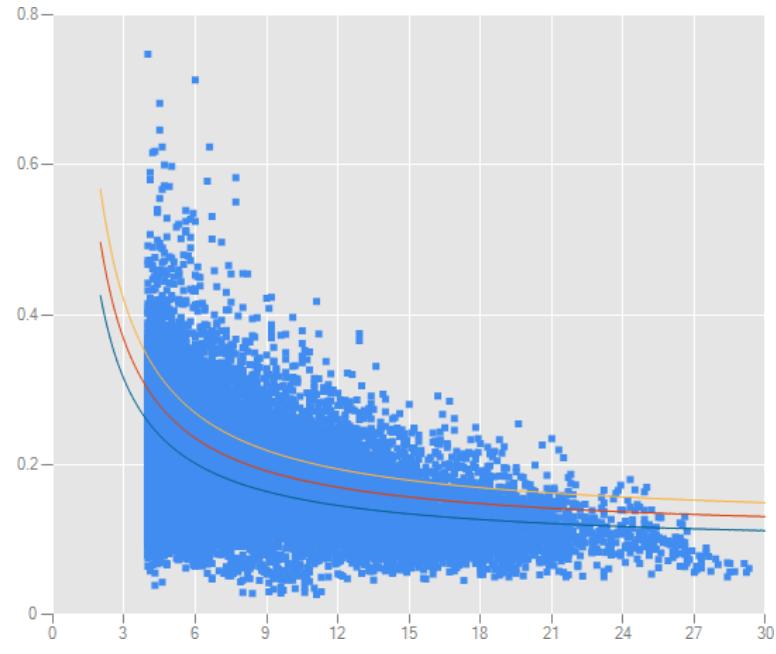
## Period of low wind speed causing "high" turbulence intensity



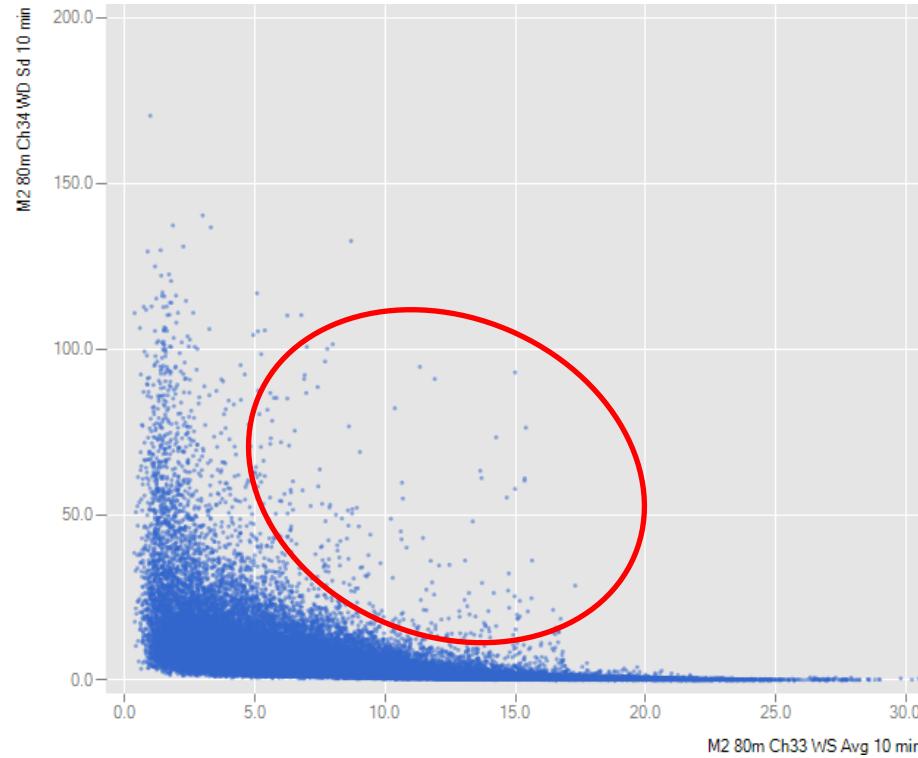
## Scotland 1



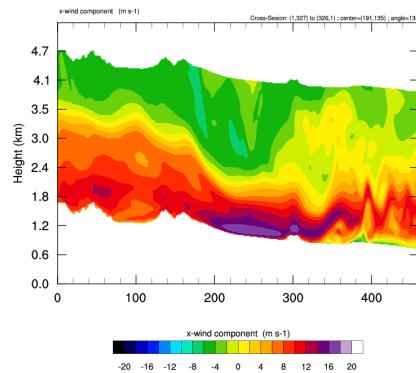
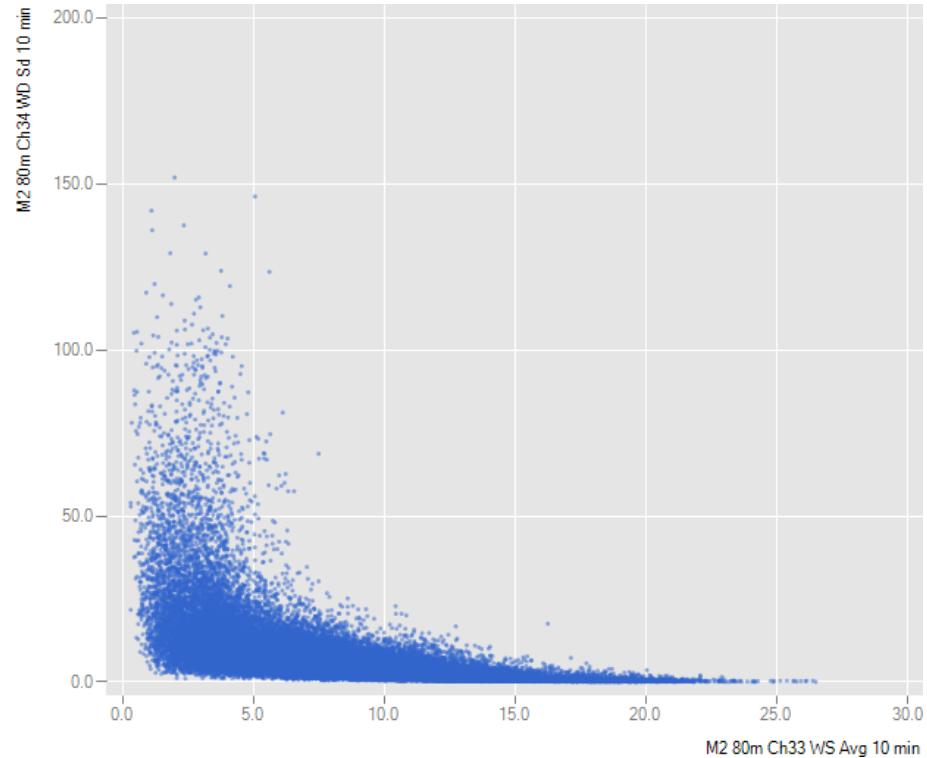
## USA 1



USA 1

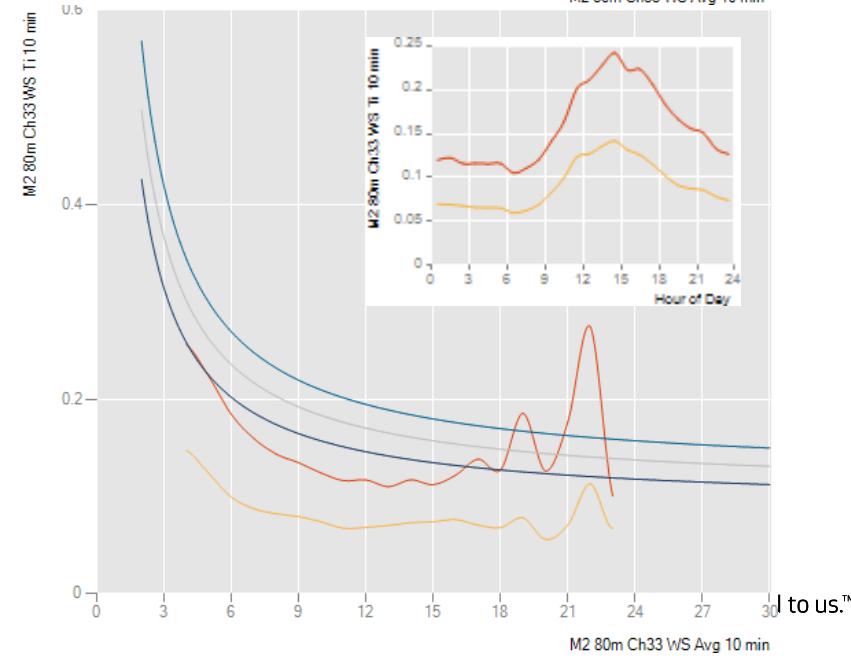
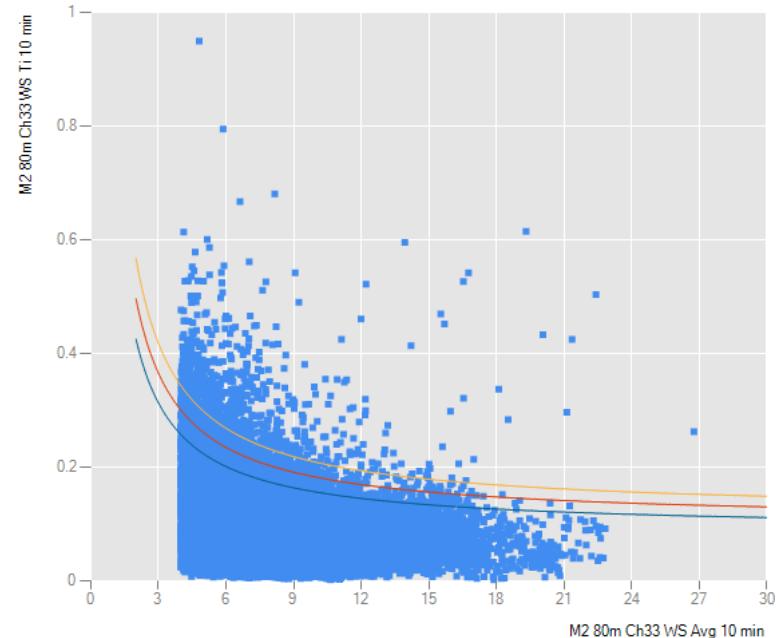
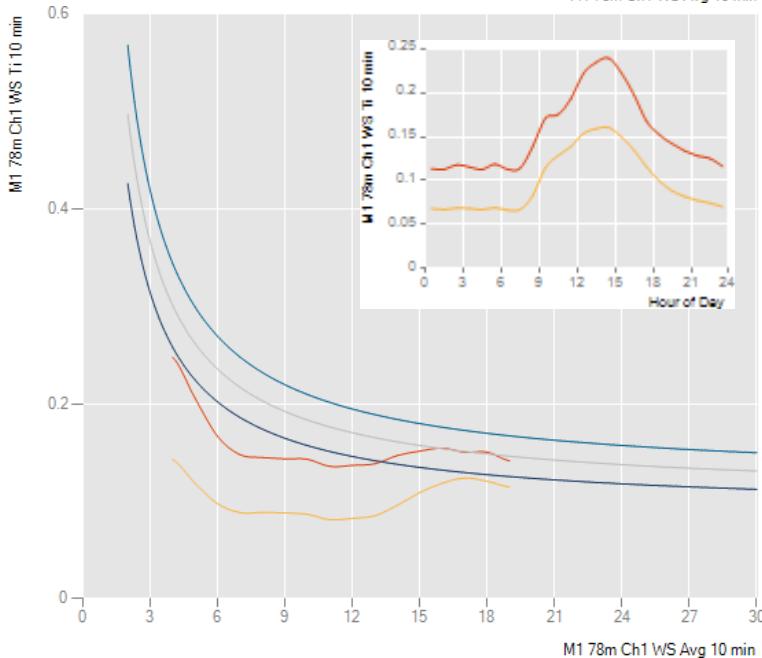
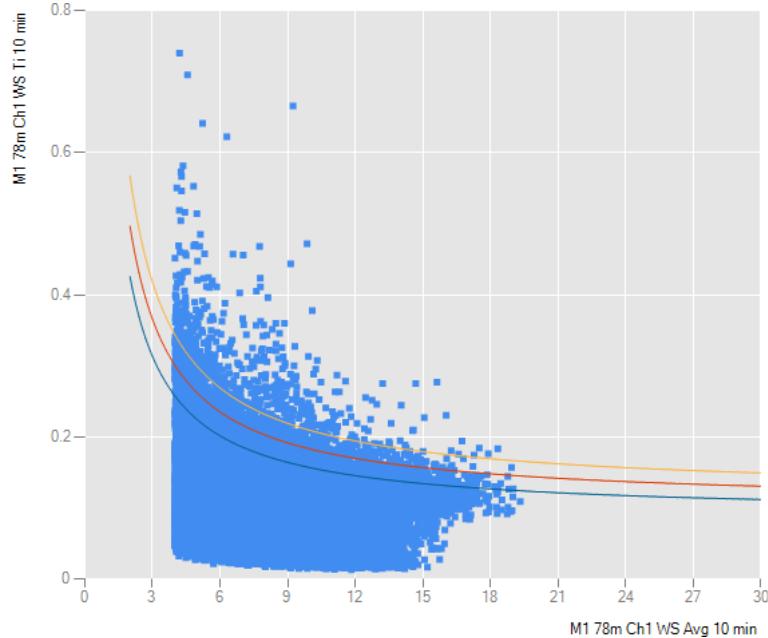


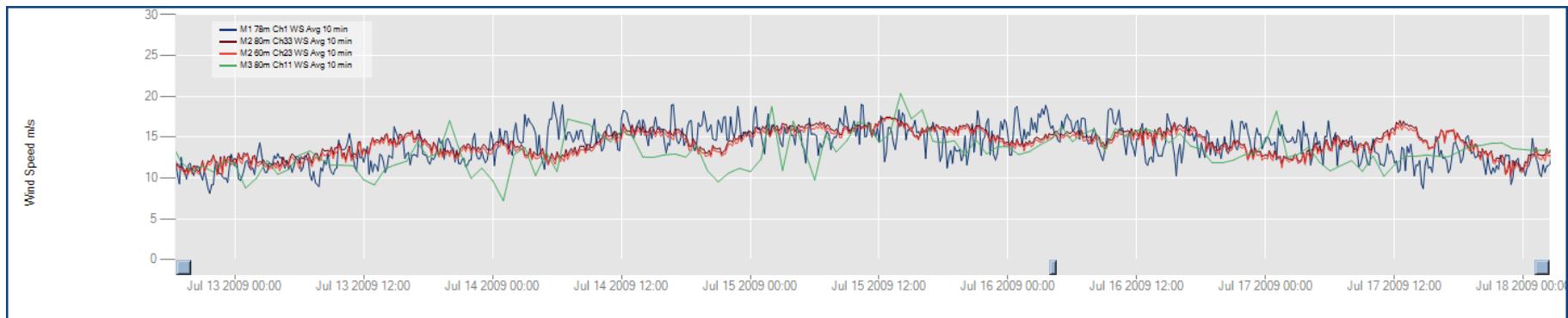
Scotland 1



$\sigma(WDir)$  vs. Wspeed  
Indicates rapid direction changes  
Available in Vortex WRF-LES output

## India 1

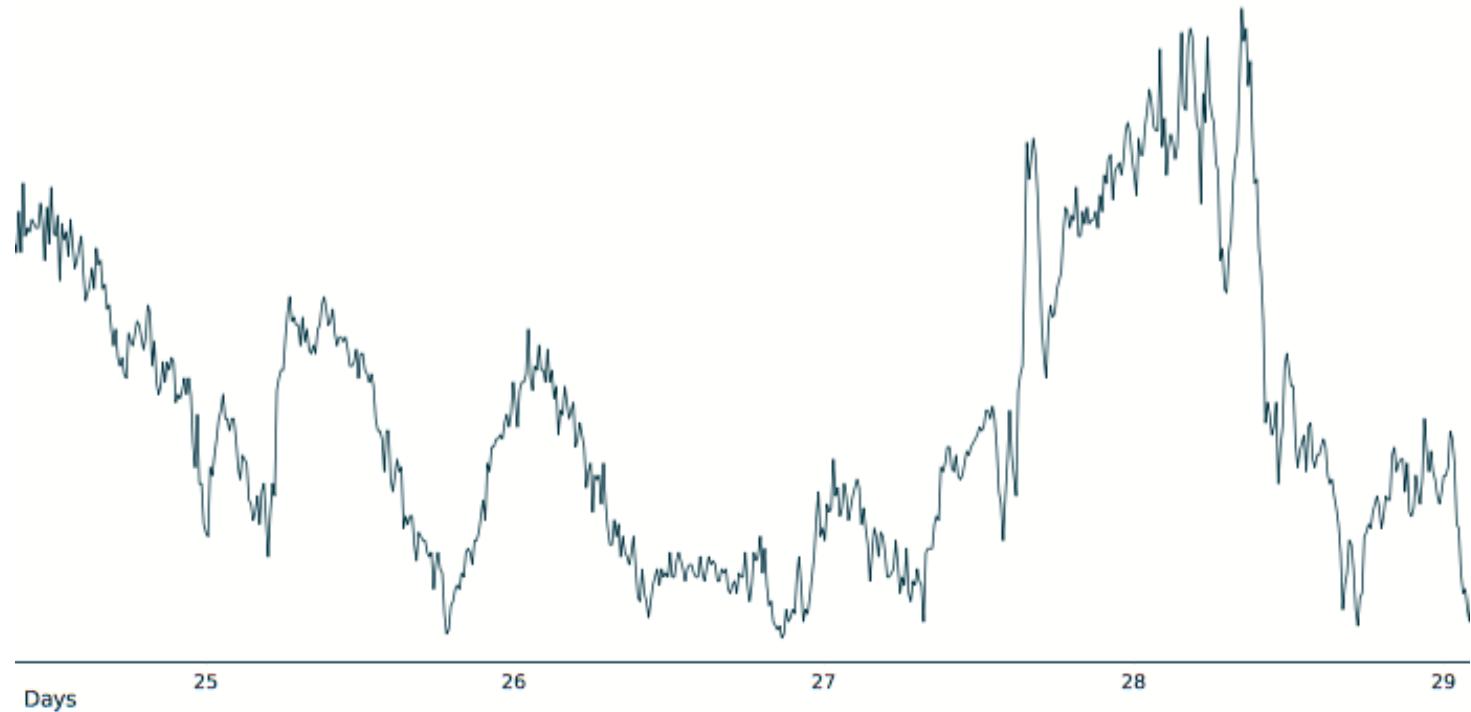




Observed at met-mast  
Vestas WRF 3km  
Vortex WRF-LES

- Not whole weather is simulated accurately
- But the statistics of wind speed, turbulence, ... is very comparable
- Future development? (e.g. surface shape and characteristics, ...)

Guess which are the measurements...

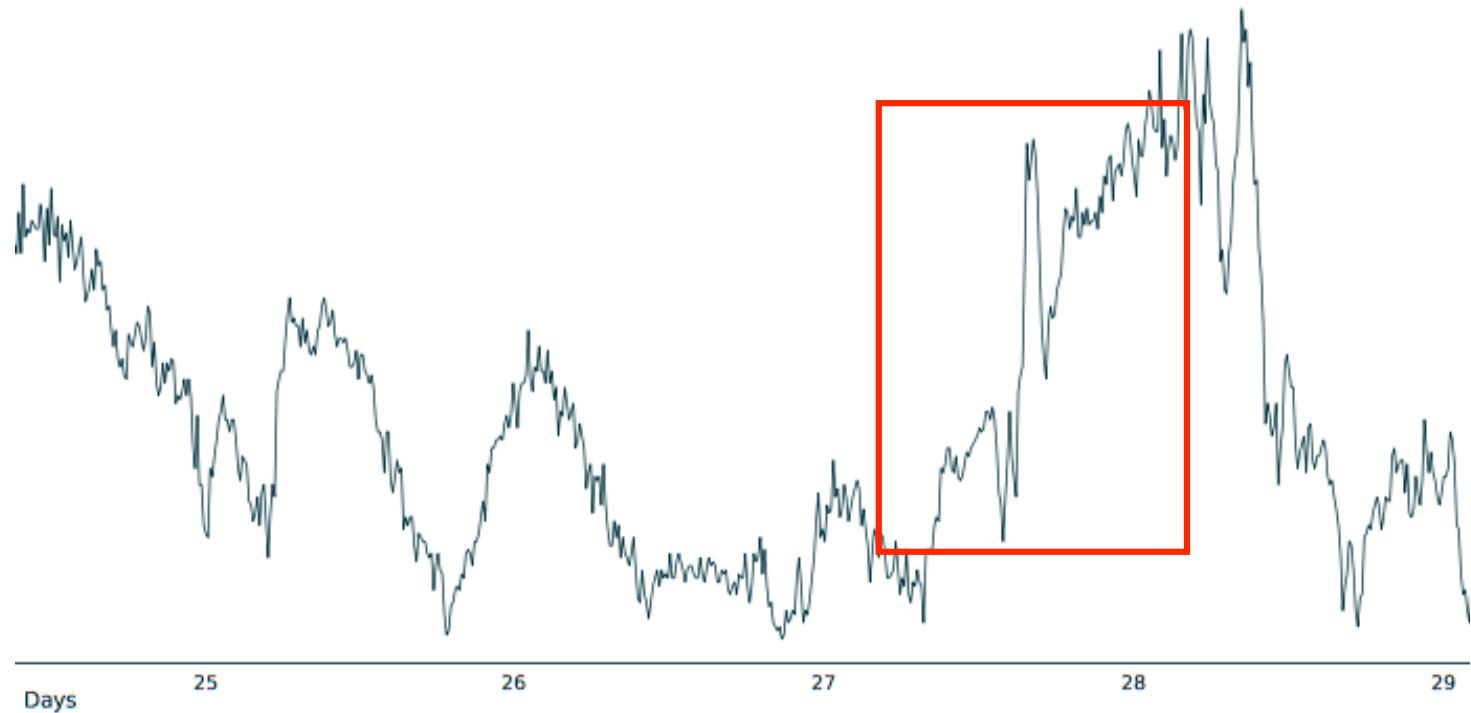


...and which are the model results



LES IS MORE!

Guess which are the measurements...

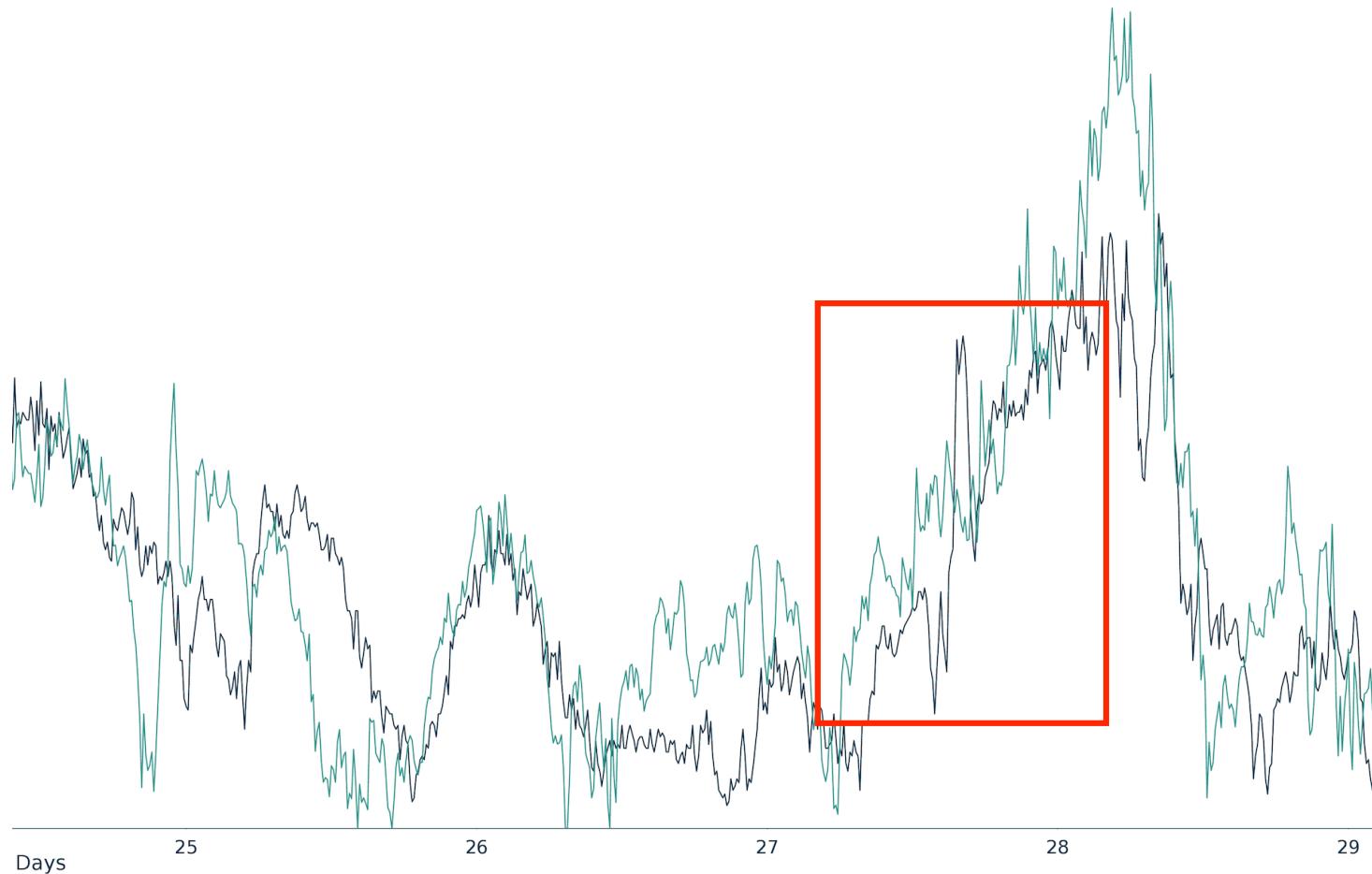


...and which are the model results



LES IS MORE!

Guess which are the measurements...



...and which are the model results



LES IS MORE!

Guess which are the measurements...

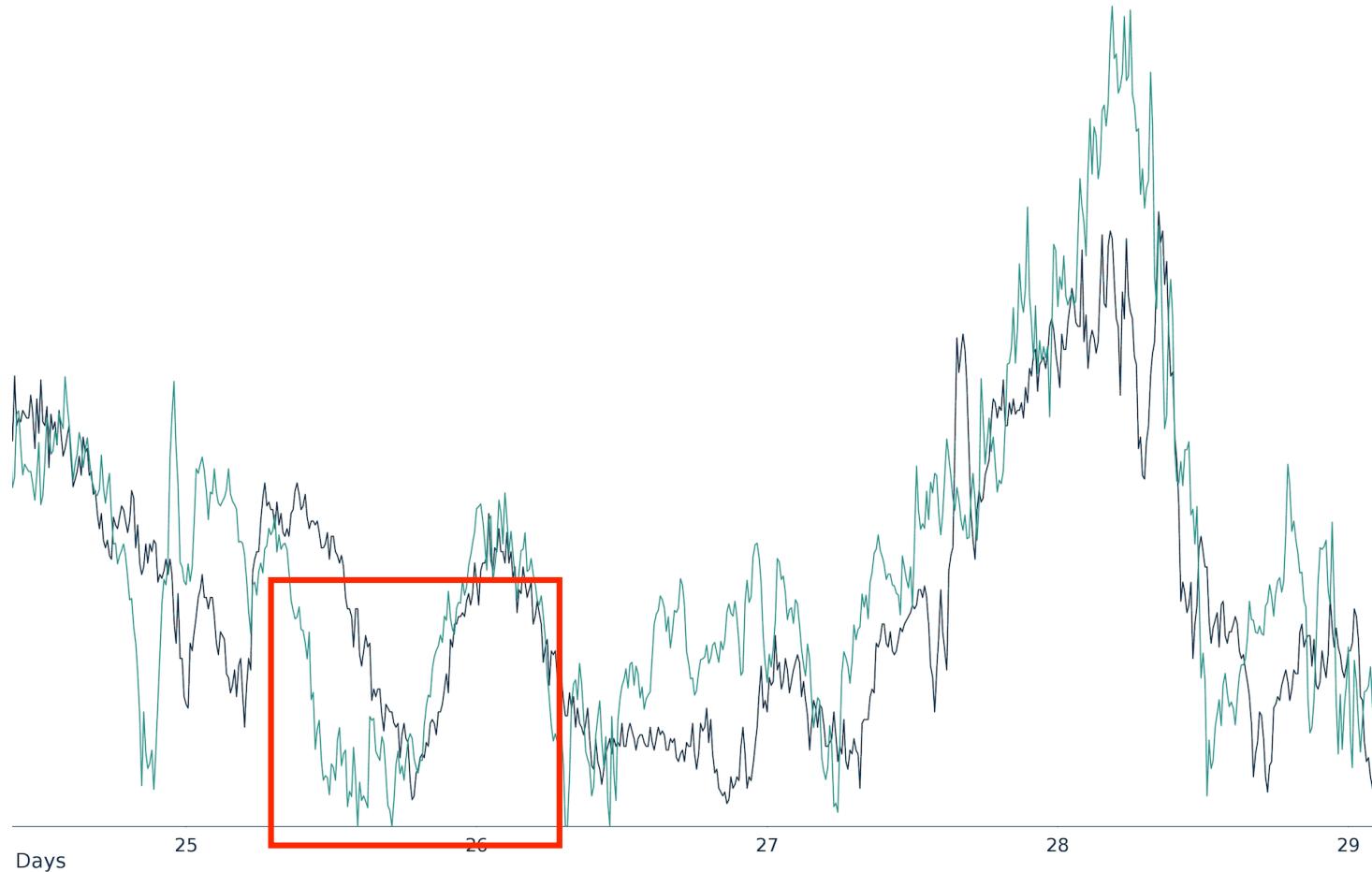


...and which are the model results



LES IS MORE!

Guess which are the measurements...

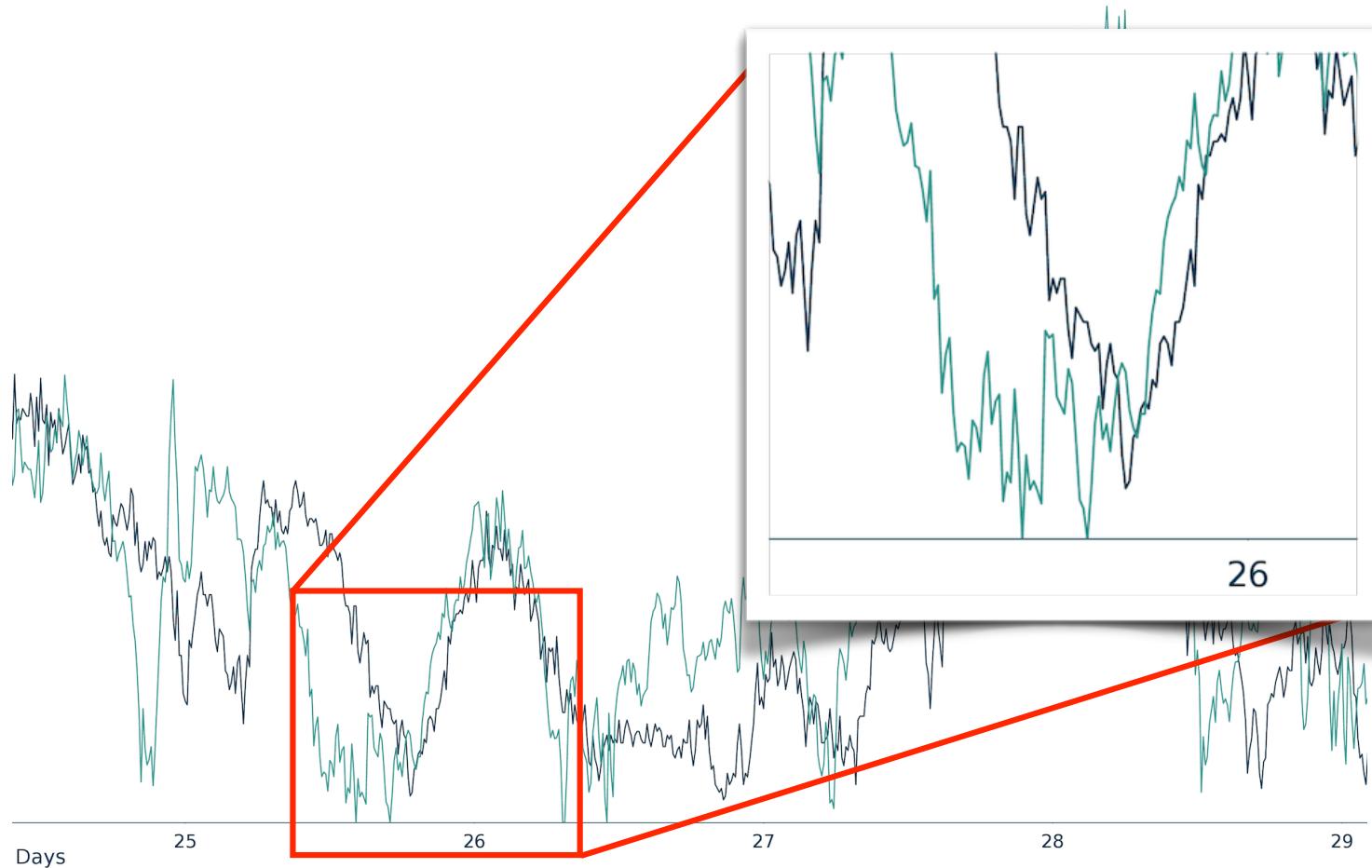


...and which are the model results



LES IS MORE!

Guess which are the measurements...



...and which are the model results

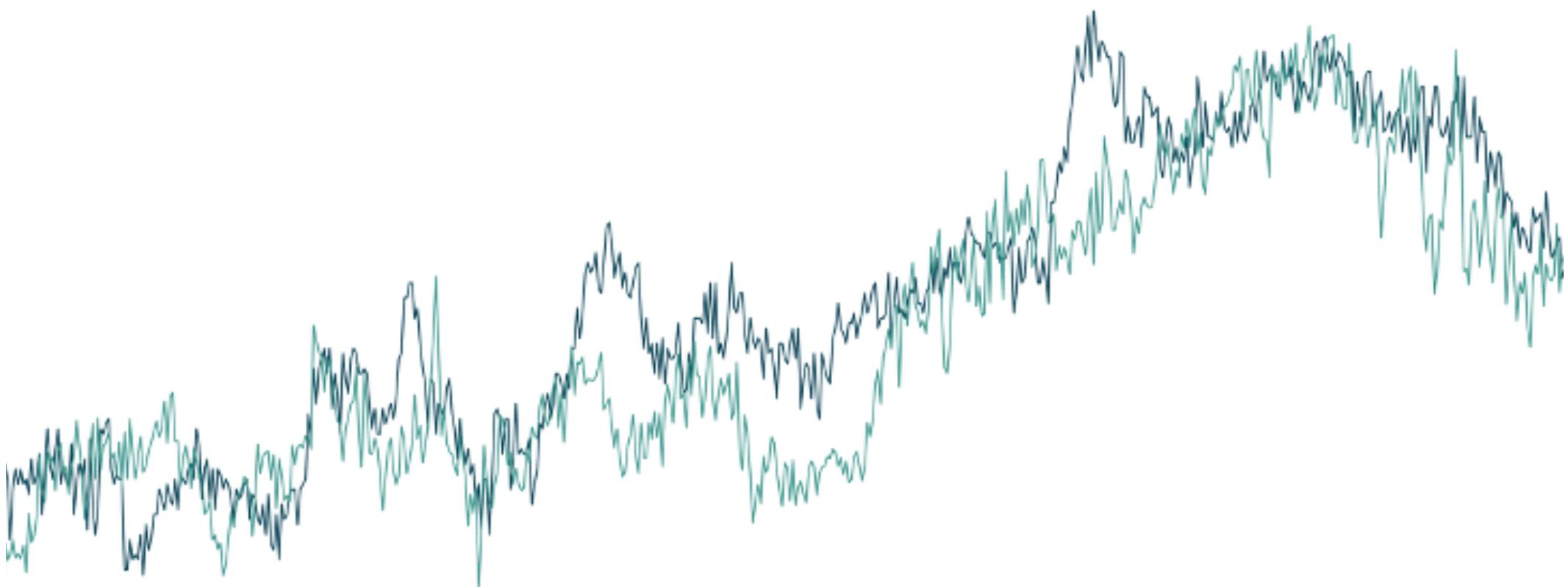


LES IS MORE!



# LES\* IS MORE!

\*LARGE EDDY SIMULATIONS BY VORTEX



WindEnergy Hamburg 2016