WRF-LES in the real world: Towards a seamless modeling chain for wind industry applications

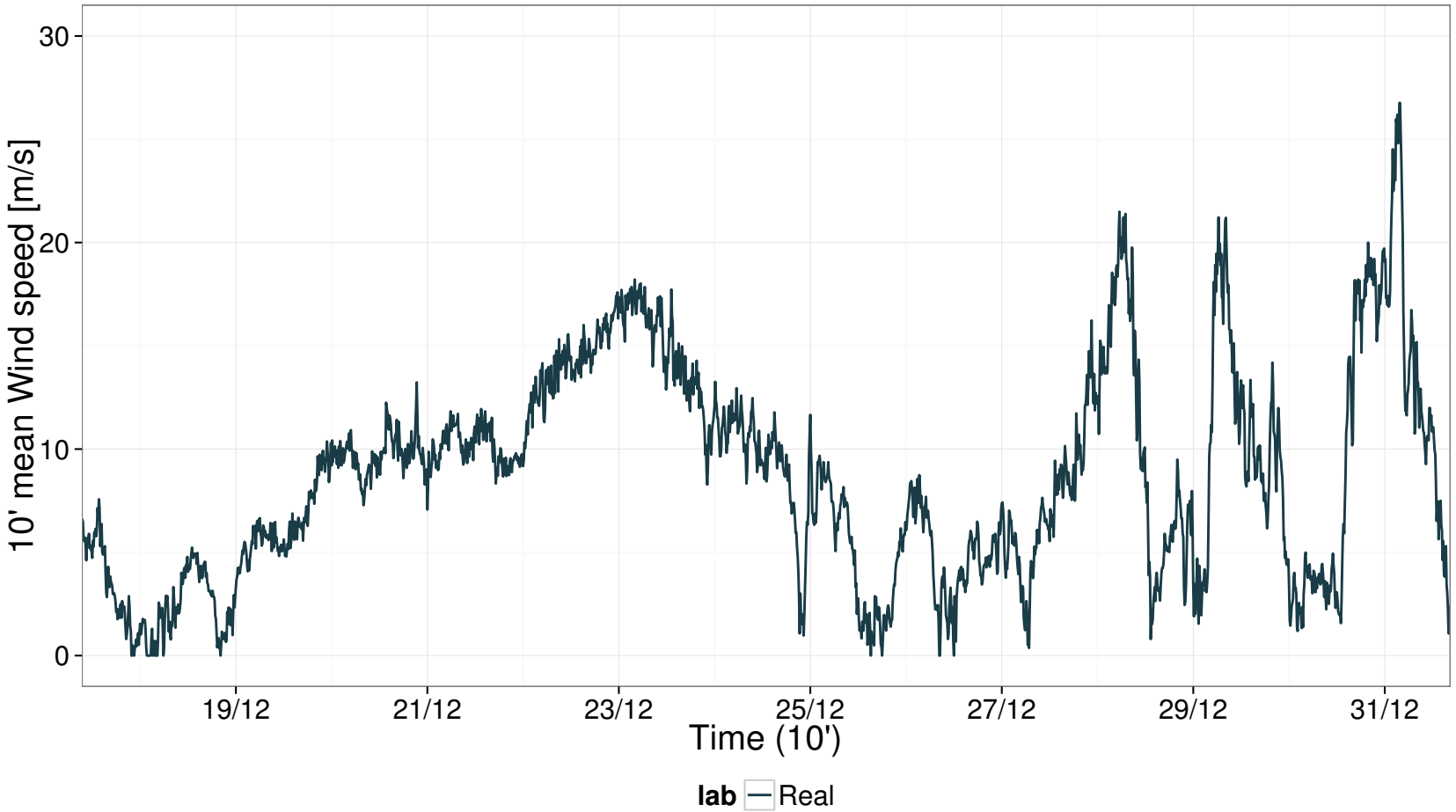
A. Montornès[1] P. Casso[1] B. Kosovic[2] G. Lizcano[1]

[1]Vortex, [2]NCAR–RAL

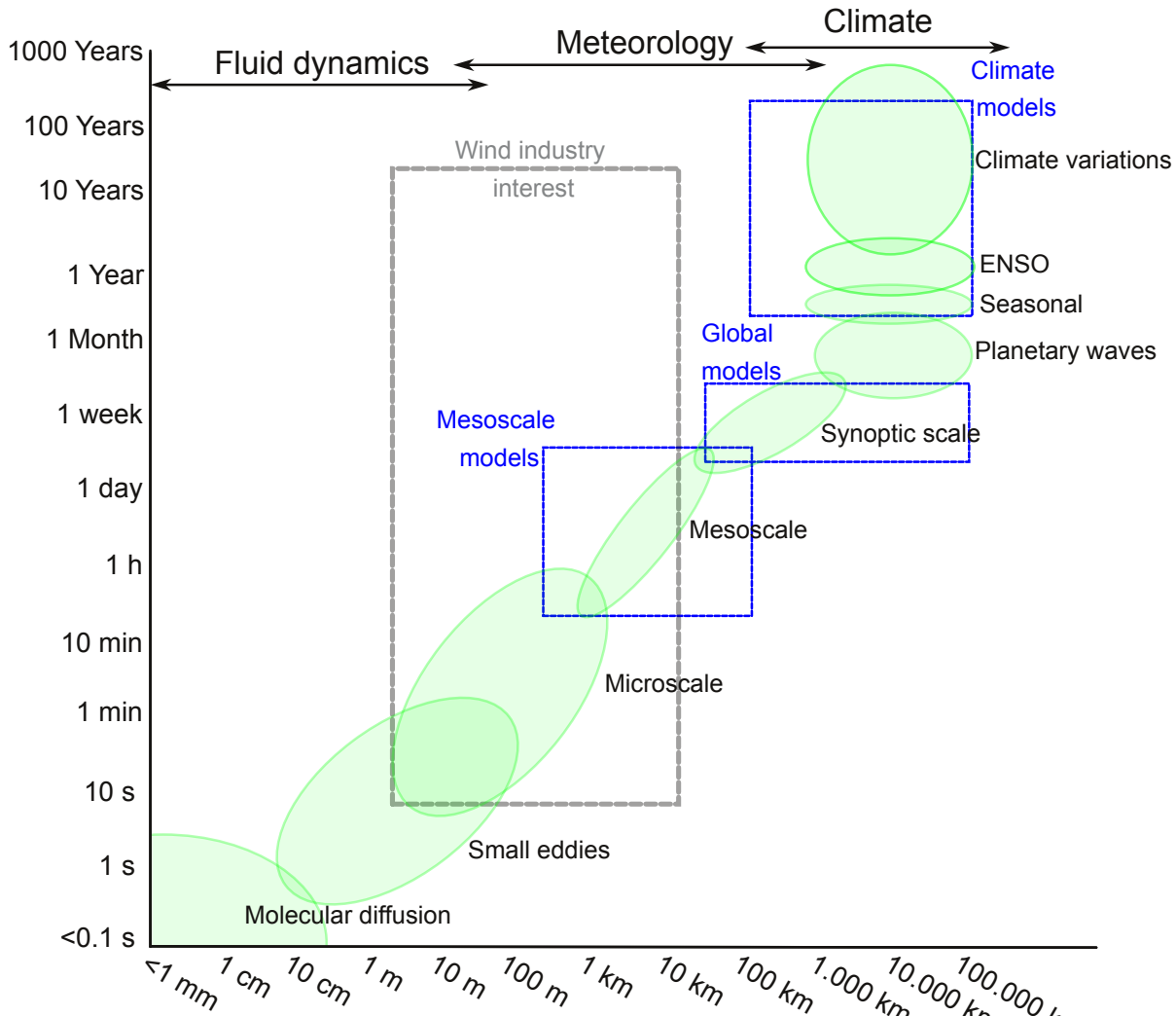
VORTEX

VORTEX 

- **Experienced** Vortex started its technology development in 2005 by former Wind Site engineers, atmospheric physicists and computer experts in a unusual collaborative team of experienced professionals with active researchers.
- **Wind industry** Vortex provides wind resource maps and series oriented for wind resources assessment and forecasting purposes.


30
20
10
0
10' mean Wind speed [m/s]
19/12
21/12
23/12
25/12
27/12
29/12
31/12
Time (10')
lab
Real

2000s - 2010s


Fluid dynamics
Meteorology
Climate
1000 Years
100 Years
10 Years
1 Year
1 Month
1 week
1 day
1 h
10 min
1 min
10 s
1 s
<0.1 s
<1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
10 km
100 km
1.000 km
10.000 km
100.000 km
Wind industry interest
Climate models
Climate variations
ENSO
Seasonal
Global models
Planetary waves
Synoptic scale
Mesoscale models
Mesoscale
Microscale
Small eddies
Molecular diffusion

Mesoscale models 2000s - 2010s

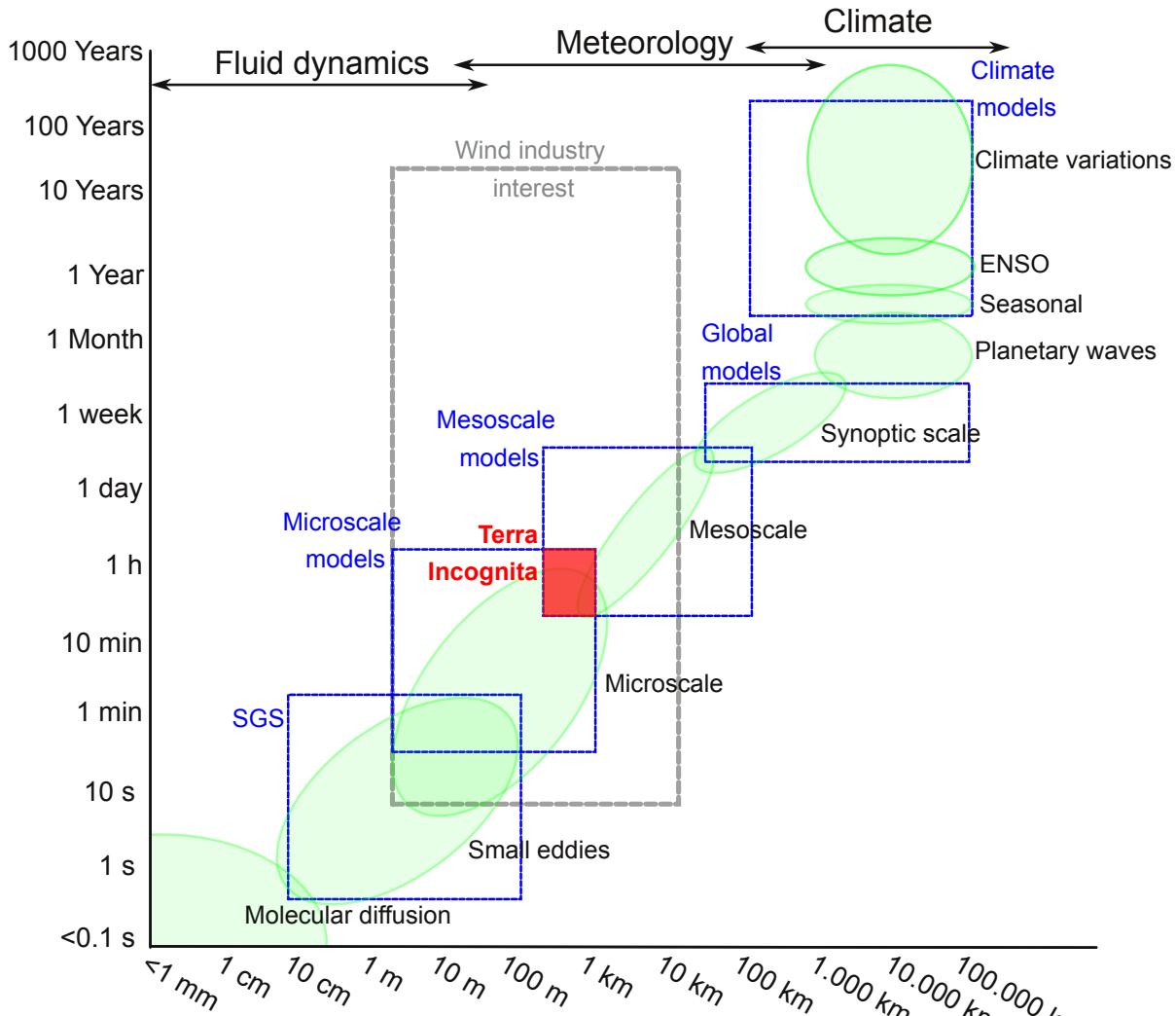
$$F = \bar{F} + F'$$

- $\Delta \mathbf{x} \geq \mathbf{500\ m}$
- Wind resolved at each grid-point of the domain describes the mean state flow $\bar{F}$.
- Mixing motions F' must be simplified and parameterized.
- Model splits the spatial diffusion
  - **Vertical diffusion** $\rightarrow$ PBL schemes.
  - **Horizontal diffusion** $\rightarrow$ represented in terms of the deformation of the large-scale flow.

2000s - 2010s


30
20
10
0
10' mean Wind speed [m/s]
19/12
21/12
23/12
25/12
27/12
29/12
31/12
Time (10')
lab
Real
Vortex−PBL 3 km

2016: Microscale is here

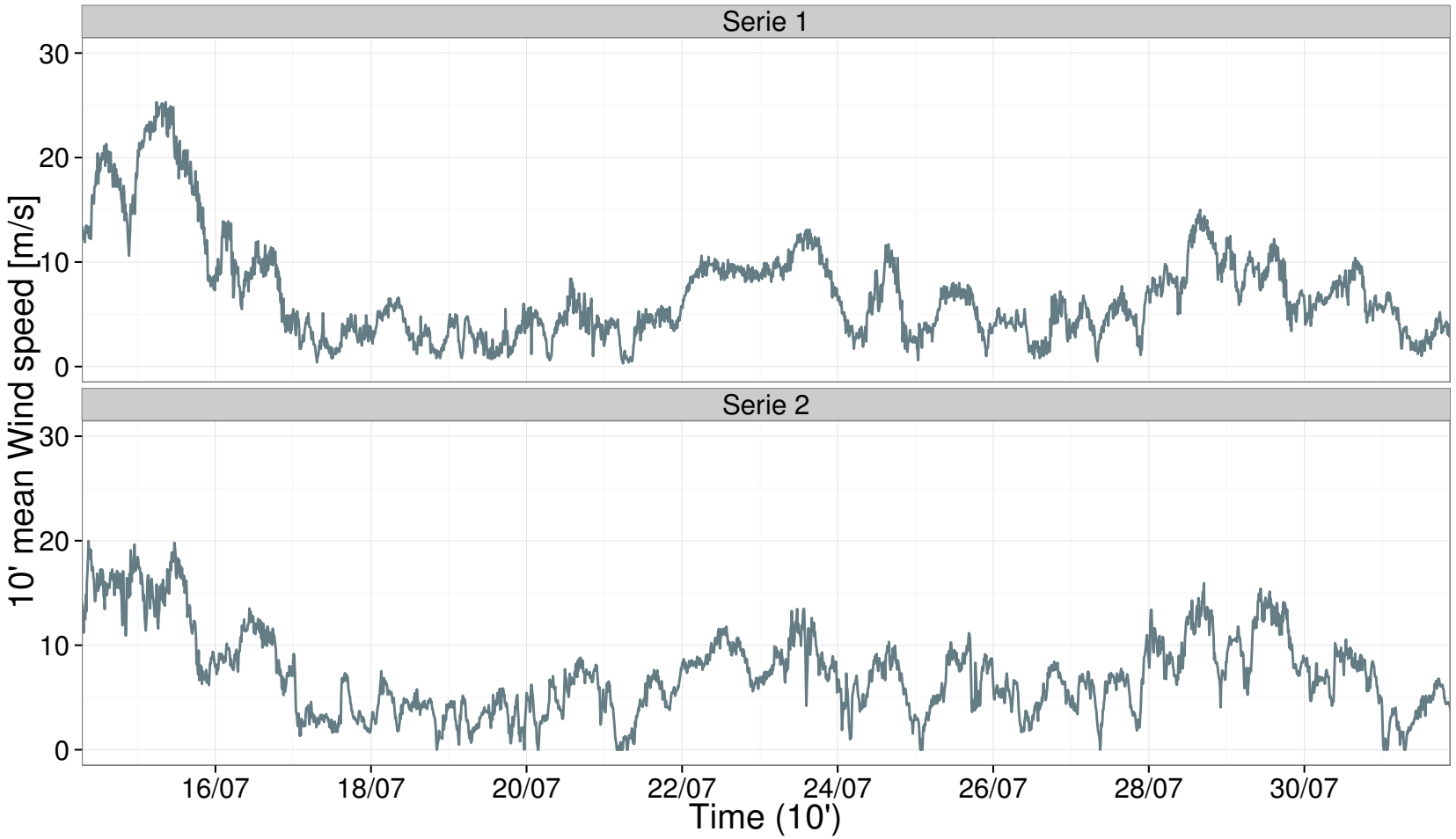


Large Eddy Simulations

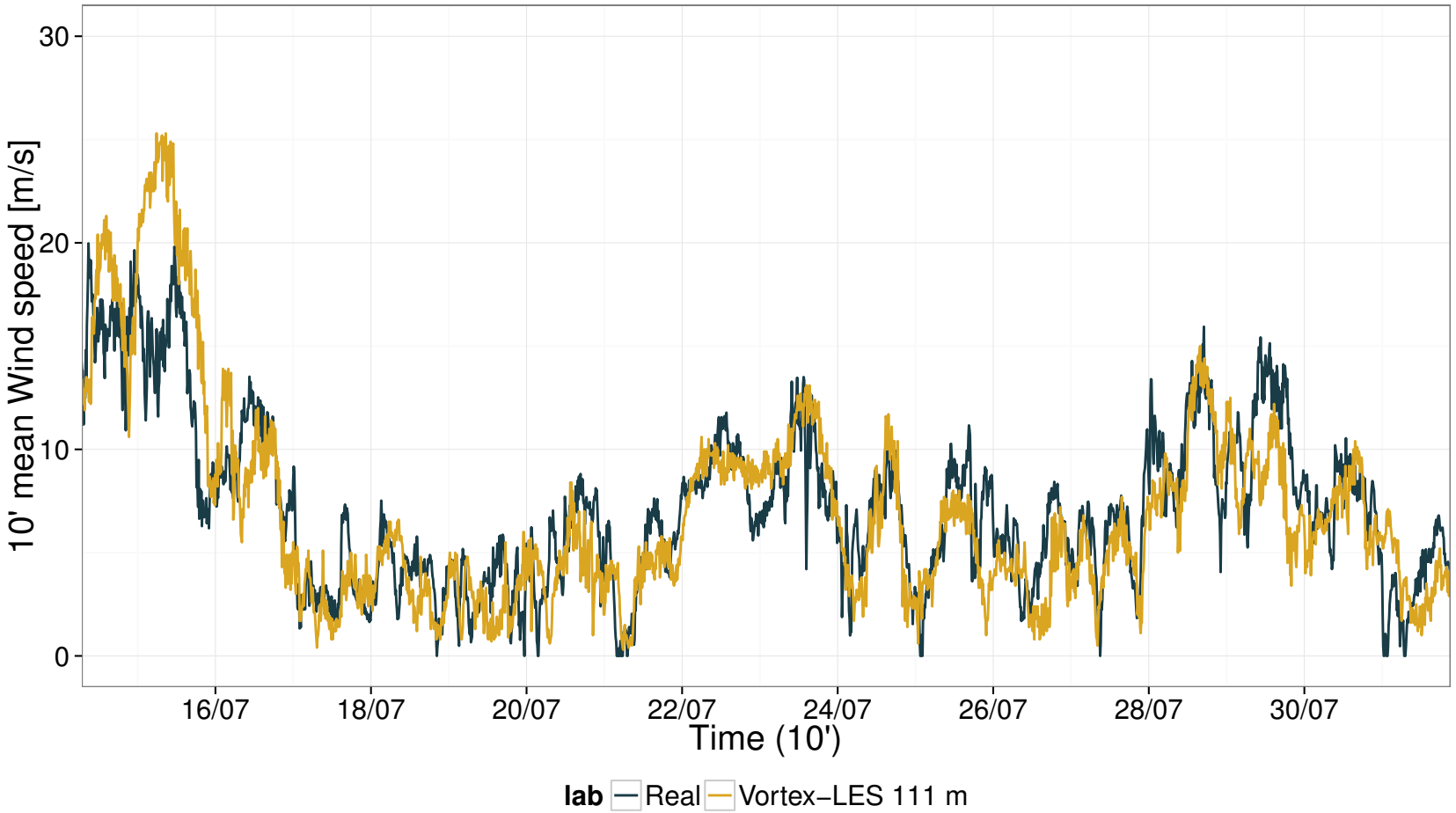
$$F' = \textbf{Large Eddies}\ (> \Delta x) + \textbf{Small Eddies}\ (< \Delta x)$$

- Turbulence motions are divided in **Large Eddies** and **Small Eddies**.
- **Large Eddies** ($> \Delta x$) are solved as a solution of the Navier-Stokes Equations.
- **Small Eddies** ($< \Delta x$) need to be parameterized in subgrid-scale models (SGS) and resolved sub-filter scales (SFS).

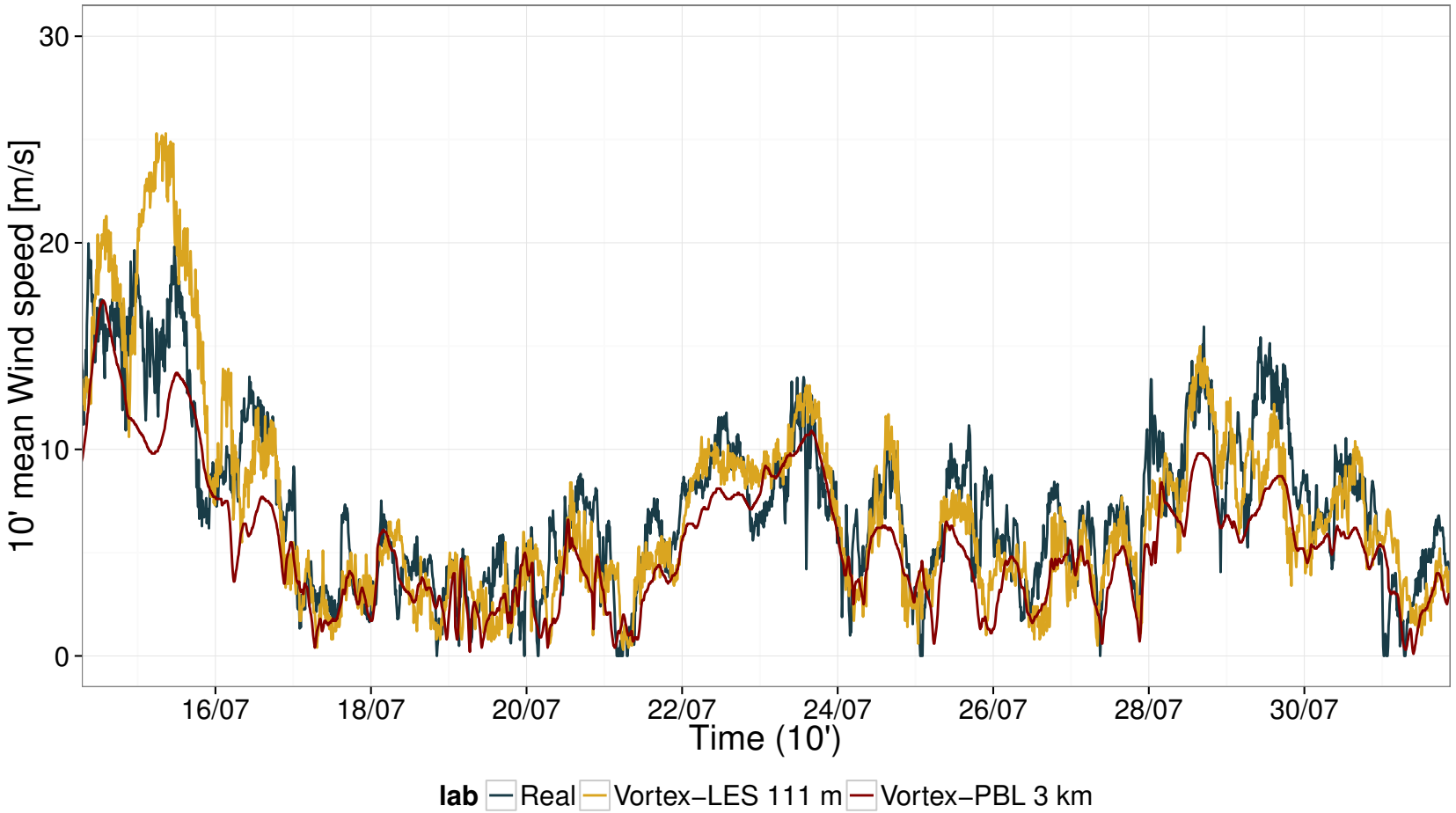
2016: Real or model?



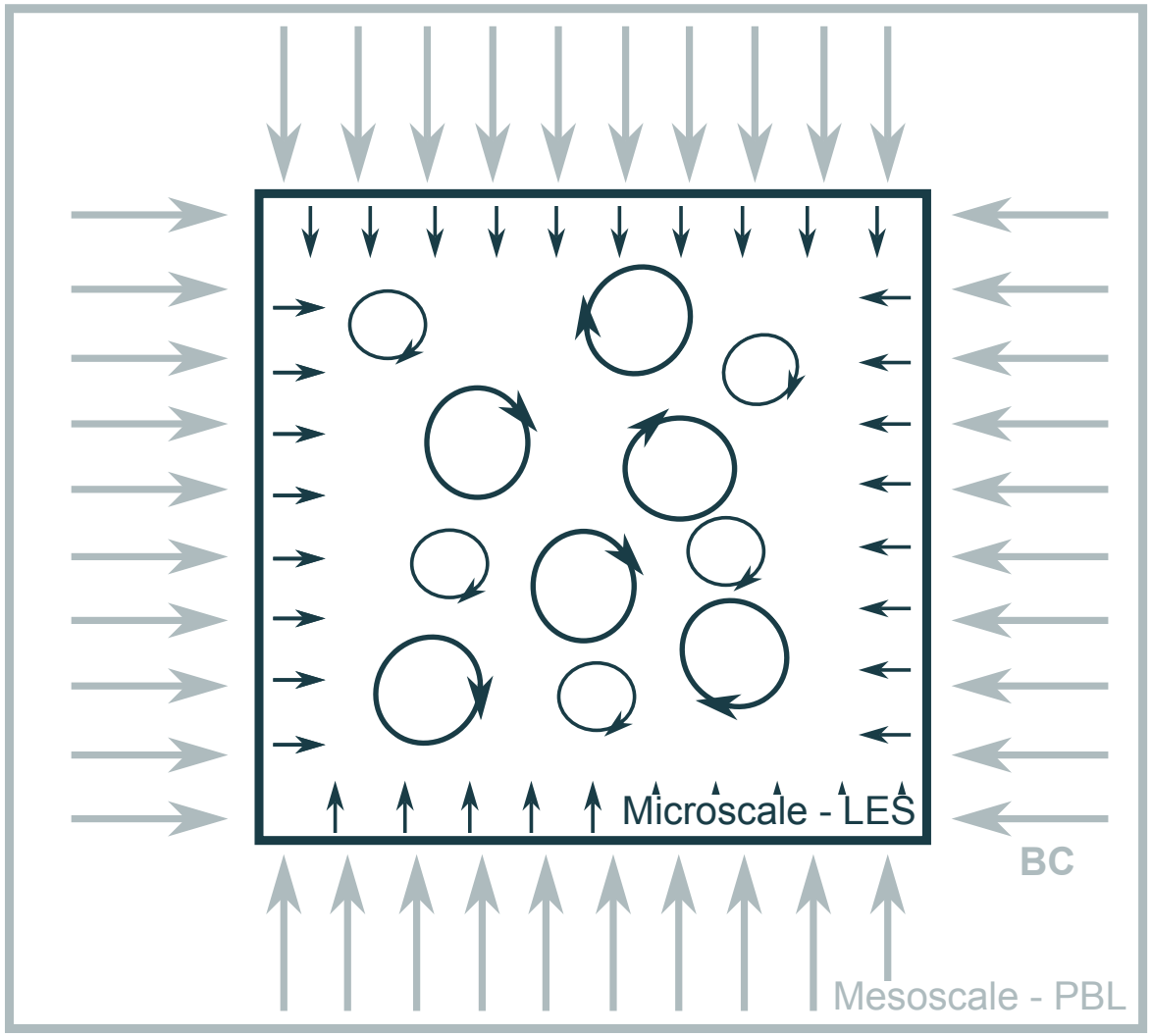
2016: Real or model?



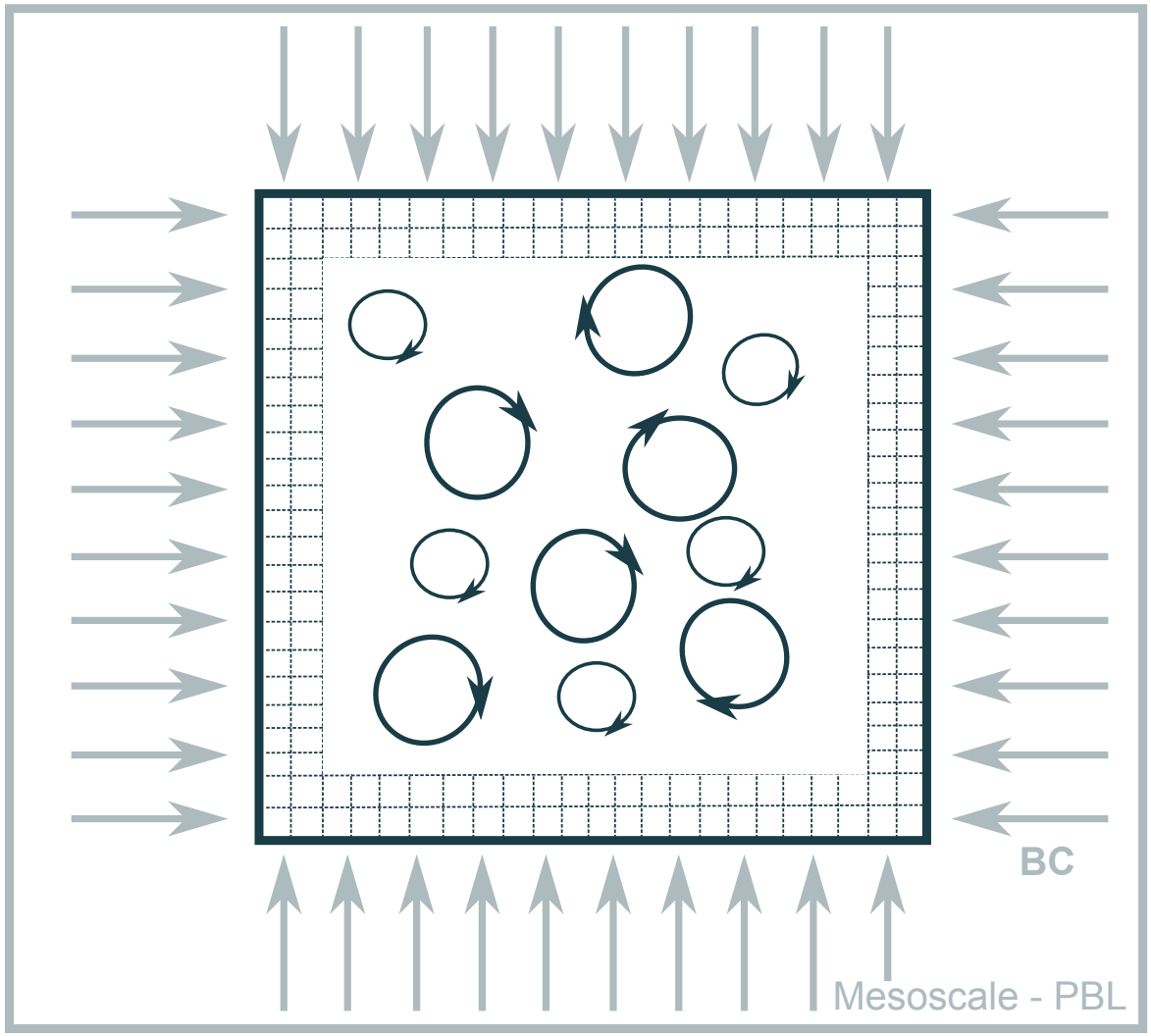
2016: Real or model?



Limitations in real simulations



Limitations in real simulations



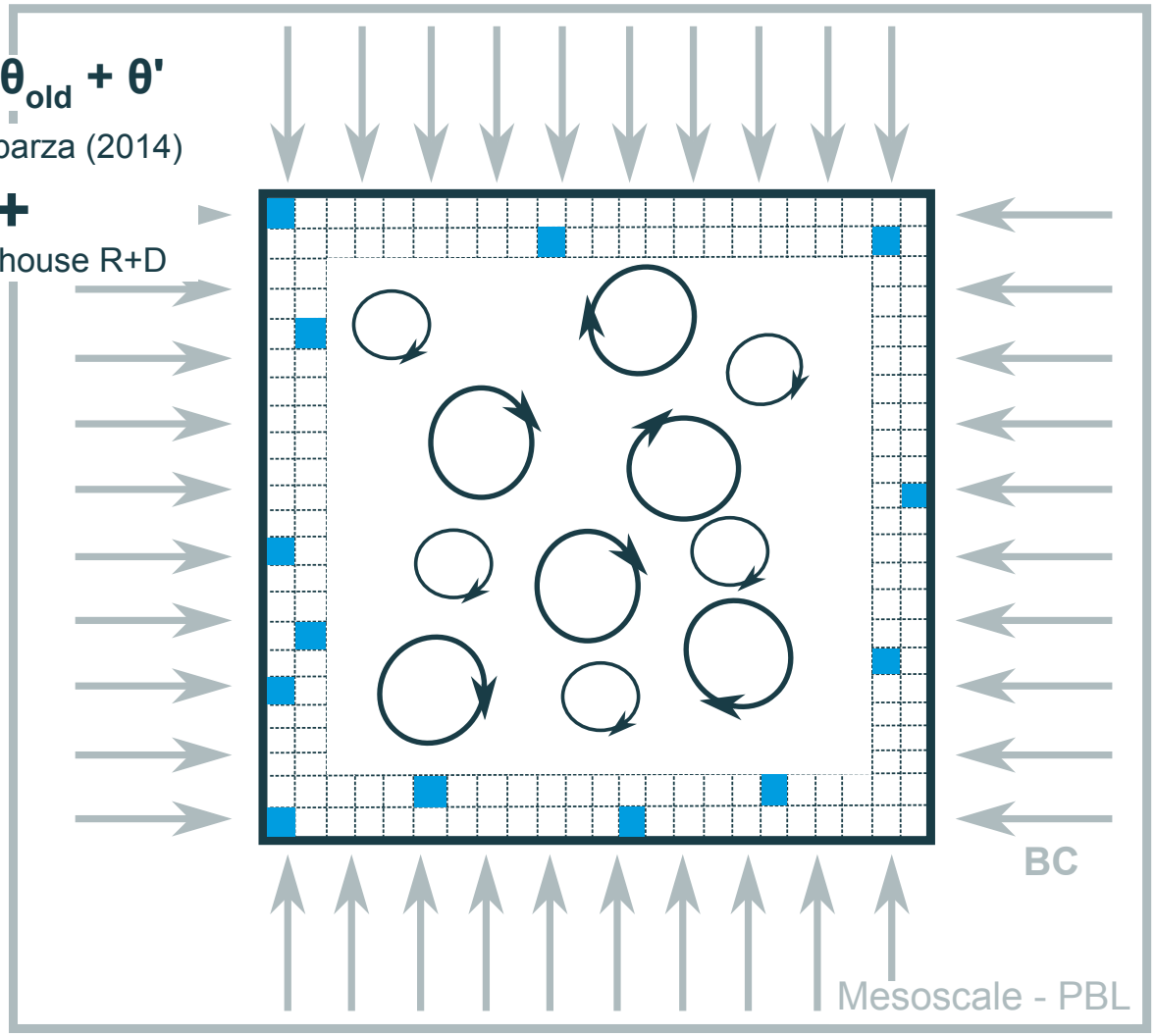
Limitations in real simulations

$\theta_{new} = \theta_{old} + \theta'$

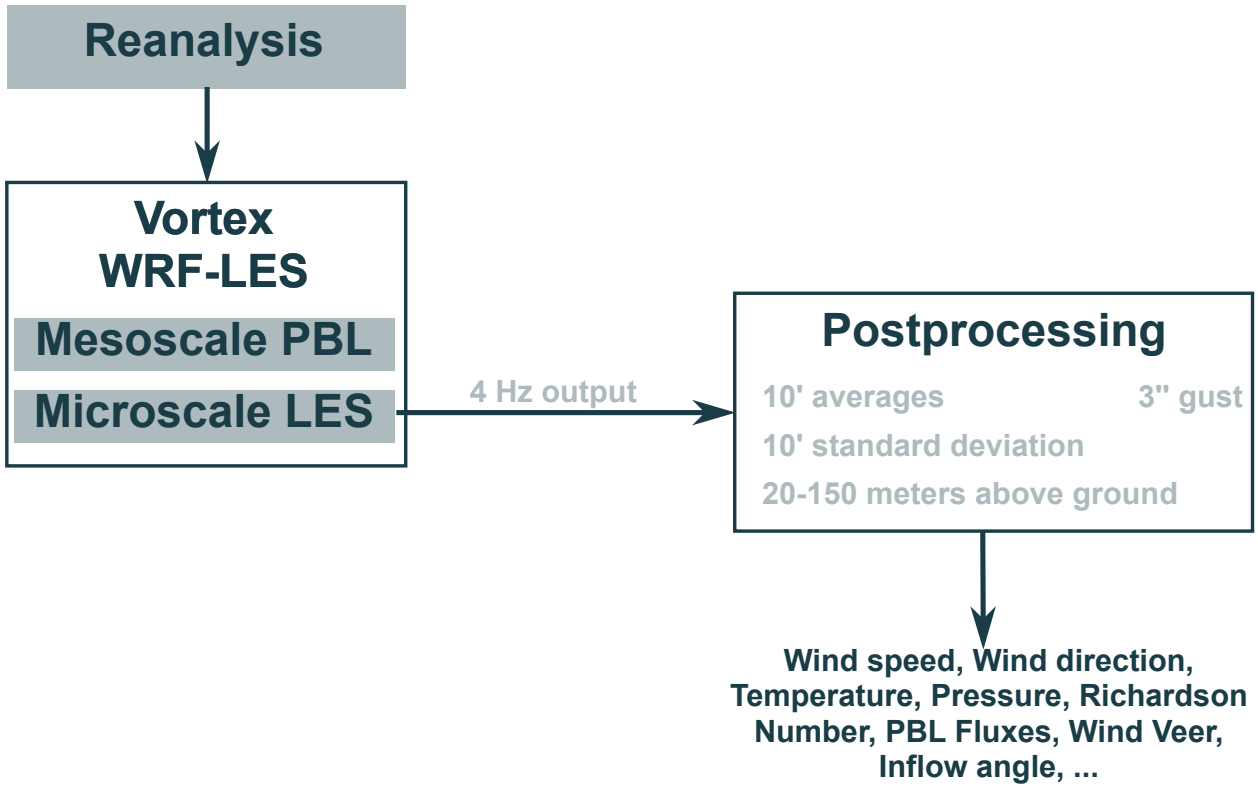
Muñoz-Esparza (2014)

+

Vortex in-house R+D

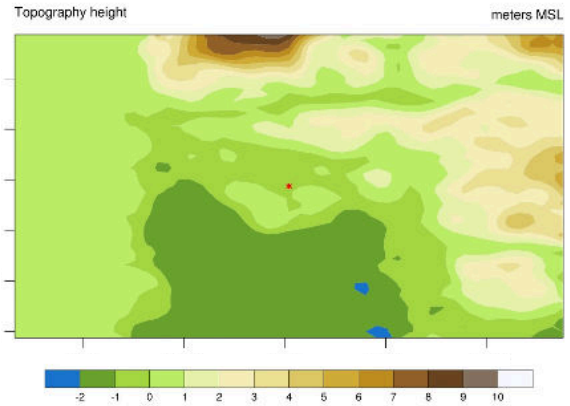


Vortex approach

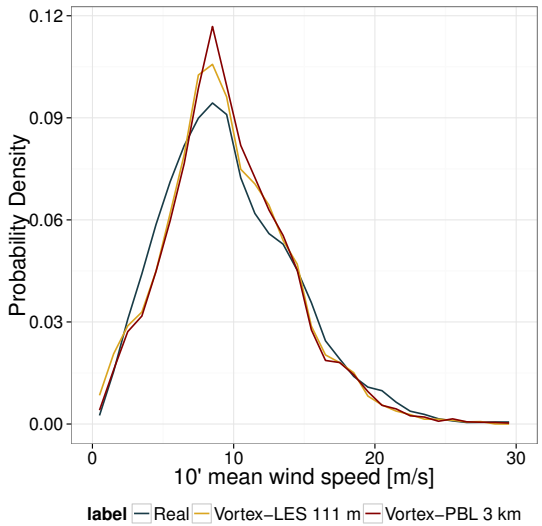


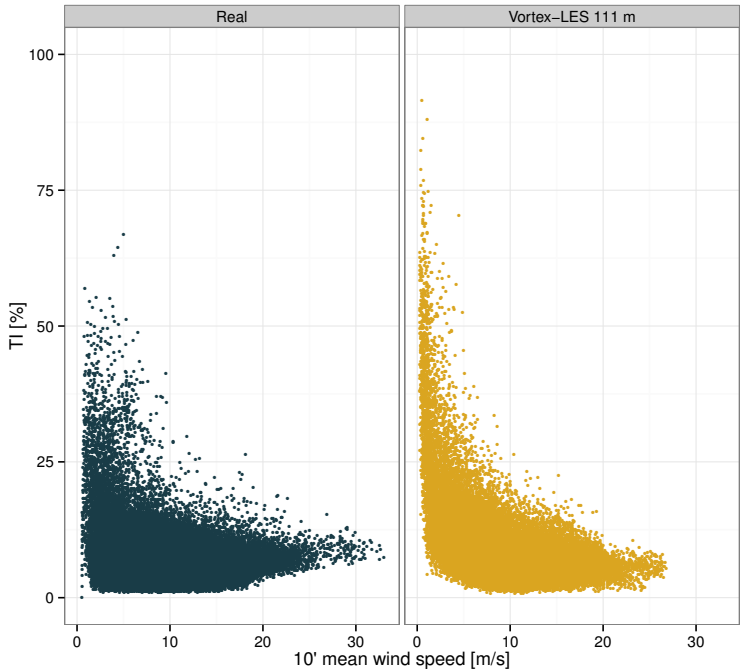
Site 1

Metmast: 60 m
Period: 1-year



	$Bias_{10'}$	$RMSE_{10'}$	R^2_{hourly}	R^2_{daily}
Vortex-3 km	1.0 ms^{-1}	1.7 ms^{-1}	0.87	0.95
Vortex-111 m	1.0 ms^{-1}	1.7 ms^{-1}	0.86	0.94





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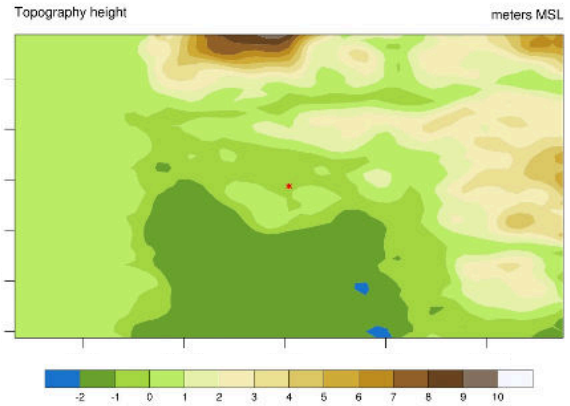

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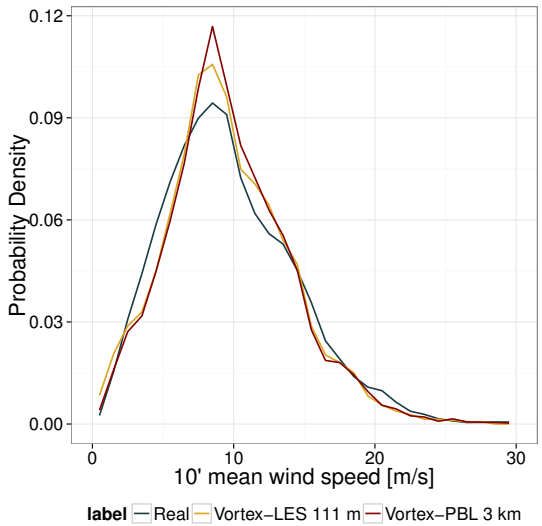

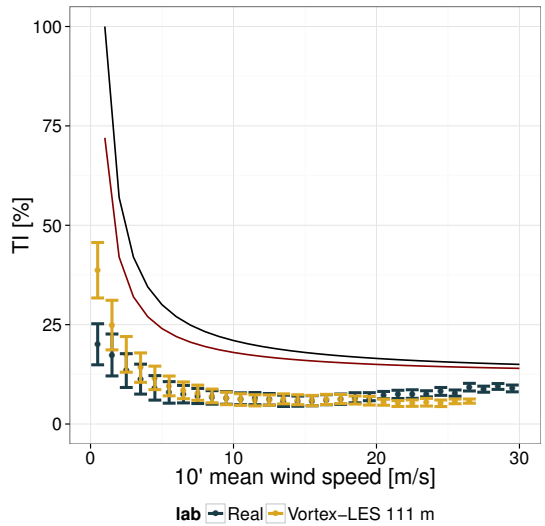

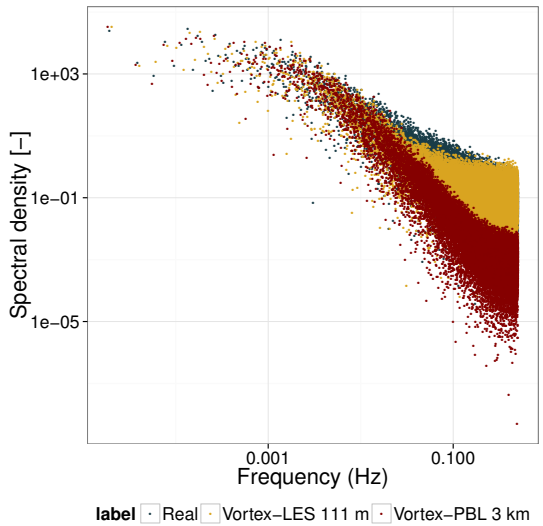

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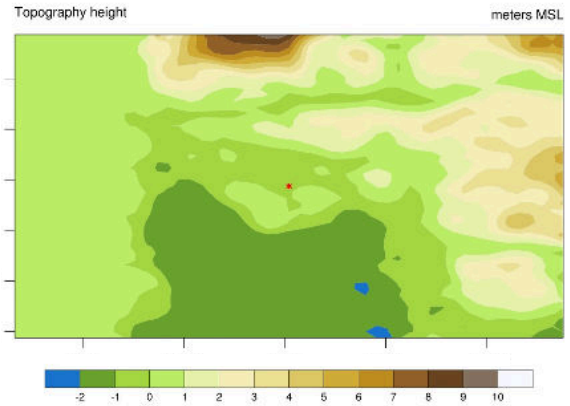

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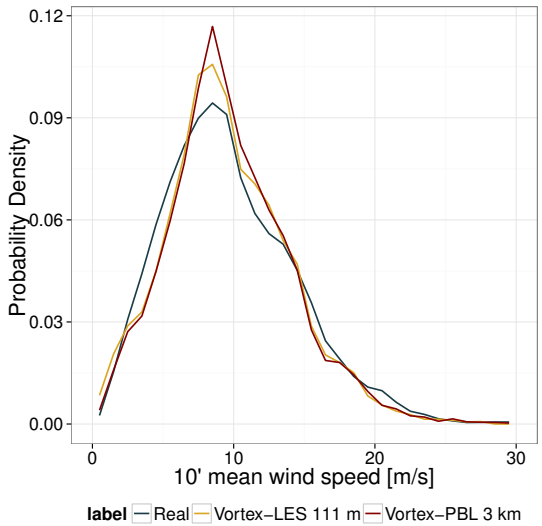
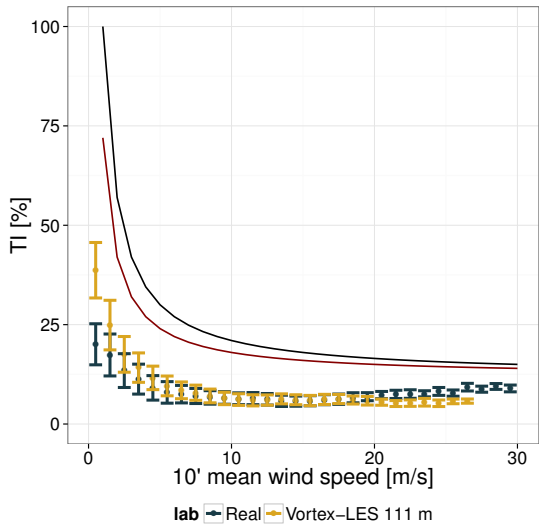
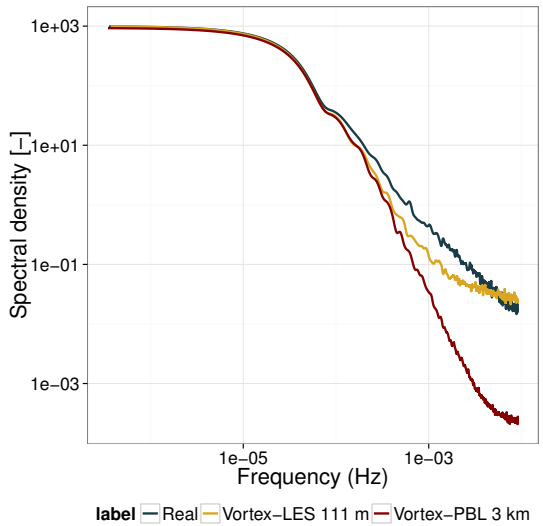
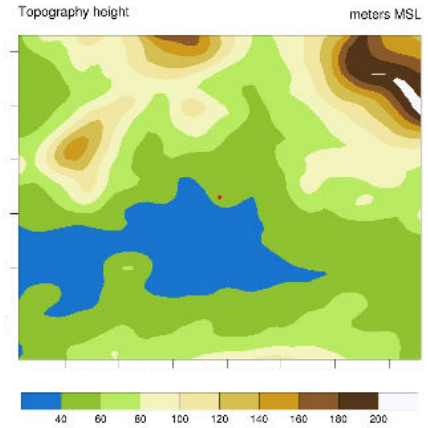




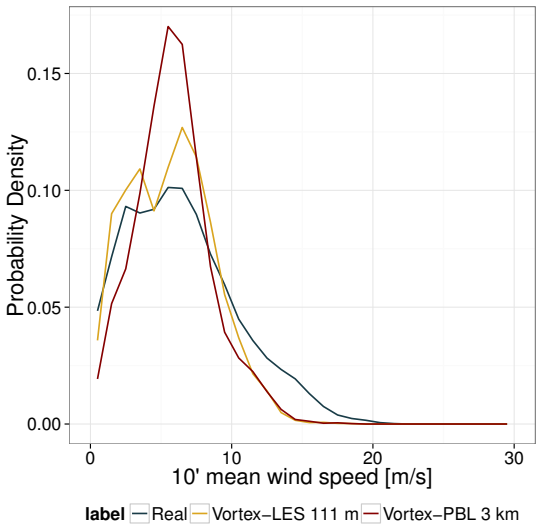


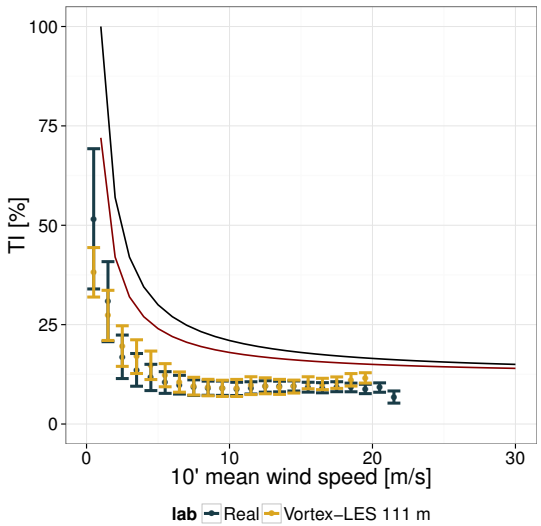
Site 2

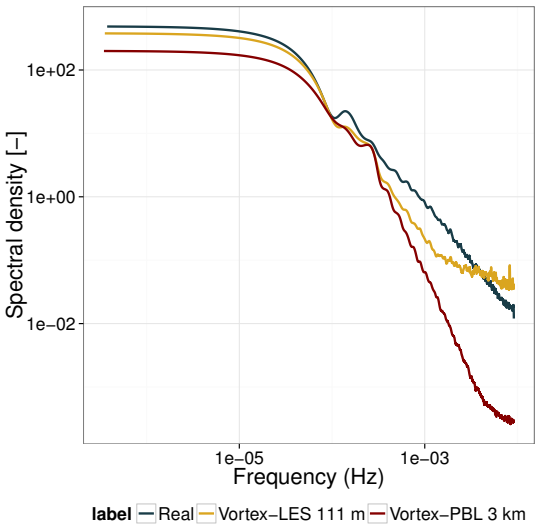
Metmast: 70 m
Period: 1-year



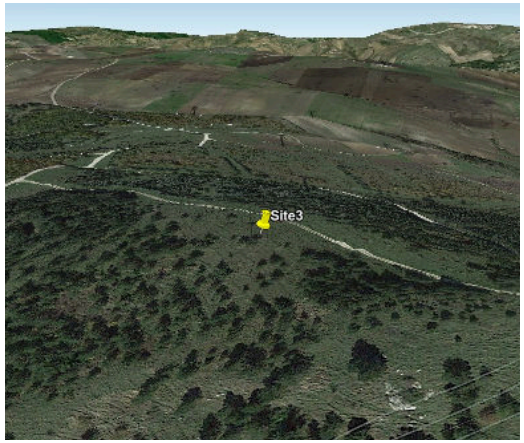
	$Bias_{10'}$	$RMSE_{10'}$	R^2_{hourly}	R^2_{daily}
Vortex-3 km	-0.5 ms^{-1}	2.9 ms^{-1}	0.51	0.70
Vortex-111 m	-0.7 ms^{-1}	2.6 ms^{-1}	0.62	0.80







Site 3 70 m

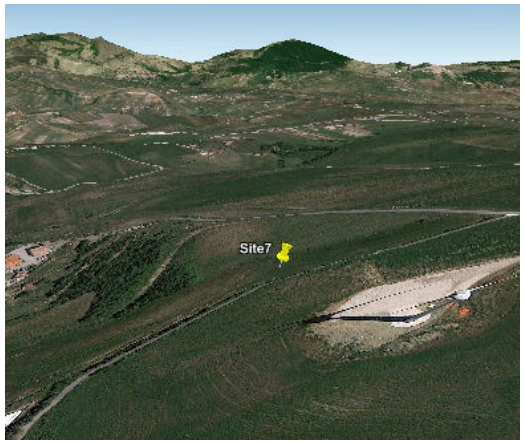


Site 4 60 m

Site 5 90 m

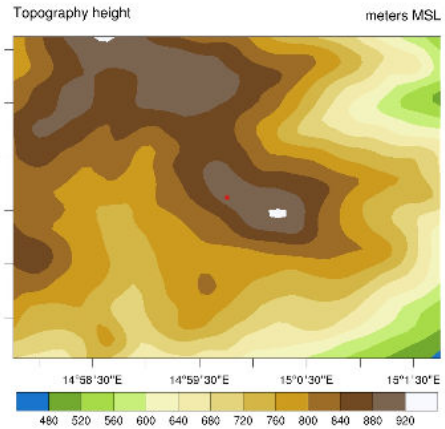
Site 6 97 m

Site 7 30 m

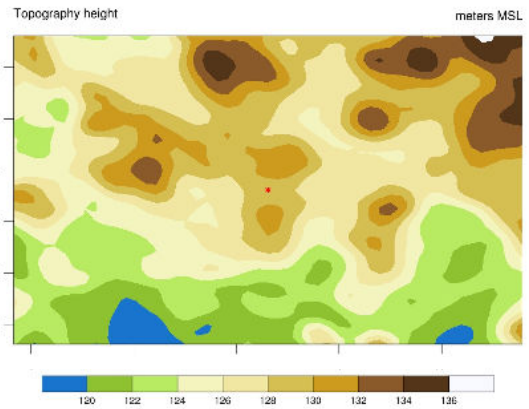


Site 8 60 m

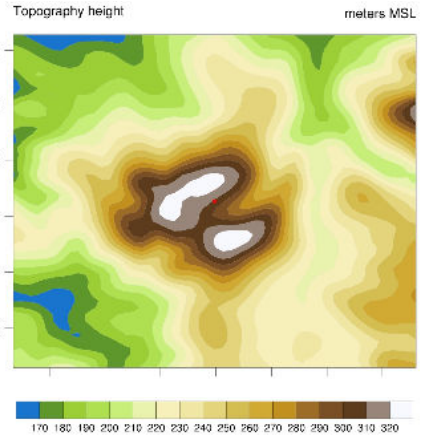
Site 3 70 m



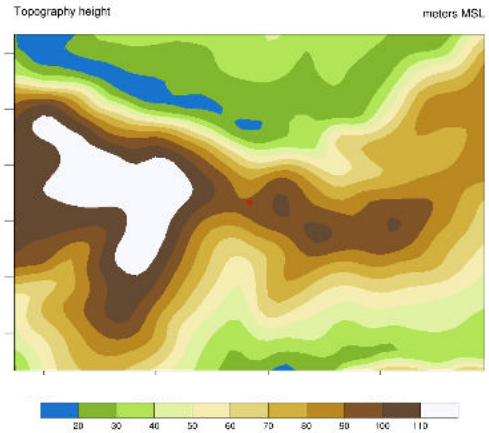
Site 4 60 m



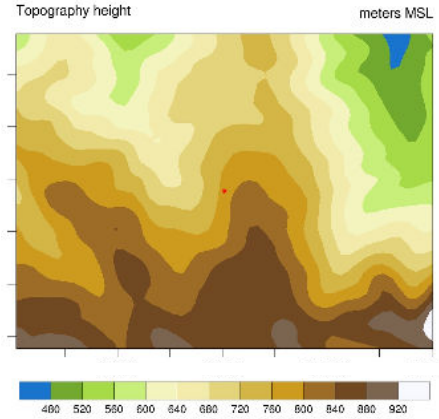
Site 5 90 m



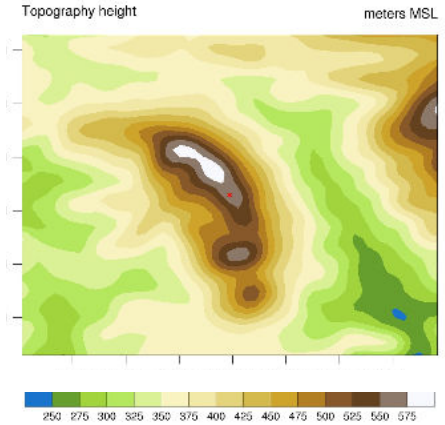
Site 6 97 m



Site 7 30 m



Site 8 60 m

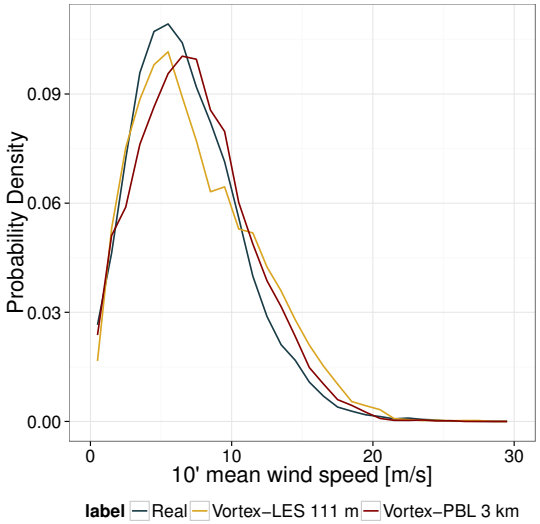


Metrics summary

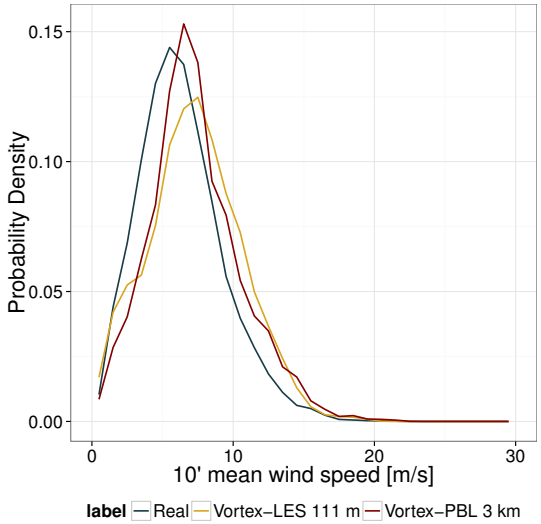
Averaged values **8 sites**

	$Bias_{10'}$	$RMSE_{10'}$	R^2_{hourly}	R^2_{daily}
Vortex-3 km	0.3 ms^{-1}	2.6 ms^{-1}	0.64	0.81
Vortex-111 m	0.3 ms^{-1}	2.3 ms^{-1}	0.68	0.84

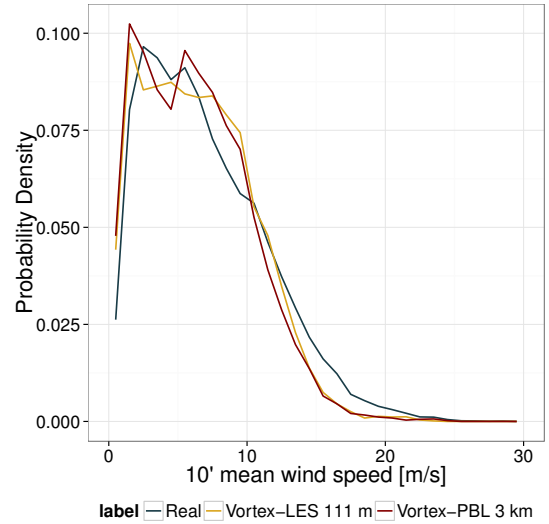
Site 3 — 70 m



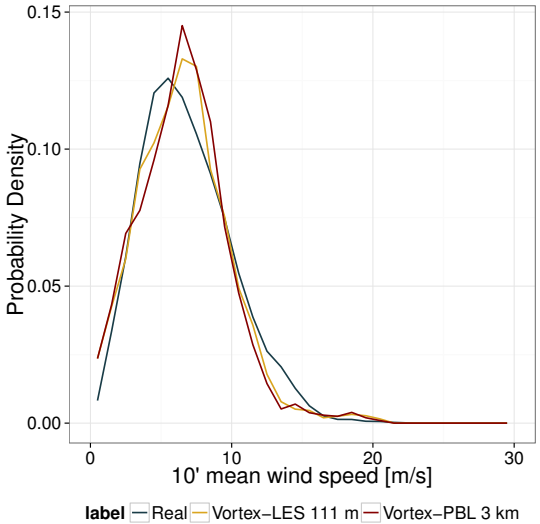
Site 4 — 60 m



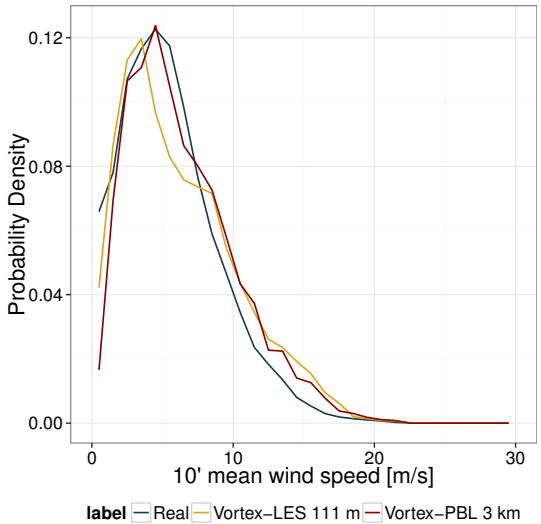
Site 5 — 90 m



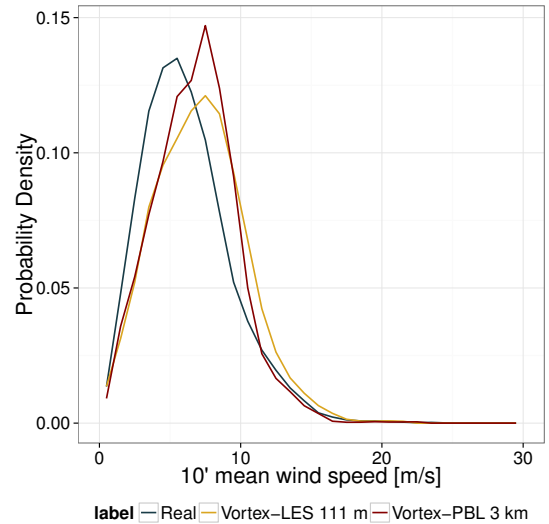
Site 6 — 97 m



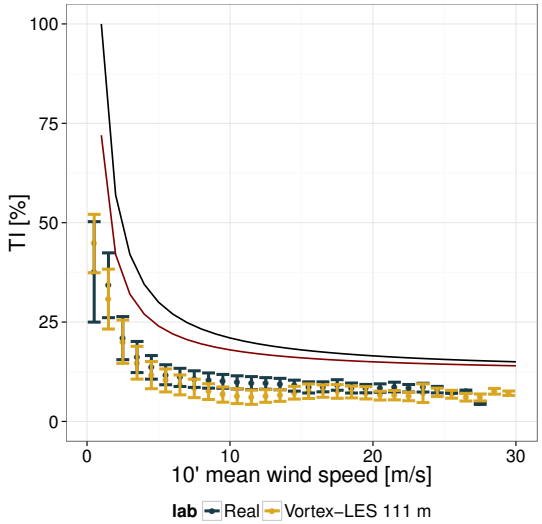
Site 7 — 30 m



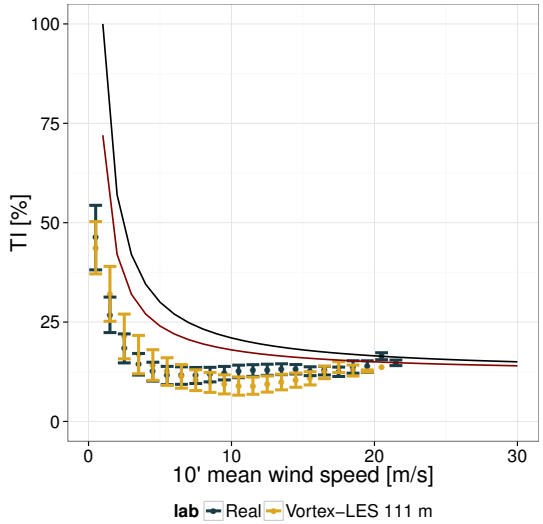
Site 8 — 60 m



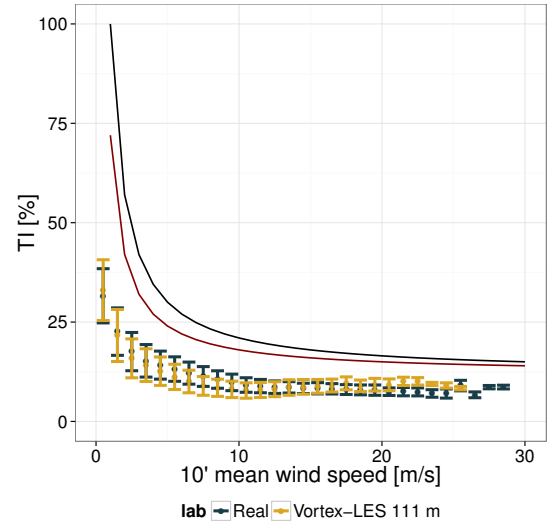
Site 3 — 70 m



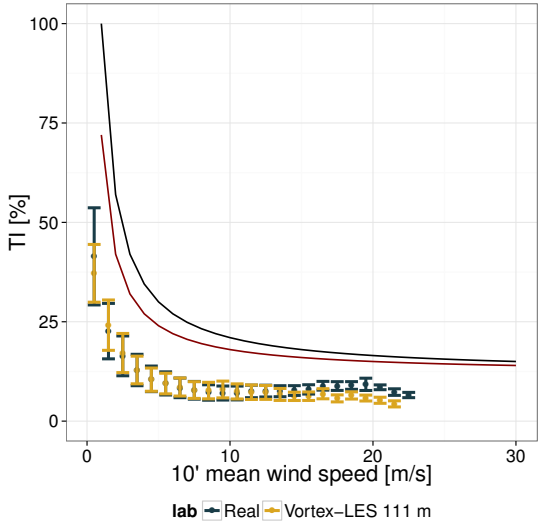
Site 4 — 60 m



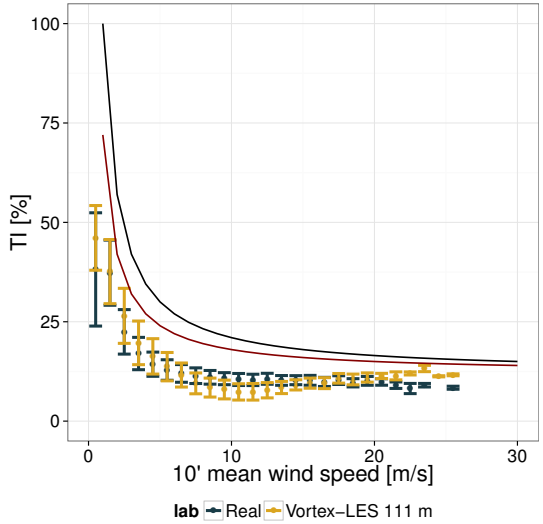
Site 5 — 90 m



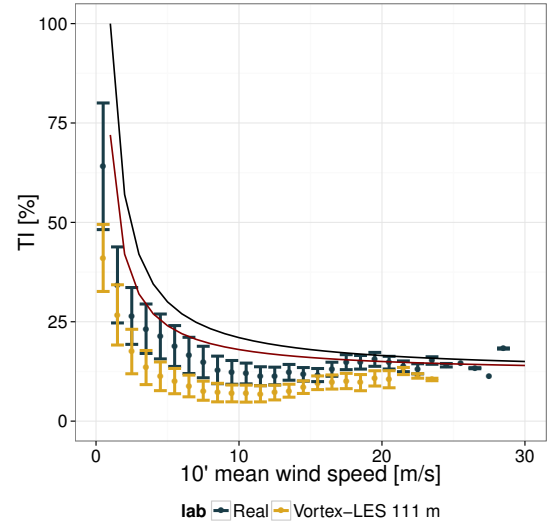
Site 6 — 97 m

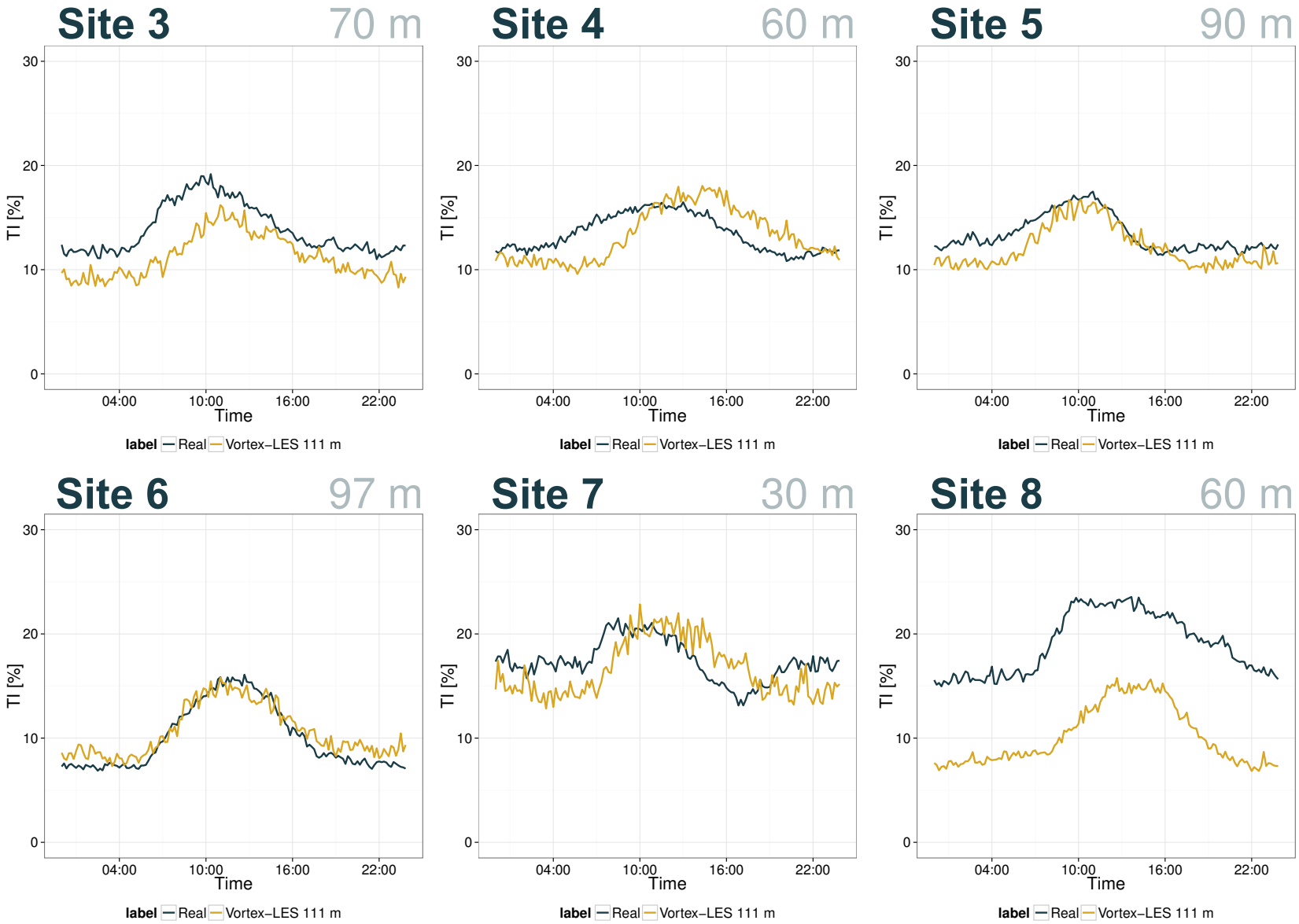


Site 7 — 30 m

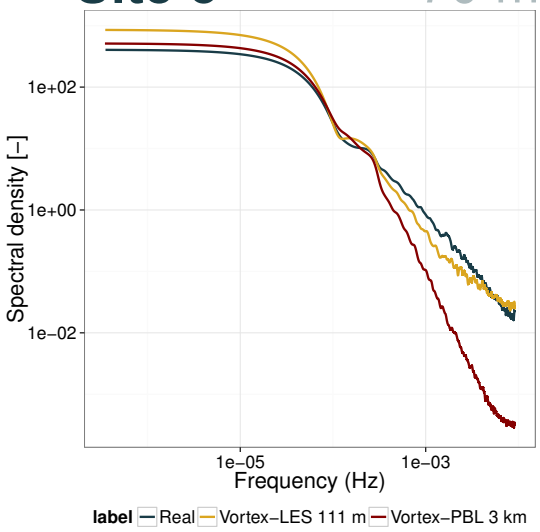


Site 8 — 60 m

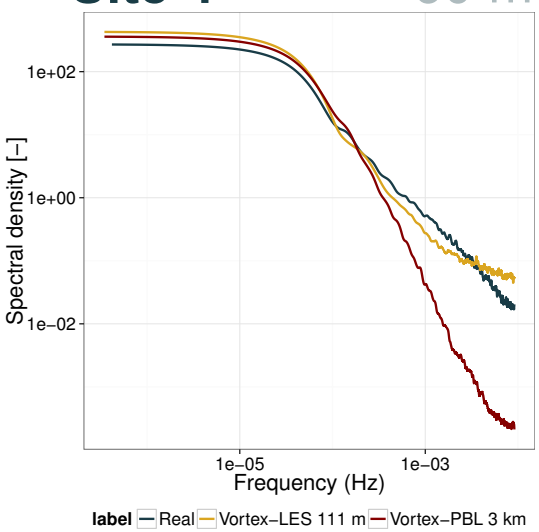



Site 3
70 m
Site 4
60 m
Site 5
90 m
Site 6
97 m
Site 7
30 m
Site 8
60 m
TI [%]
Time
04:00
10:00
16:00
22:00
0
10
20
30
label
Real
Vortex−LES 111 m

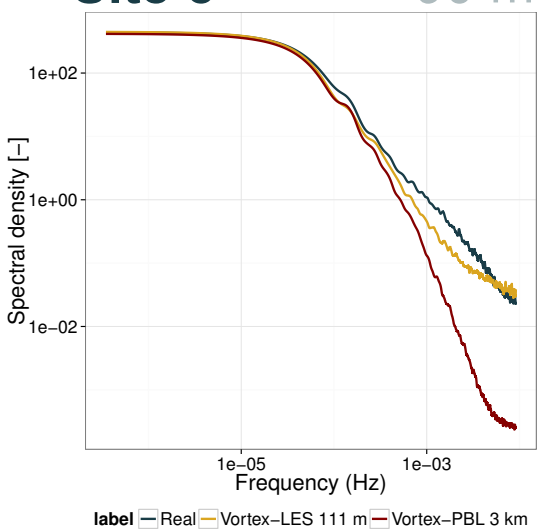
Site 3 — 70 m



Site 4 — 60 m



Site 5 — 90 m



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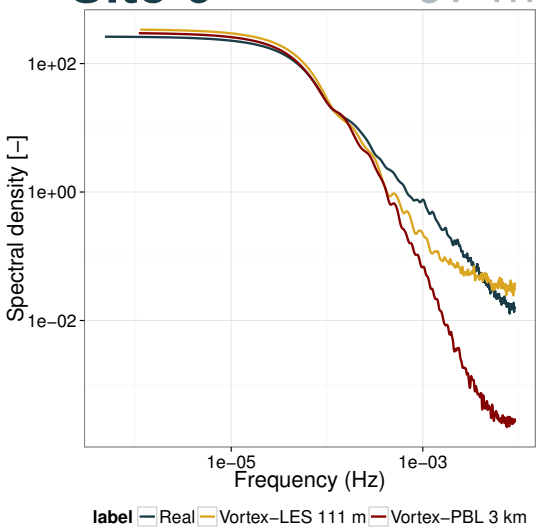
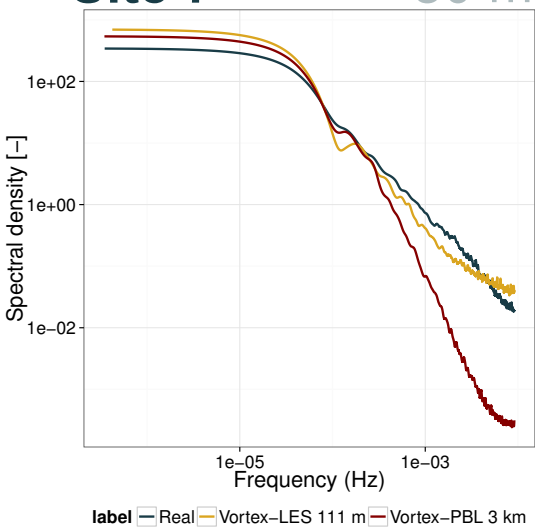
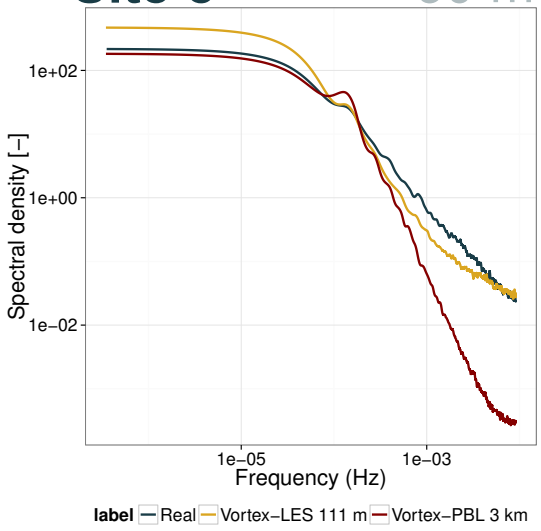


Site 7 — 30 m



Site 8 — 60 m

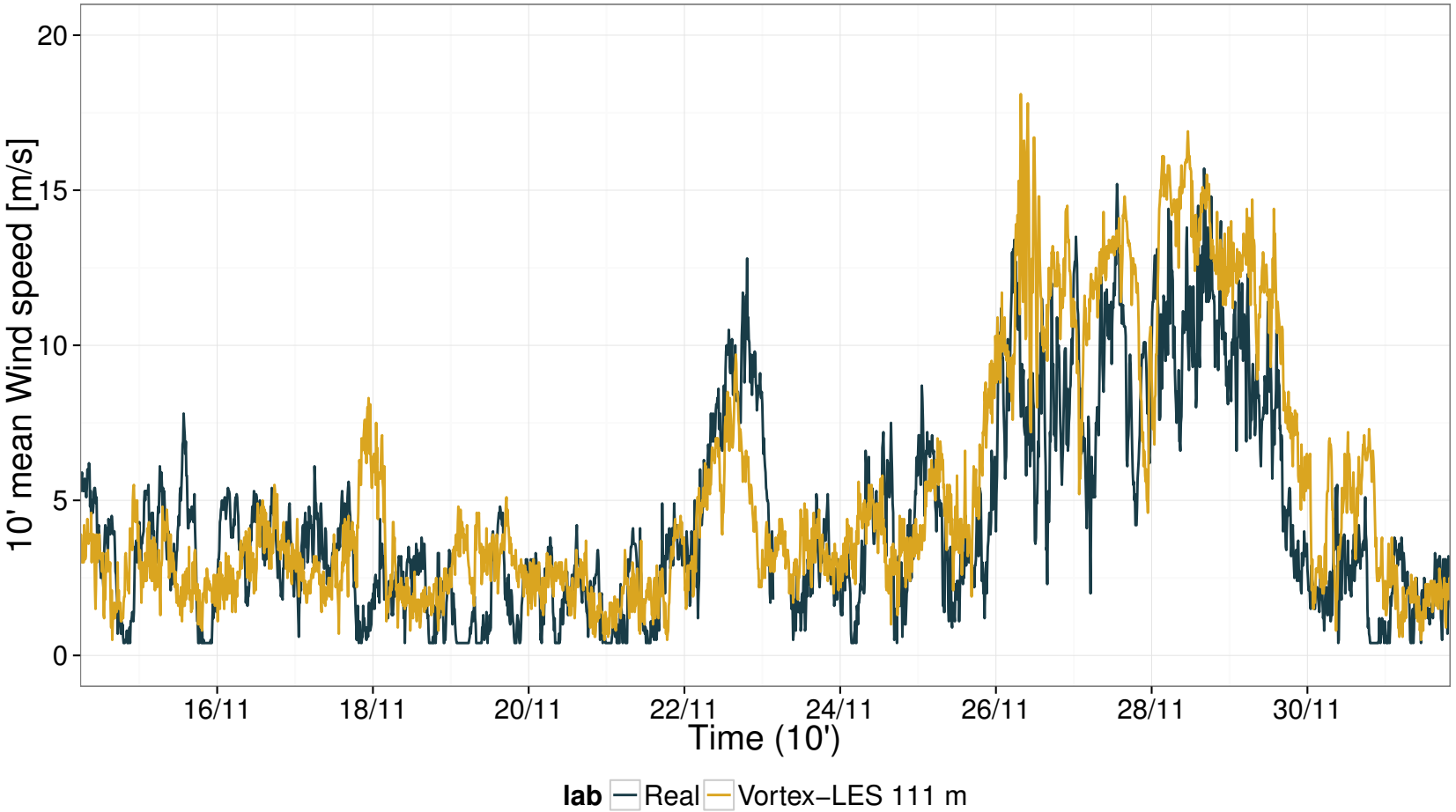


WRF-LES Challenges

- Energy cascade in the terra-incognita is underestimated.
- Peak of energy below 1-hour eddies. Stability vs Convective regimes?
- Surface processes must be improved.
- Unaccurate results when real turbines are installed.
- The tail in the TI-WS can be improved.

Conclusions

- **Vortex-LES** based on WRF produces accurate results with respect to the current mesoscale outputs.
- **WRF-LES** generates realistic turbulence.
- **WRF-PBL** underestimates the energy for motions with a characteristic time scale lower than 16 h (it is a mesoscale model!)
- **WRF-LES** improves the energy cascade for motions ranging from 10-min to 16 h.
- **WRF-LES** provides reliable and accurate turbulent time series for the wind energy industry.


20
15
10
5
0
10' mean Wind speed [m/s]
16/11
18/11
20/11
22/11
24/11
26/11
28/11
30/11
Time (10')
lab
Real
Vortex−LES 111 m

WRF-LES in the real world: Towards a seamless modeling chain for wind industry applications

A. Montornès[1] P. Casso[1] B. Kosovic[2] G. Lizcano[1]

[1]Vortex, [2]NCAR–RAL

VORTEX