LES* IS MORE!

*LARGE EDDY SIMULATIONS BY VORTEX

WindEnergy Hamburg 2016
OUTLINE

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BASIS  Alex Montornés. Modelling Specialist, Vortex

VALIDATION  Mark Žagar. Modelling Specialist, Vestas

Q & A
Time series, why?
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)…
Time series, why?

If full time series were available, you could…

…cross-relate variables (TI vs. shear)
Time series, why?

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

...analyse extreme events (ramps)
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
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 produces real (physical) 10’ averages
LES IS MORE!

LES produces 3” samples (TI, gust…)

Les Is More!
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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
WRF–LES coming to age

VORTEX
Vortex-LES: A new horizon in wind resource assessment applications
Vortex-LES: A new horizon in wind resource assessment applications

Characteristic time

Characteristic length
Vortex-LES: A new horizon in wind resource assessment applications
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**Characteristic time**
- 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

**Characteristic length**
- <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

- Fluid dynamics
- Meteorology
- Climate
- Climate variations
- ENSO
- Seasonal
- Planetary waves
- Synoptic scale
- Mesoscale
- Microscale
- Small eddies
- Molecular diffusion
Vortex-LES: A new horizon in wind resource assessment applications

The diagram illustrates the relationship between characteristic time and characteristic length, focusing on the wind industry interest scale. The time scale ranges from 1000 years to 1 second, with intervals of 100 years, 10 years, 1 year, 1 month, 1 week, 1 day, 1 hour, 10 minutes, and 1 minute. The length scale ranges from less than 1 millimeter to 100,000 kilometers, with intervals of less than 1 millimeter, 1 centimeter, 1 meter, 10 meters, 100 meters, 1 kilometer, 10 kilometers, 100 kilometers, 1000 kilometers, and 10,000 kilometers.

Key terms and concepts include:
- Fluid dynamics
- Meteorology
- Climate variations
- ENSO
- Seasonal
- Planetary waves
- Synoptic scale
- Mesoscale
- Microscale
- Small eddies
- Molecular diffusion

The diagram highlights the interdisciplinary nature of wind resource assessment, integrating aspects of fluid dynamics, meteorology, and climate science.
Vortex-LES: A new horizon in wind resource assessment applications
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Large eddies

Small eddies

RANS

LES

Resolved

Modeled

Dynamic

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Vortex

Vortex–LES in wind resource assessment applications
Vortex-LES: A new horizon in wind resource assessment applications

Large eddies

Small eddies

RANS

LES

DNS

Resolved

Dynamic

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Vortex-LES: A new horizon in wind resource assessment applications

Vortex-LES: A new horizon in wind resource assessment applications

Different tools for different applications
Vortex-LES: A new horizon in wind resource assessment 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

\[ \theta_{\text{new}} = \theta_{\text{old}} + \theta' \]

Muñoz-Esparza (2014)

Vortex in-house R+D

Mesoscale - PBL

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Vortex–LES in wind resource assessment applications
Vortex approach

Reanalysis

Vortex

WRF-LES

Mesoscale PBL

Vortex–LES in wind resource assessment applications
Vortex approach
Vortex approach

\[ \text{LES} = \text{Resolved eddies} + \text{Subgrid eddies} \]
Vortex approach

\[ \text{LES} = \text{Resolved eddies} + \text{Subgrid eddies} \]
Vortex approach

Vortex flow composer

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

LES = Resolved eddies + Subgrid eddies

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Vortex-LES in wind resource assessment applications
Vortex approach

Reanalysis

Vortex
WRF-LES

Mesoscale PBL
Microscale LES

Postprocessing

4 Hz output

10' averages
10' standard deviation
20-150 meters above ground

Wind speed, Wind direction,
Temperature, Pressure, Richardson
Number, PBL Fluxes, Wind Veer,
Inflow angle, ...

3'' gust
Vortex-LES validation exercise

- Wind metrics validated for **93 sites**
- Turbulence Intensity validated for **51 sites**
Vortex-LES validation exercise
Vortex-LES validation exercise

Mesoscale

Microscale

1-y
1-m
1-d
3-h

Terra Incognita

10-min

Spectral density [-]

Frequency (Hz)

1e-02
1e+02
1e+00
1e-02
1e-05
1e-03

label
Real
Vortex–LES 111 m
Vortex–PBL 3 km
Vortex-LES validation exercise

Wind metrics validated for 93 sites

Commonly used wind metrics in the industry:

- MAE
- Correlation
- Weibull parameters

<table>
<thead>
<tr>
<th>Metric</th>
<th>Average (%)</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE</td>
<td>8.3</td>
<td>4.3</td>
</tr>
<tr>
<td>A-shape (%)</td>
<td>8.2</td>
<td>5.0</td>
</tr>
<tr>
<td>k-shape (%)</td>
<td>9.3</td>
<td>6.1</td>
</tr>
<tr>
<td>$R^2$ 10-min</td>
<td>0.59</td>
<td>0.09</td>
</tr>
<tr>
<td>$R^2$ hourly</td>
<td>0.62</td>
<td>0.09</td>
</tr>
<tr>
<td>$R^2$ daily</td>
<td>0.80</td>
<td>0.09</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE</td>
<td>1.8</td>
<td>0.9</td>
</tr>
<tr>
<td>MAE-15</td>
<td>1.9</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Turbulence Intensity

MAE-15 = 0.5
MAE = 0.7
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.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>BIAS [m/s]</th>
<th>MAE [m/s]</th>
<th>STDE [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 km</td>
<td>-0.72</td>
<td>0.75</td>
<td>0.54</td>
</tr>
<tr>
<td>1 km</td>
<td>-0.44</td>
<td>0.53</td>
<td>0.36</td>
</tr>
<tr>
<td>1/3 km</td>
<td>+0.01</td>
<td>0.32</td>
<td>0.22</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Method</th>
<th>MAE</th>
<th>STDE</th>
<th>EtotP</th>
</tr>
</thead>
<tbody>
<tr>
<td>WRF raw</td>
<td>16.2%</td>
<td>18.2%</td>
<td>4.7%</td>
</tr>
<tr>
<td>WRF corr</td>
<td>8.0%</td>
<td>9.4%</td>
<td>2.7%</td>
</tr>
</tbody>
</table>
Purely downscaling of 1° 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

Actual

Assumed

136 m rotor @ 120 m

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!

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

2% wind speed error → 5% AEP error
How does WRF-LES by Vortex do?
<table>
<thead>
<tr>
<th></th>
<th>avg(V)</th>
<th>σ(V)</th>
<th>A</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs. data</td>
<td>8.1 m/s</td>
<td>4.3 m/s</td>
<td>9.1 m/s</td>
<td>2.0</td>
</tr>
<tr>
<td>Model</td>
<td>8.7 m/s</td>
<td>4.0 m/s</td>
<td>10.0 m/s</td>
<td>2.5</td>
</tr>
</tbody>
</table>

- **Scotland 1**

### Observed Data
- 8.1 m/s
- 4.3 m/s
- 9.1 m/s
- 2.0

### Model Data
- 8.7 m/s
- 4.0 m/s
- 10.0 m/s
- 2.5
Period of low wind speed causing "high" turbulence intensity
σ(WDir) vs. Wspeed
Indicates rapid direction changes
Available in Vortex WRF-LES output
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
Guess which are the measurements…

…and which are the model results

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