How to use CFD for long-term energy assessments

Bechmann, Andreas

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How to use CFD for long-term energy assessments

Andreas Bechmann
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1. Modelling of Wind Resources
2. Example: WAsP CFD
3. Example: Forestry modeling based on aerial LIDAR scans
How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
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Modelling of wind resources

RANS equations:

\[
\frac{\partial (\bar{u}_i \bar{u}_j)}{\partial x_j} = -\frac{1}{\rho} \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \left( (\nu_T) \left( \frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) \right) - C_d \lambda \bar{u}_i |U|
\]

Askervein Experiment 1983:
Modelling of wind resources

![Graph showing wind speed vs distance](image-url)

- **U [m/s]**
- **Distance [m]**

- Measurements

---

DTU Wind Energy, Technical University of Denmark

14 April 2014
Modelling of wind resources
Modelling of wind resources

![Graph showing wind resource measurements and modeled scenarios]

- **Measurements**
- **High**
- **Normal**
- **Low**

The graph illustrates the comparison between measured wind speeds and modeled scenarios, indicating areas of high, normal, and low wind resource potential.
Modelling of wind resources

Reynolds number: $\text{Re} = \frac{U_0 L_0}{\nu}$

$\Delta S = \frac{U}{U_0}$ (Speedup)

Jensen number = $\frac{L_0}{z_0}$

$\Delta L = \frac{L}{L_0}$
Modelling of wind resources
Modelling of wind resources
Modelling of wind resources

Askervein, Line A

- Measurements
- High
- Normal
- Low

Distance [m]

$U/U_0$ [-]
Modelling of wind resources

Askervein, Line A

Distance/Height [-]

Speedup [-]

Measurements
High
Normal
Low
Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy

2. A model cannot predict wind resources; it extrapolates measurements
Extrapolate wind resources
Extrapolate wind resources
Extrapolate wind resources
Extrapolate wind resources
Extrapolate wind resources

\[ \Delta S_1 = \frac{U_1}{U_0} \]

\[ \Delta S_2 = \frac{U_2}{U_0} \]
Extrapolate wind resources

\[ \Delta S_1 = \frac{U_1}{U_0} \]

\[ \Delta S_2 = \frac{U_2}{U_0} \]

\[ \frac{U_2}{U_1} = \frac{\Delta S_2}{\Delta S_1} \]
Extrapolate wind resources

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Extrapolate wind resources

Problem:
1. Large scale effects omitted (Coriolis, Bouyancy)
2. Large computational resources

Solutions:
1. Do nothing
2. Micro-Meso scale coupling
3. Micro model -> meso scales
4. Meso model -> micro scales

\[
\frac{U_2}{U_1} = \frac{\Delta S_2}{\Delta S_1}
\]
Extrapolate wind resources

Problem:
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1. Do nothing
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4. Meso model -> micro scales
Extrapolate wind resources

**Problem:**
1. Large scale effects omitted (Coriolis, Bouyancy)
2. Large computational resources

**Solutions:**
1. Do nothing
2. **Micro-Meso scale coupling**
3. Micro model -> meso scales
4. Meso model -> micro scales
Extrapolate wind resources

\[ \Delta S_1 = \frac{U_1}{U_{01}} \]

\[ \Delta S_2 = \frac{U_2}{U_{02}} \]

\[ \frac{U_2}{U_1} = \frac{\Delta S_2}{\Delta S_1} \times \frac{U_{02}}{U_{01}} \]

Micro  Meso
Modelling of wind resources

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Modelling of wind resources

1. The flow is Re-independent when omitting Coriolis and Buoyancy

2. A model cannot predict wind resources; it extrapolates measurements

3. A method to couple micro- and meso-scales is needed
Micro - Meso coupling
Micro - Meso coupling

Micro scale inflow:

\[
\frac{\langle M \rangle}{u_{*0}} = \frac{1}{\kappa} \ln \left( \frac{z}{z_0} \right) = C_D^{-1/2}
\]

Meso scale, Geo. drag Law:

\[
\frac{G}{u_{*0}} \cos \theta = \frac{1}{\kappa} \left[ \ln \left( \frac{u_{*0}}{f_d z_0} \right) - A \right] = C_D^{-1/2}
\]

1. The inflow is defined by a surface \( z_{01} \)
2. \( z_{01} \) represents a “large-scale” terrain roughness

- The inflow should balance the “large-scale” \( z_{01} \).
- The CFD model simulates the micro-scale variances from the meso-scale mean.
Micro - Meso coupling

Large-scale roughness length:  
Rossby radius: $G/f \geq 10\text{km}$

Inflow boundary condition:  
For homogeneous farfield terrain

$$\frac{\langle M \rangle}{u_{\ast 0}} = \frac{1}{\kappa} \ln \left( \frac{z}{z_0} \right)$$

$$k = \frac{u_{\ast 0}^2}{\sqrt{C_\mu}}$$

- The inflow should balance the “large-scale” $z_0$.
- The CFD model simulates the micro-scale varians from the meso-scale mean.
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4. Farfield conditions should balance the meso-scale mean
How to use CFD for long-term energy assessments

1. Modelling of Wind Resources
2. **Example: WAsP CFD**
3. Example: Forestry modeling based on aerial LIDAR scans
Example: Prepare Terrain
Example: Prepare Terrain
Example: Prepare Terrain
Example: Prepare Terrain
Example: Prepare Terrain
Example: Prepare Terrain
Example: Prepare Terrain
Example: Mesh
Example: Mesh

One domain for all comp.  A dedicated mesh for each direction

N.N. Sørensen
Example: Mesh

- Simple projection of a surface grid onto terrain, leads to coarse cells at steep slopes. Not suited for grid convergence studies.
Example: Mesh

34 km
Example: Mesh

34km
Example: Mesh

15km
Example: Mesh

6km
Example: Mesh

3km
Example: Mesh

1km
Example: Mesh

1km
Example: Mesh

1km
Example: Mesh

$1km$
Example: Mesh

6km
Example: Mesh

15km
Example: Mesh

34km
Example: Mesh

34km
Example: Mesh

34km
Example: Mesh

1km
Example: Mesh

34km

A. Bechmann
Example: Mesh

1km
Example: CFD
Example: CFD
Example: CFD
Example: CFD
Example: CFD

- Third order QUICK scheme
- RANS k-ε turbulence model
- Residuals < 5E-5
Example: CFD
Example: CFD
Example: CFD
Example: CFD
How to use CFD for long-term energy assessments

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Example: Forest
**Example: Forest**

### Roughness length model

\[
\bar{u} = \frac{u_*}{k} \ln \left( \frac{z - d}{z_0} \right)
\]

- \(z_0\): roughness length
- \(d\): displacement height

### Porous drag model

\[
\frac{\partial u_i}{\partial t} = \ldots - C_d LAD(z) u_i |U|
\]

- \(LAD\): leaf area density
- \(C_d\): drag coefficient
Example: Forest
Example: Forest

The Beer-Lambert law

\[ \frac{I}{I_0} = \exp(-\gamma L) \]

Light attenuation in plant canopies:
[Monsi and Saeki, 2005]

\[ LAI = -\frac{1}{\gamma} \ln \left( \frac{I}{I_0} \right) \]

\[ L = n_p \]

\[ l_0 = n_l + n_p \]

\[ \left\{ \begin{array}{c} \Delta z \end{array} \right\} \]

\[ LAI = \int_0^z LAD \, dz \Rightarrow LAD = \frac{dLAI}{dz} \]
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest
Example: Forest

Figur 22 Turbulensintensitet som funktion af vindretning ved målestation Syd for 45m måleøjde (blå) og 100m måleøjde (brun).
Example: Forest

Turbulence Intensity at South cmu=0.05

Figur 22 Turbulensintensitet som funktion af vindretning ved målestation Syd for 45m måleøjde (blå) og 100m måleøjde (brun).
Example: Forest
Example: Forest

Turbulence Intensity at west cmu=0.05

Figure 20 Turbulence intensity as a function of wind direction at measurement station West for 45m measurement height (blue) and 100m measurement height (brown).
Example: Forest
Example: Forest

Turbulence Intensity at north cmu=0.05

Figur 21 Turbulensintensitet som funktion af vindretning ved målestation Nord for 45m måleøjse (blå) og 100m måleøjse (brun).
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