Atmospheric turbulence characteristics over complex terrain

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Atmospheric flow over complex terrain

Understanding the flow over complex terrain:
- Wind turbine load estimation.
- Wind resource assessment.
- Wind farm control.
Turbulence flow over hills

- The maximum wind speed-up ratio, \( \Delta S = (\Delta u/u_0)_{\text{max}} \)
- The height of the maximum wind speed-up, \( h_{\text{max}} \)
Turbulence flow over an isolated hill

- The perturbation of the ABL turbulent flow (1):
  - Outer layer: inertia and pressure gradient are dominated (i.e. inviscid), $Z > l$.
  - Inner layer: inertia and turbulence are dominated, $Z < l$.

\[
\frac{L}{l} \ln \left( \frac{l}{Z_0} \right) = 2k^2. \tag{1}
\]
\[
\frac{L}{l} \ln^2 \left( \frac{l}{Z_0} \right) = 2k^2. \tag{2}
\]
\[
\frac{L}{l} \ln \left( \frac{l}{Z_0} \right) = \text{cons.} \tag{3}
\]

- $h_{\text{max}} \approx l$

(3): Claussen, 1988, Boundary Layer Meteorology.
Turbulence flow over an isolated hill

- The maximum wind speed-up ratio for a low terrain (4)

\[ \Delta S_{\text{max}} = 2(h/l) \quad \text{for 2D ridges} \]
\[ \Delta S_{\text{max}} = 0.8(h/l) \quad \text{for 2D escarpments} \]
\[ \Delta S_{\text{max}} = 1.6(h/l) \quad \text{for 3D axisymmetric hills} \]

Flow over multiple hills

- The effects of the downstream hill?
- The effects of distance between hills?

2H7L
2H4L
1H
Case setup

- **Hills**
  - 3D axisymmetric, 20% of the ABL height $Z_i = 400m$.
  - $h = 80m$, $l = 125m$, $h/l = 0.64$.
  - 0.1m roughness height.

- **Geometry**
  - (2400m, 1200m, 800m), (6$Z_i$, 3$Z_i$, 2$Z_i$).
  - (240, 120, 110) cells, 80 grid points for $Z_i = 400m$.
  - About 4 point inside $l$.
  - 400m stable inversion layer ($\Delta T/\Delta Z = 0.01k/m$).
Case setup

Method

- Large Eddy Simulations
- One-equation SGS model.
- Wall model based on local MOST for the surface.
- Periodic boundary conditions for the sides.
- Logarithmic velocity inlet.
- Slip boundary conditions for the upper surface.
- OpenFOAM 2.1.3, Buoyant solver, Boussinesq approximation.
Mean stream-wise velocity

- A vertical plane in the middle of the domain 1H
Mean stream-wise velocity

- A vertical plane in the middle of the domain 2H4L
Mean stream-wise velocity

- A vertical plane in the middle of the domain

2H7L
Mean stream-wise velocity

- Above the surface
Mean stream-wise velocity

- 10m above the surface
The maximum speed-up ratio

<table>
<thead>
<tr>
<th>Hills</th>
<th>1H</th>
<th>2H4L</th>
<th>2H7L</th>
<th>Theo.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>1.10</td>
<td>0.67</td>
<td>1.09</td>
<td>1.024</td>
</tr>
<tr>
<td>2nd</td>
<td>-</td>
<td>0.52</td>
<td>1.22</td>
<td>-</td>
</tr>
</tbody>
</table>
The atmospheric turbulence

- Above the surface
  - $< uu >$

- $< uw >$
The atmospheric turbulence

- Above the surface
Summary and future work

- **Summary**
  - The speed-up ratio of the isolated hill is almost the same as the theoretical one.
  - The speed-up ratios of the multiple hills are almost the same as the speed-up of the isolated hill in the 7l case and much lower in the case of 4l.
  - Even though the flow accelerates in the same rate above the hills in the 7L case as the isolated hill, the flow characteristics and the atmospheric turbulence are different.

- **Future work**
  - Considering separated flow hills, i.e. hills with higher slopes.
  - Considering hills with different heights relative to each other.
  - Considering ABL of different heights and stratifications.