E 3.2 Wind turbine model

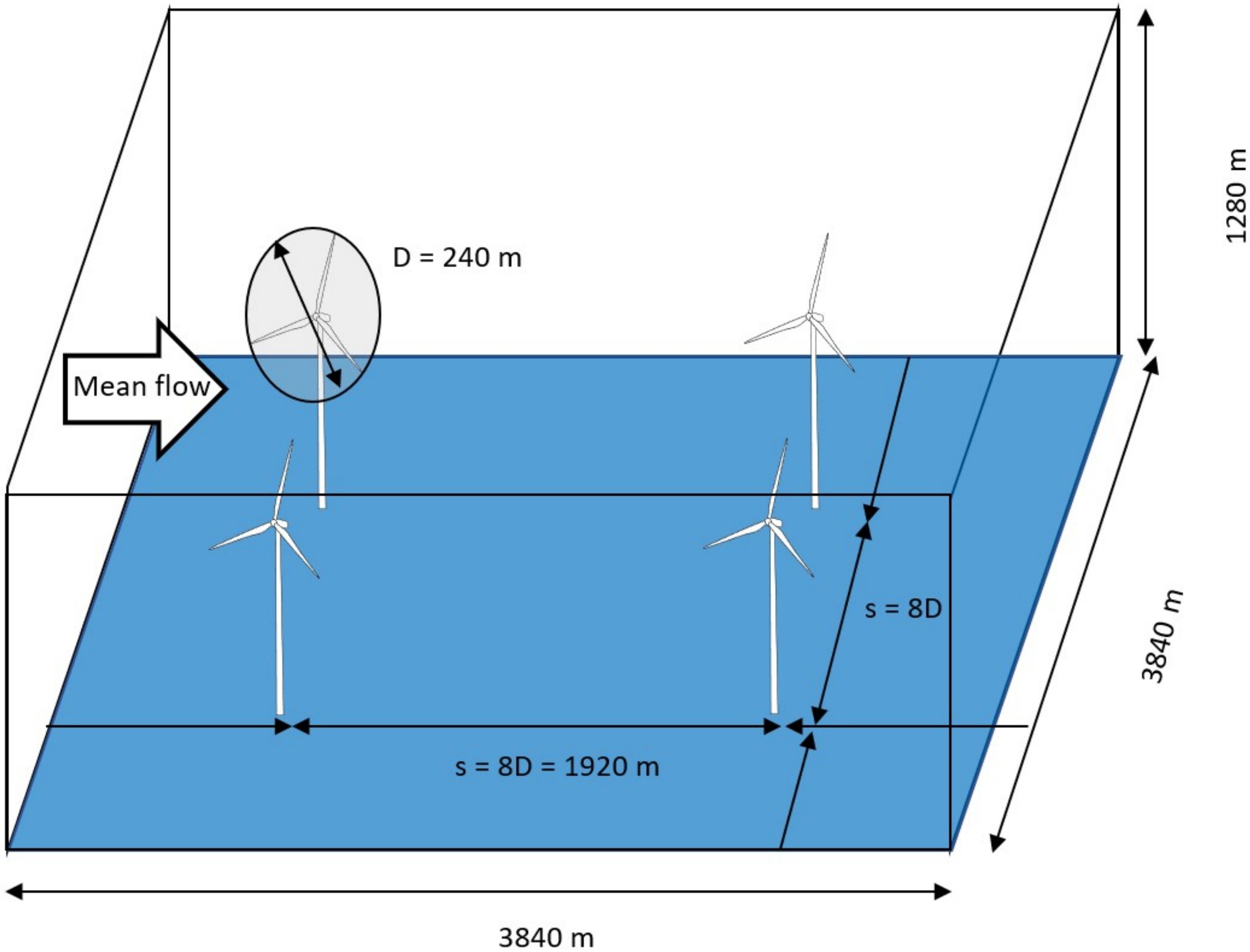
E3.2: Wind turbine model

Introduction

- In this exercise you will simulate a 1-4 wind turbines in a conventionally neutral boundary layer.
- The wind farm consists of max. 4 wind turbines.
- The IEA 15 MW Reference wind turbine is used, it has:
  - a rotor diameter of D = 240 m,
  - a hub height of h = 150 m and
  - a rated power of 15 MW
- Cyclic boundary conditions are applied in x- and y-direction, so that the wind farm is effectively infinitely large.

E3.2: Wind turbine model

Setup with 4 turbines



E3.2: Wind turbine model

Setup

- Physics
  - Flow is initialized with vertically constant velocity profiles, corresponding to the geostrophic wind: u(z) = ug_surface, v(z) = vg_surface
  - initial potential temperature profile is constant up to z = 500 m and has a lapse rate of +0.35 K/(100 m) above
  - Flow is driven by a geostrophic wind of ug, vg = 12.0, -3.8 m/s
    - This results in a wind direction at hub height that is approximately aligned with the x-axis after 2 h.
  - No surface heating or cooling → neutral boundary layer
- Numerics
  - grid spacing is 40 m → 6 grid points per rotor diameter
  - cyclic boundary conditions along x and y → infinite wind farm
  - Data output of instantaneous and averaged data every 30 minutes
- Wind turbines:
  - 4 equally spaced wind turbines, spacing 8 rotor diameters = 1920 m
  - hub height = 150.0 m, Rotor diameter = 240 m
  - active pitch and yaw control

How to start the simulation

- The wind turbine model requires NetCDF version 4. Do the following steps in your installation directory:
  - create a copy of the .palm.config.default file and rename it to: .palm.config.default_netcdf4
  - In this file add „ -D__netcdf4“ to the „%cpp_options …“
  - recompile palm using the new config: palmbuild –c default_netcdf4

- Provide the input files
  - create a new directory “wtm_exercise/INPUT” in your “JOBS” directory
  - copy the input files *wtm_exercise_p3d* and *wtm_exercise_wtm* to the INPUT directory

- Start the simulation using the new configuration file (adapt if you have more cores available!):
  - palmrun -r wtm_exercise -c default_netcdf4 –a “d3#” –X 4 –T 4

Part 1: wind park simulation

1. Is the mean flow in a steady state at the end of the simulation (t = 2 h)?
   - use: plot_time_series.py, plot_profiles.py
2. Describe the mean velocity field at hub height, especially near the turbines. Explain how it is related to the pressure field.
   - use: plot_xy_av.py
3. Are the wakes rotating? In which direction and why?
   - use: plot_xy_av.py, plot_xz_av.py

Part 2: single wind turbine & wake interaction

4. Reduce the set-up to a single turbine located at the center of the domain. Vary the geostropic wind speed in and try to reproduce the power curve of the turbine!

   Hints:

   - you can set vg_surface = 0.0 for a single turbine set-up

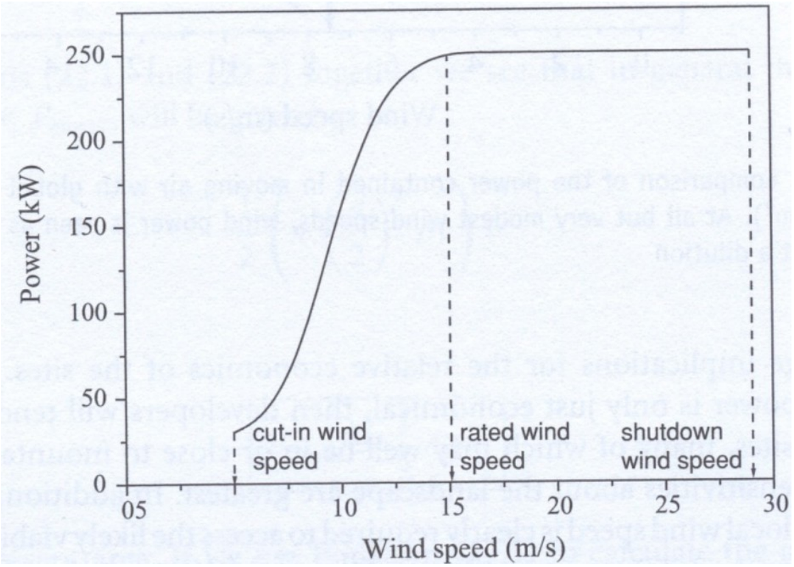
   - you might use MS Excel/LO Spreadsheet for that purpose

5. Place a 2nd turbine in the wake of the first one using different spacings:

   2 D, 5 D, 8 D

   How do the turbines interact regarding wind speed recovery?

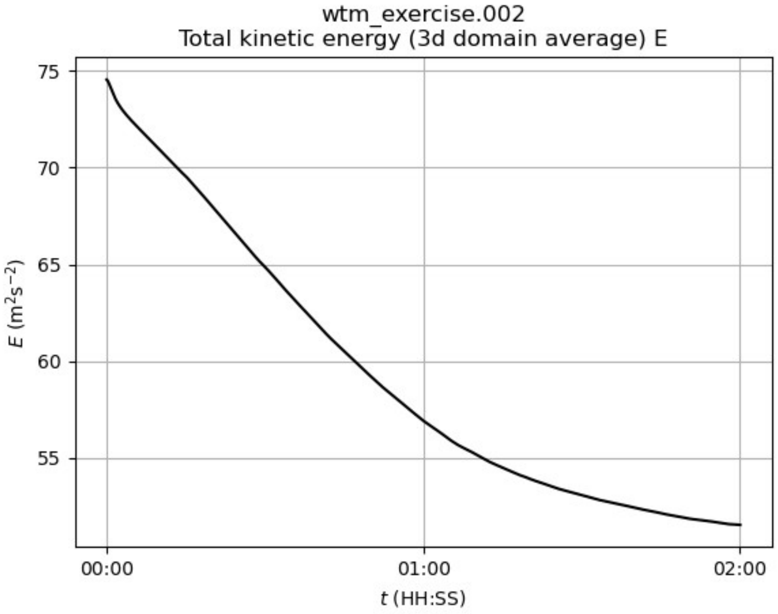
   What distance between turbines do you recommend based on these lightweight simulations?

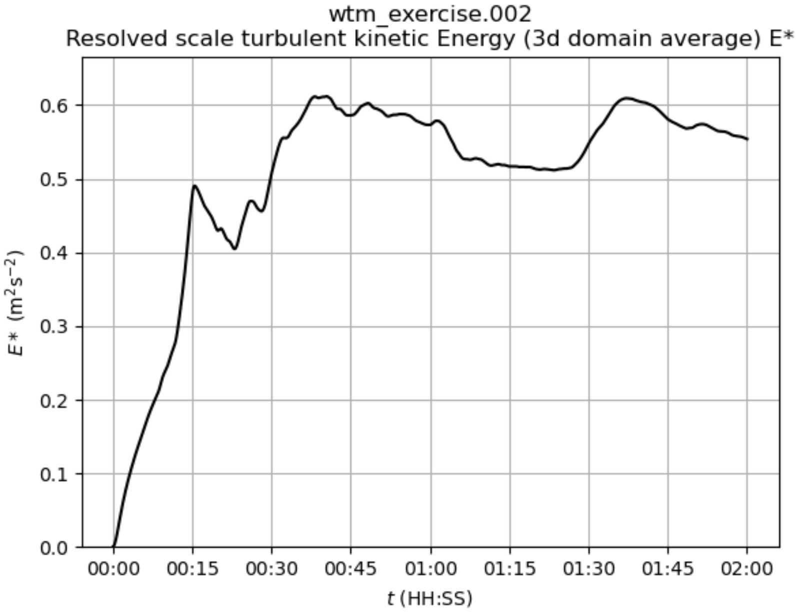


Example of a power curve

1. Is the mean flow in a steady state at the end of the simulation (t = 2 h)?

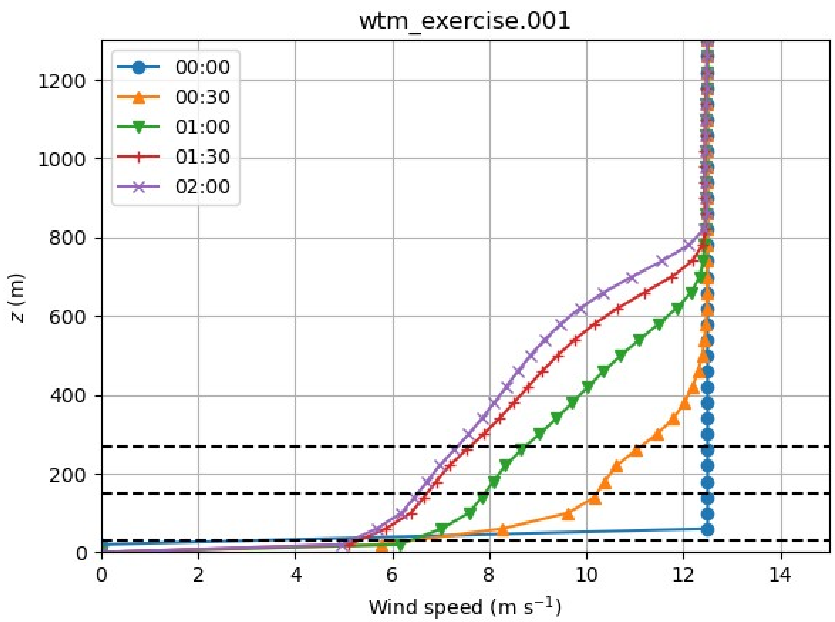
- No. It seems that the total kinetic energy E has reached a steady state, but it is only a minimum of the inertial oscillation.
- The inertial oscillation has a period of ~15 h at a latitude of +-55°

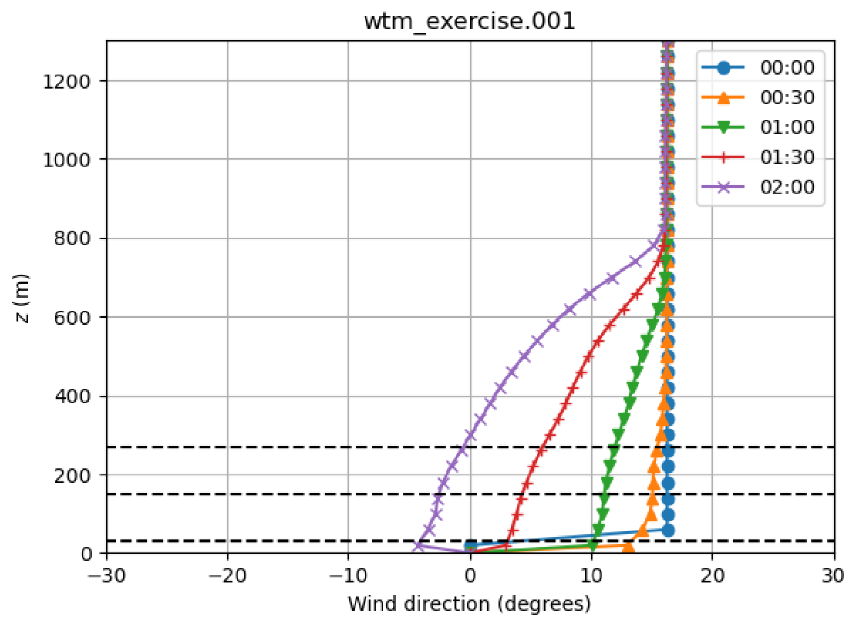




Answers

- The u-component is nearly steady at t = 2 h, but the v-component changes.
- A longer run will take too much time for a seminar exercise.
- If averaging is done over a relatively short period of time (here 30 minutes), the flow can be assumed to be quasi-stationary. But averaged results have to interpreted with care.

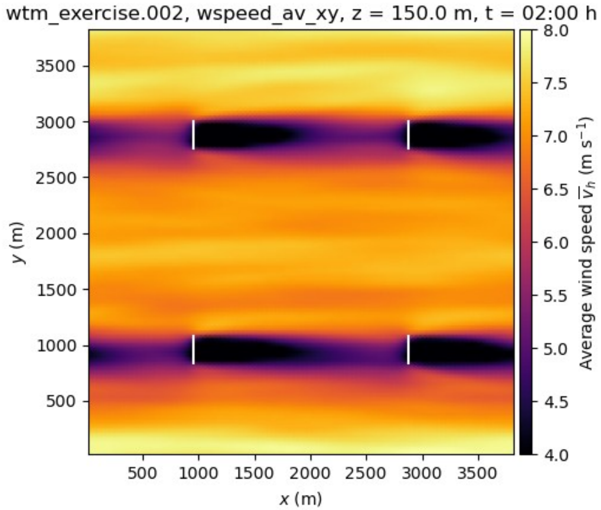


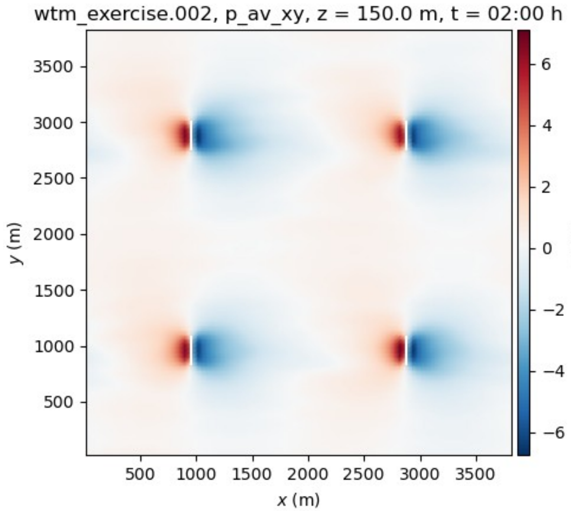


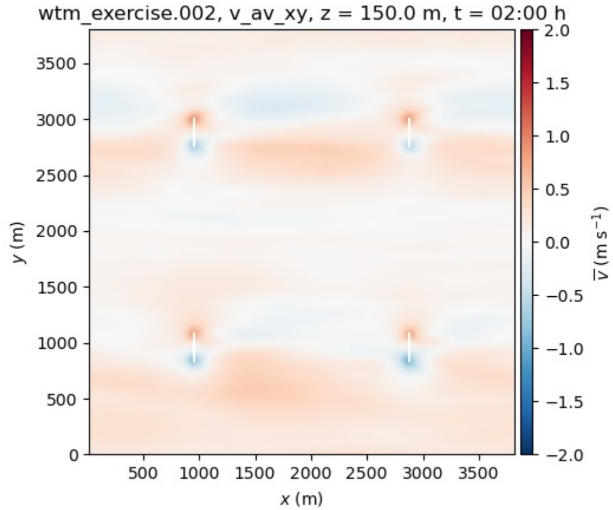
Answers

2. Describe the mean velocity field at hub height, especially near the turbines. Explain how it is related to the pressure field.

- Decreased wind speed behind the wind turbines (= wake)
  - deceleration caused by positive pressure gradient upstream and downstream of the rotor disc
- Higher wind speed between the turbine rows
- Lateral deflection of the flow (+-v), (flow divergence) at the rotor edges.



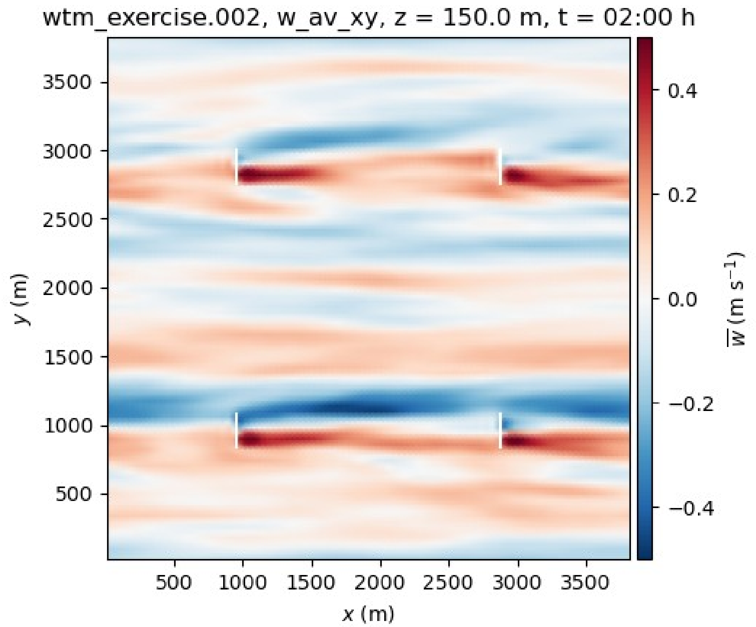


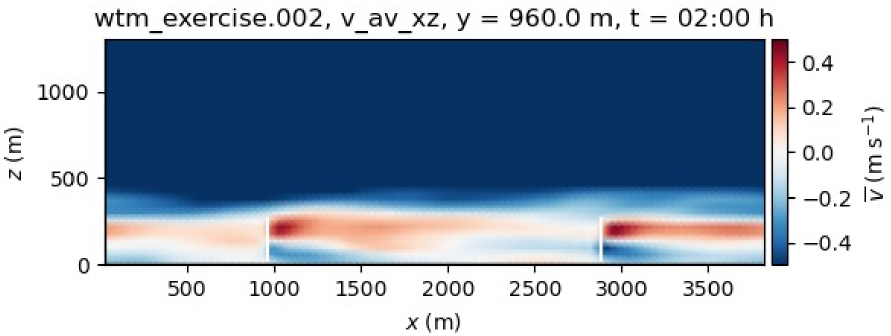


Answers

3. Are the wakes rotating? In which direction and why?

- Yes, they rotate counterclockwise around the positive x-axis.
- Why? The rotor rotates clockwise. The opposite sense of direction is the result of conservation of angular momentum: The flow applies clockwise torque on the rotor and the rotor applies counterclockwise torque on the flow.

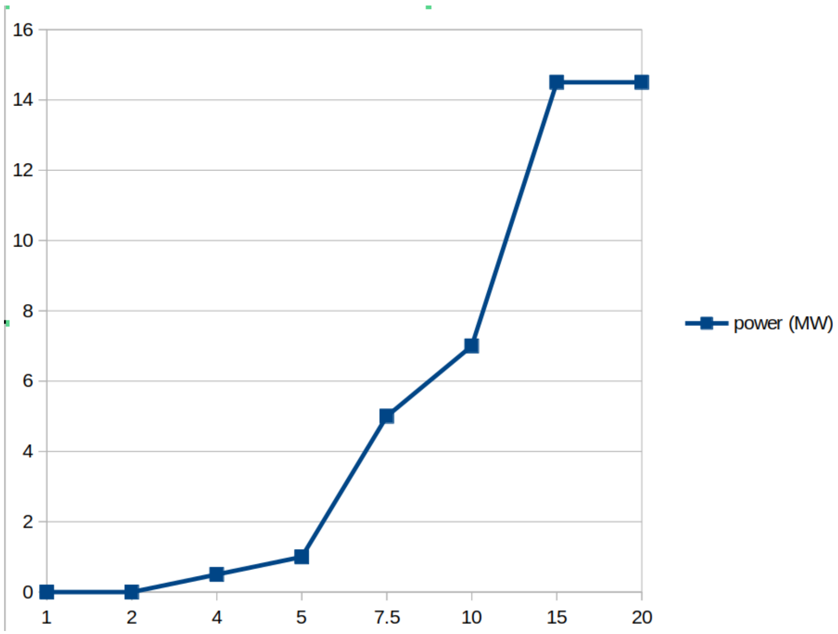




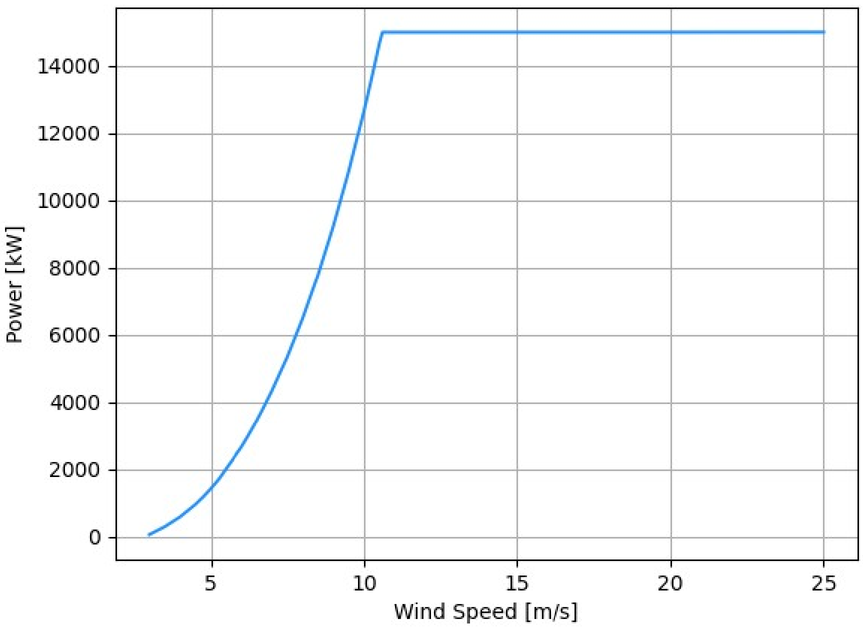
Answers

4. Reproduce the power curve of the turbine

Power curve from PALM



IEA 15 MW power curve



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Answers

4. Reproduce the power curve of the turbine

IEA_15MW_240_RWT

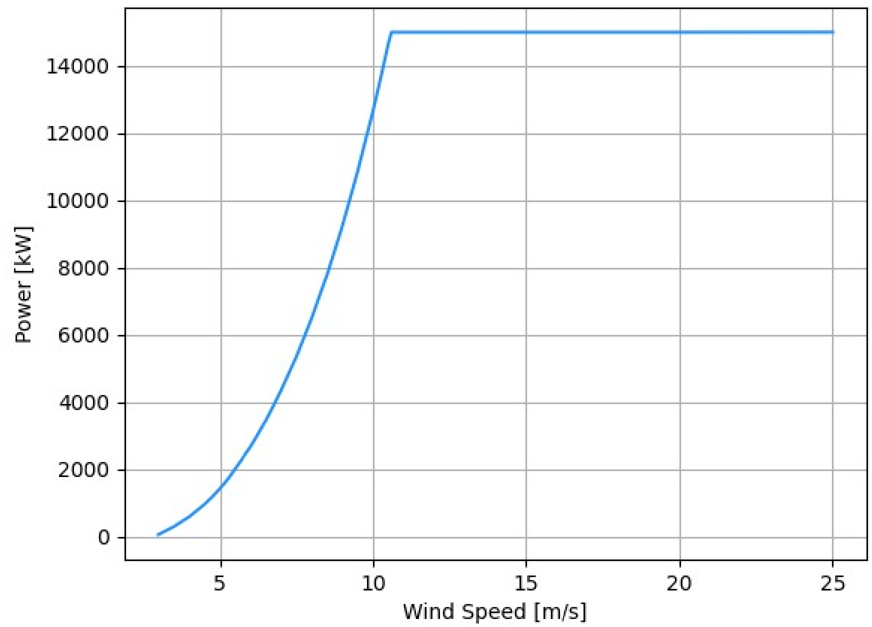
Link to Tabular Data

A .csv file is available on GitHub.

Key Parameters

Item	Value	Units
Name	IEA 15 MW RWT	N/A
Rated Power	15000	kW
Rated Wind Speed	10.6	m/s
Cut-in Wind Speed	3	m/s
Cut-out Wind Speed	25	m/s
Rotor Diameter	240	m
Hub Height	150	m
Drivetrain	Direct Drive	N/A
Control	Pitch Regulation	N/A
IEC Class	1B	N/A

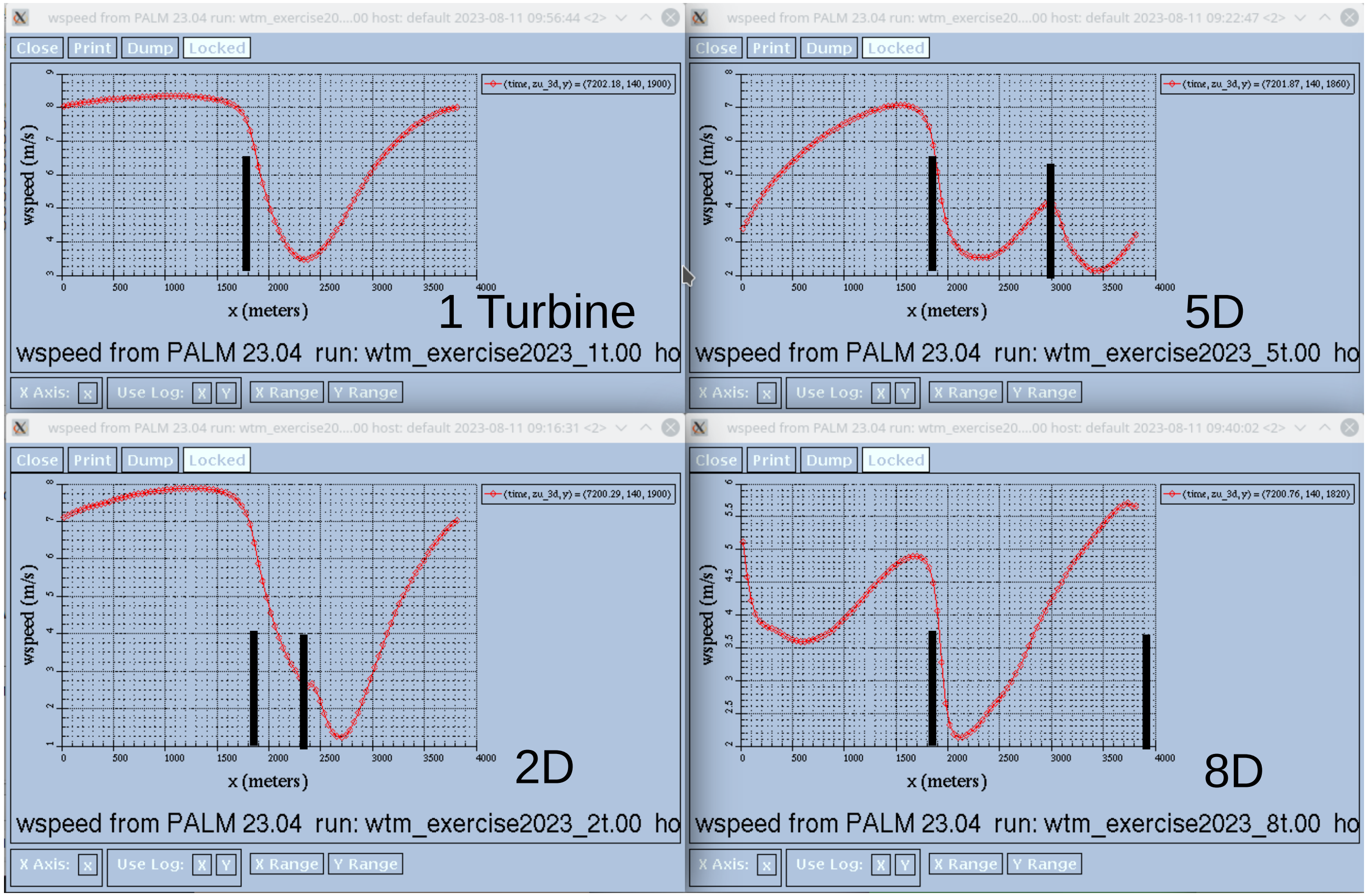
IEA 15 MW power curve



Answers

5. How do the turbines interact regarding wind speed recovery?

Flow recovery



Answers

5. How do the turbines interact regarding wind speed recovery?

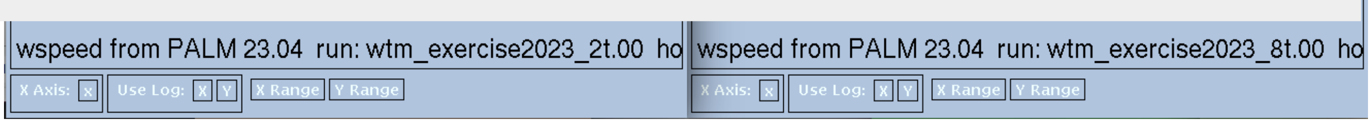
Flow rec

Results

2D
- the flow is not recovered when it approaches the 2nd turbine

5D
- the flow is partially recovered when it approaches the 2nd turbine
- The wake of the 2nd turbine affects the first turbine as well

8D
- The flow is mostly recovered after the turbines (some differences persist, though due to unsteady flow)



Answers

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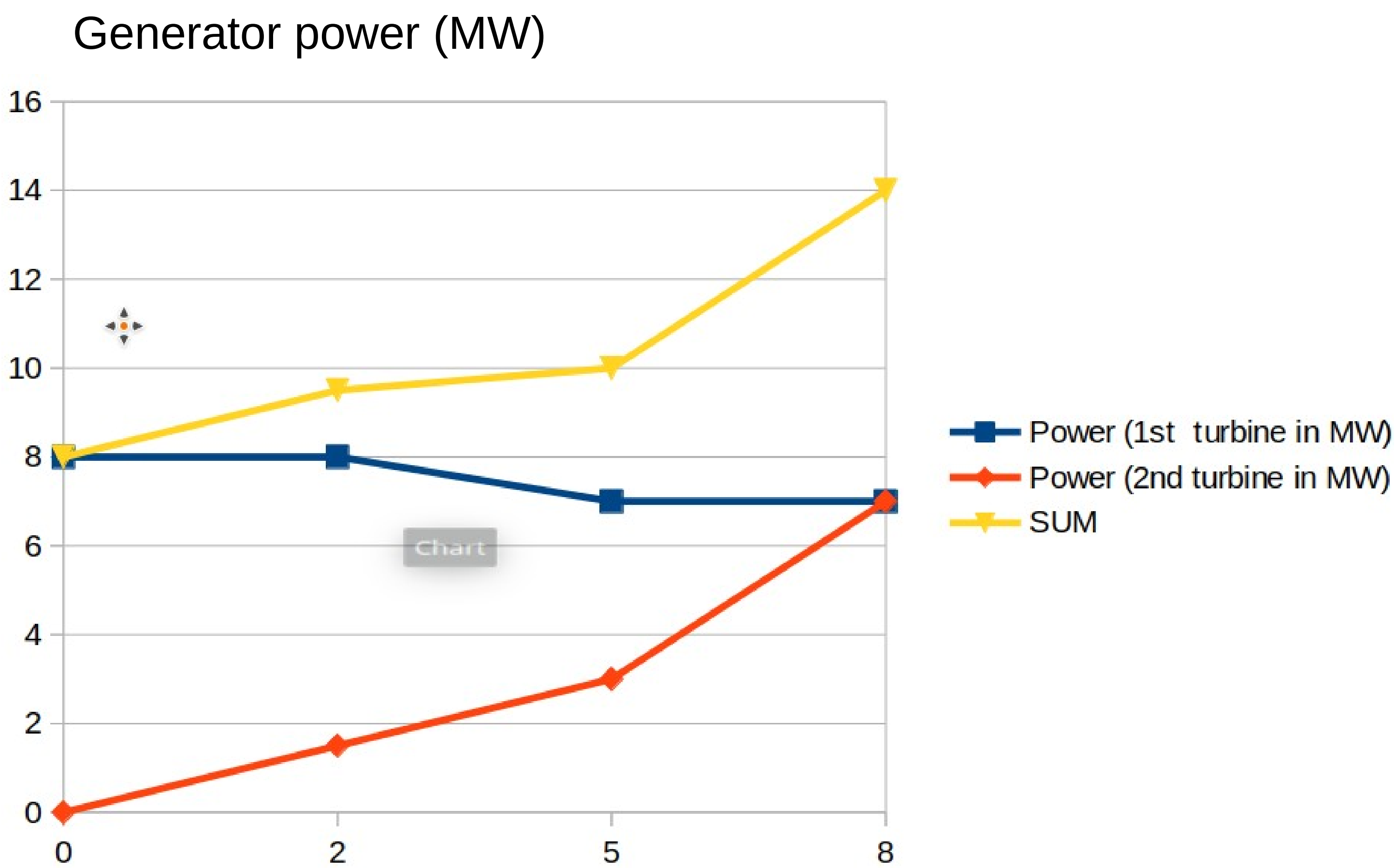

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Answers

5. What distance between turbines do you recommend based on these lightweight simulations?

Results:

- Power yield of turbine 1 suffers from wake effects of turbine 2
- For 8D, power yield is about 14 MW (compared to 8 MW for a single turbine)

→ A distance of ~ 8D is recommended!