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Computational methods for windfarm aerodynamics

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vrijdag 27 mei 2011 (w)

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The physics...

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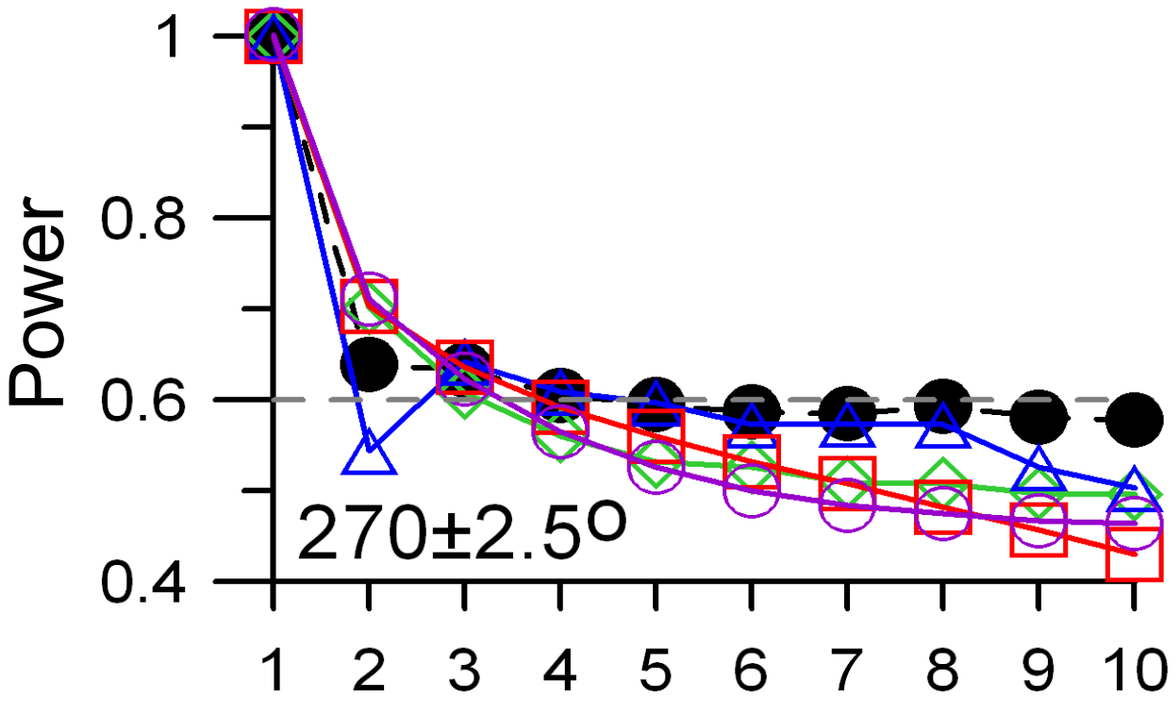
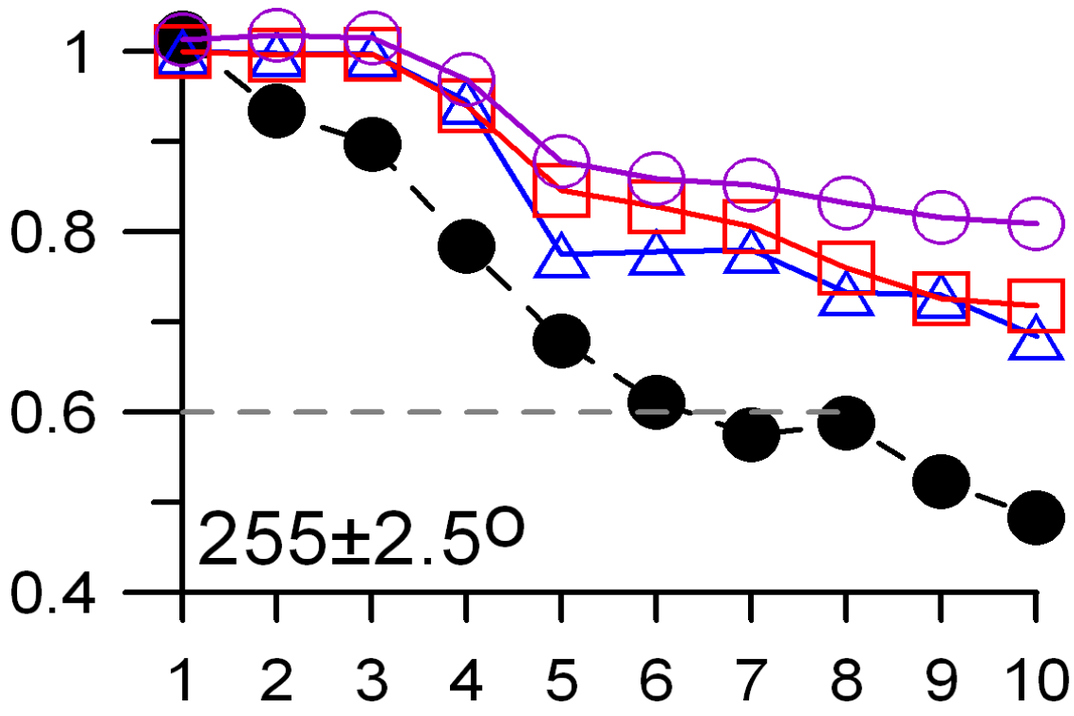
Effects of wakes

- Reduced power production of downstream turbines
- Increased loads on downstream turbines





R.J. Barthelmie et al. Modelling the impact of wakes on power output at Nysted and Horns Rev. In *European Wind Energy Conference and Exhibition*, Marseille, 2009.

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Modeling

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Modeling

turbine model

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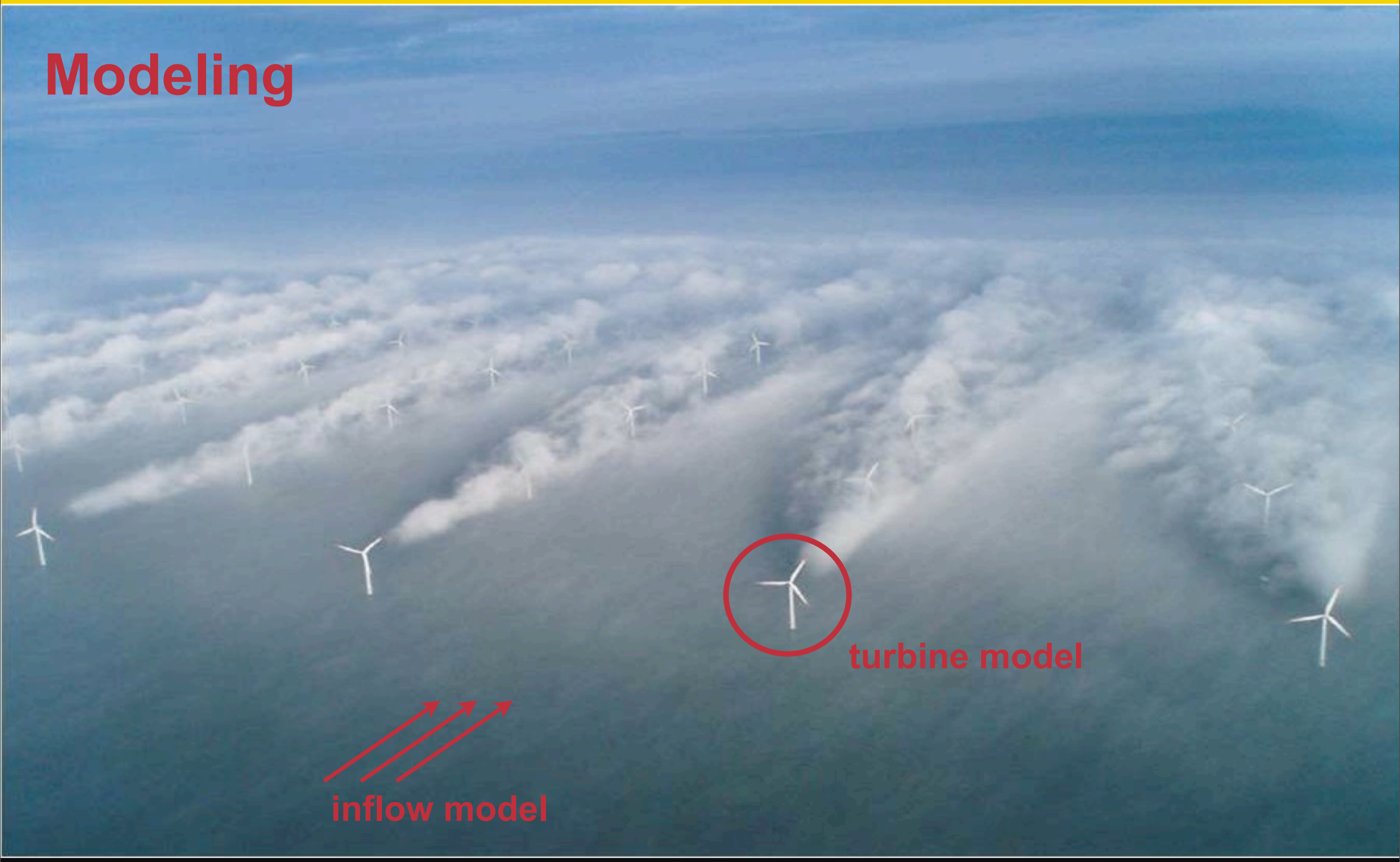

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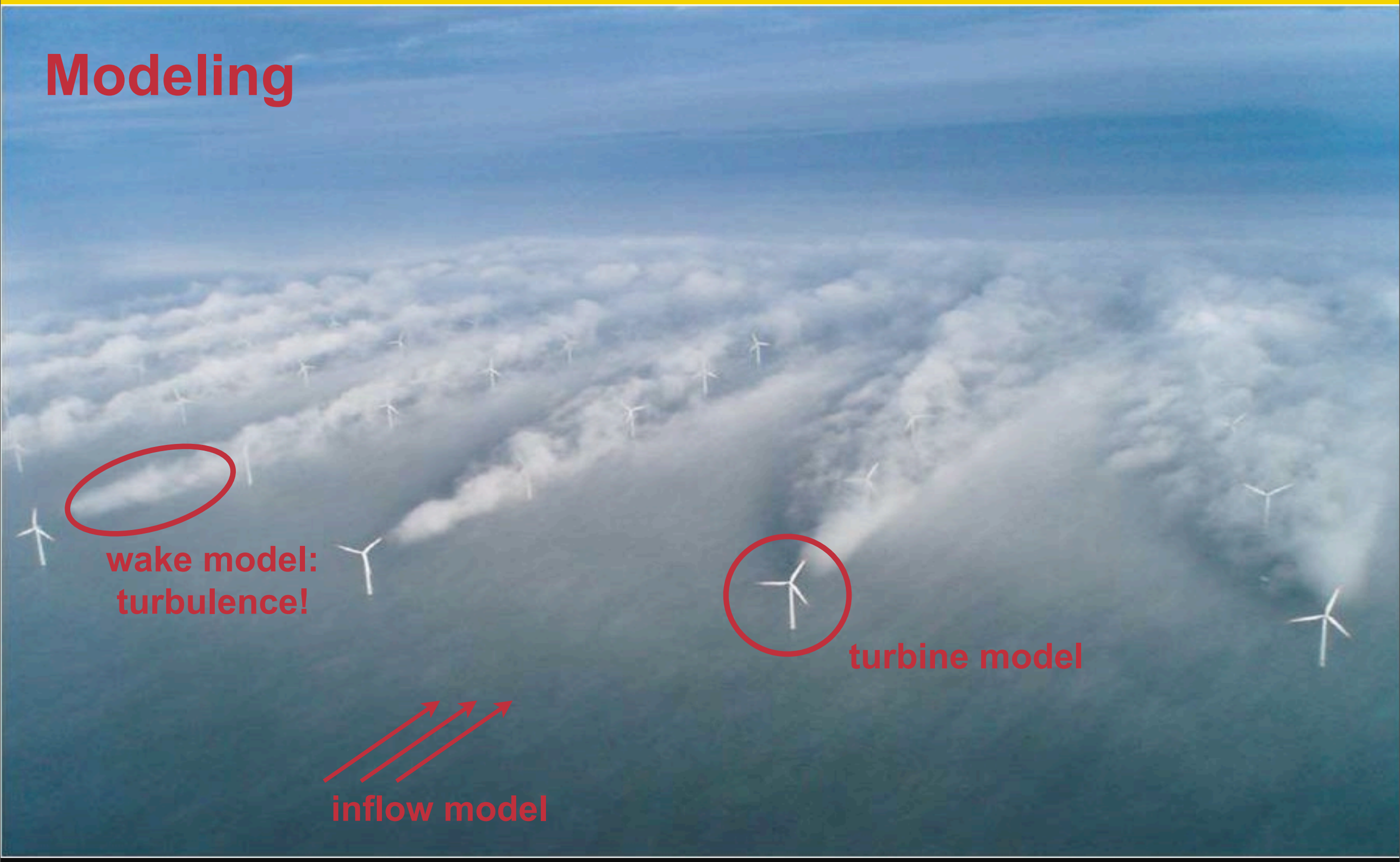
Modeling



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Turbulence and the Navier-Stokes equations

- Wind turbine wakes are highly turbulent
- The incompressible Navier-Stokes equations describe turbulent flows:

$$\nabla \cdot \boldsymbol{u} = 0,$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + (\boldsymbol{u} \cdot \nabla)\, \boldsymbol{u} = -\nabla p + \nu \nabla^2 \boldsymbol{u}.$$

To compute flows of practical interest, we need:

- A numerical approximation to the NS equations
- A turbulence model

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Numerical approximation (‘discretization’)

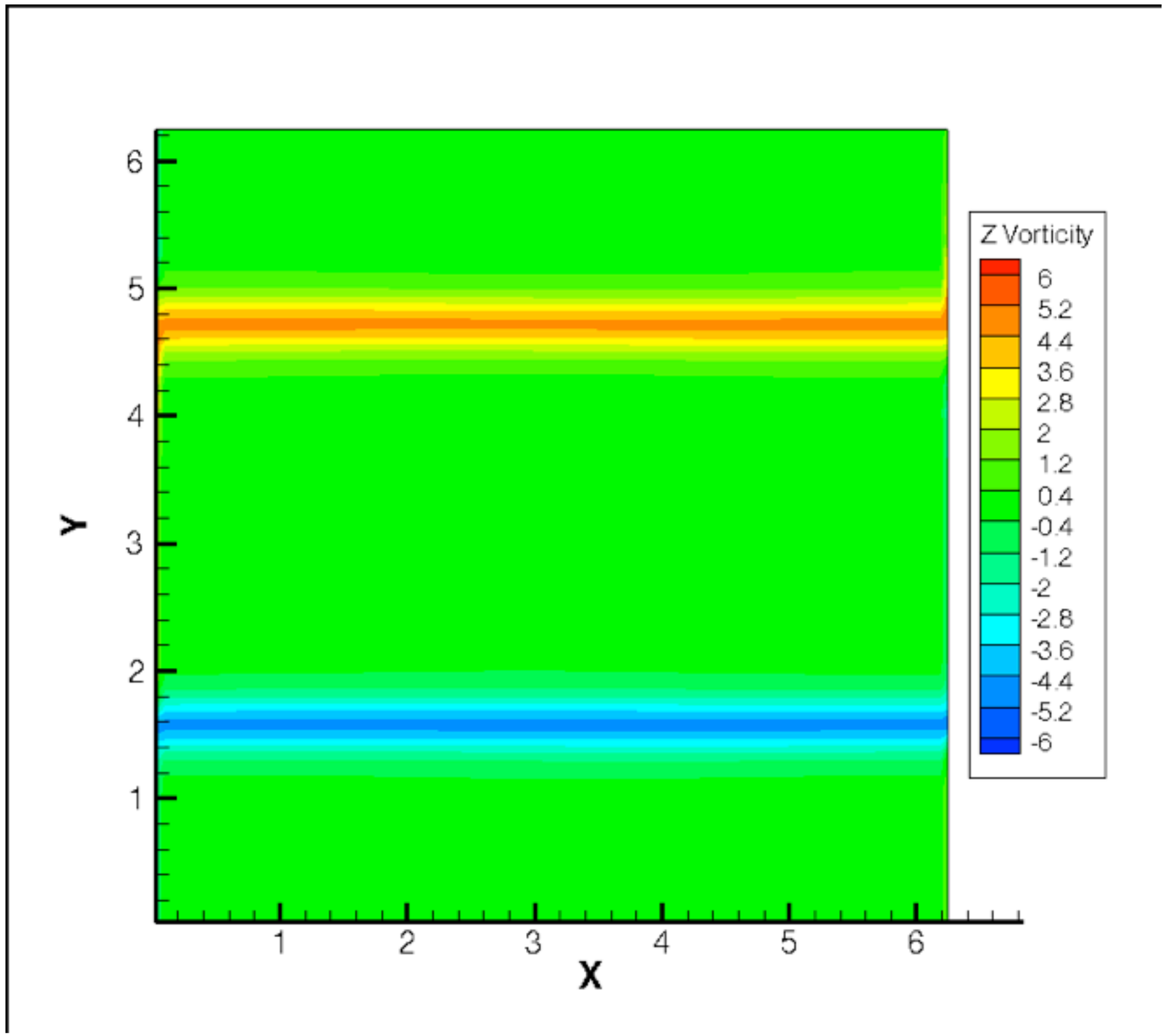
- Requirements for the discretization:
  - Low numerical diffusion
  - High order accuracy in space and time
  - Stable long-term integration

- **Energy-conserving** discretizations:
  - Unconditionally stable (any mesh, any time step)
  - Correctly capture the turbulence energy spectrum and cascade

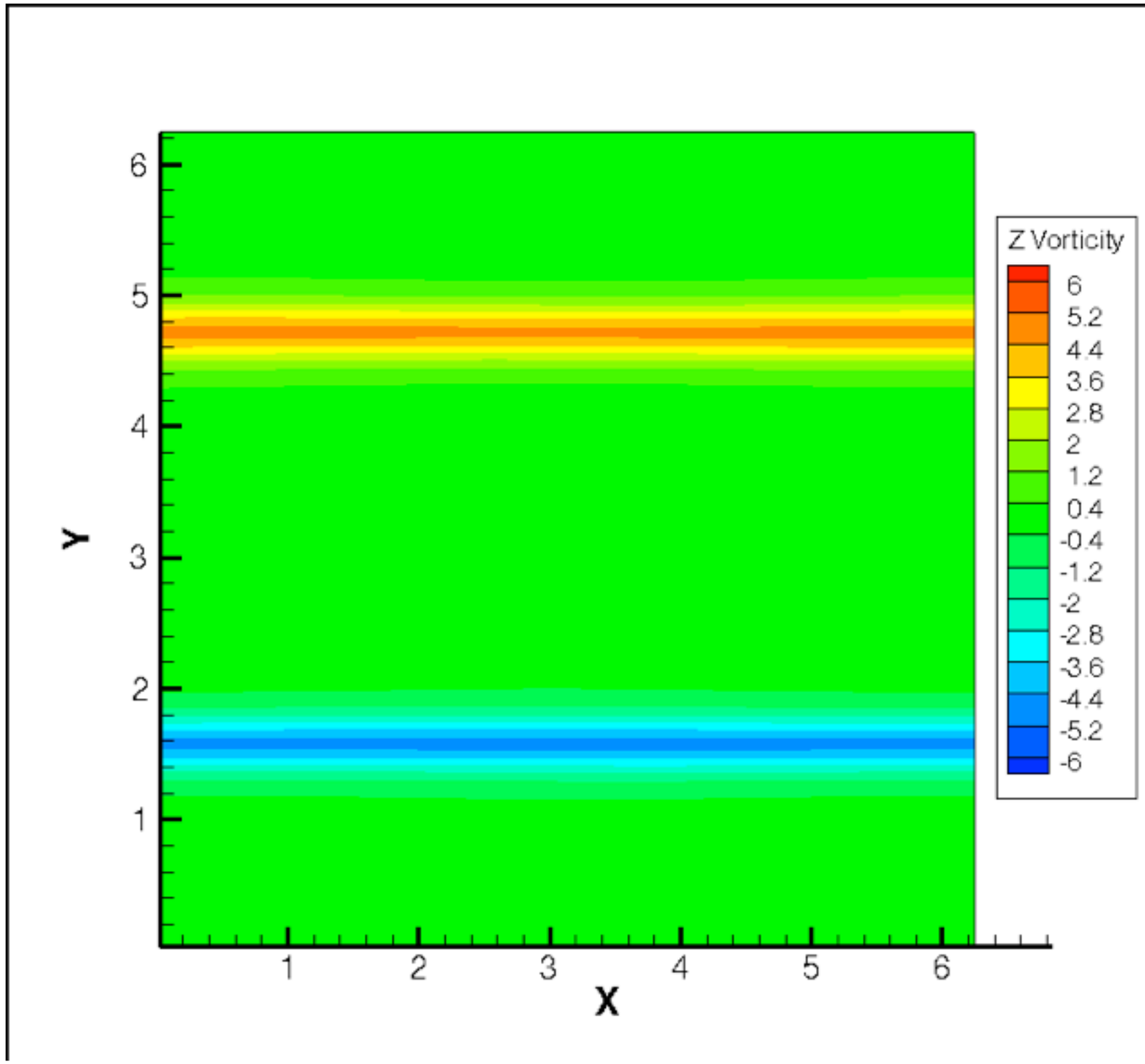
Example: shear layer roll-up

- Shear layer roll-up occurs at the edge of the wake
- Effect of time integration method on energy conservation
- Energy conservation errors lead to irreversible time integration

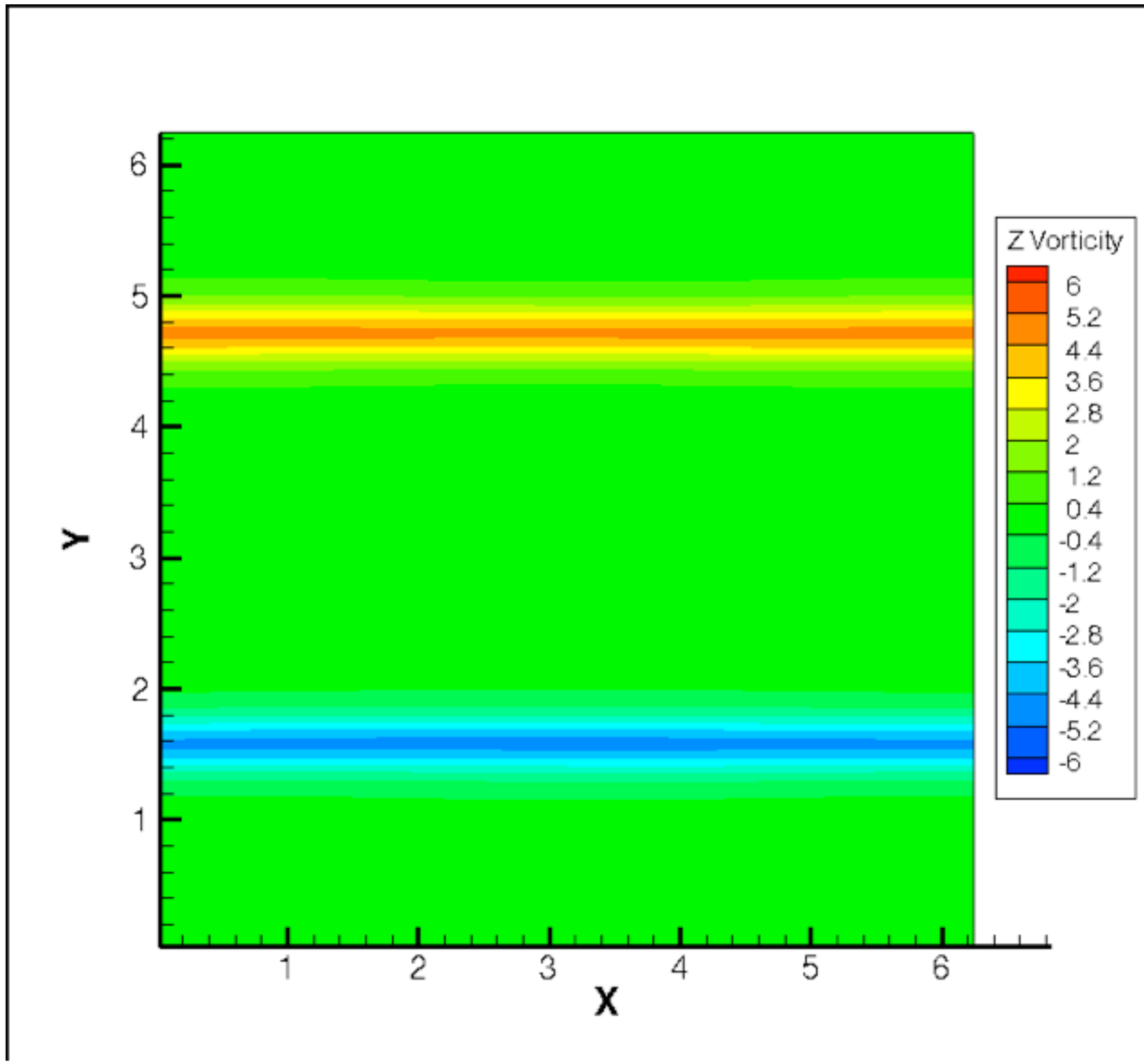
Adams-Bashforth

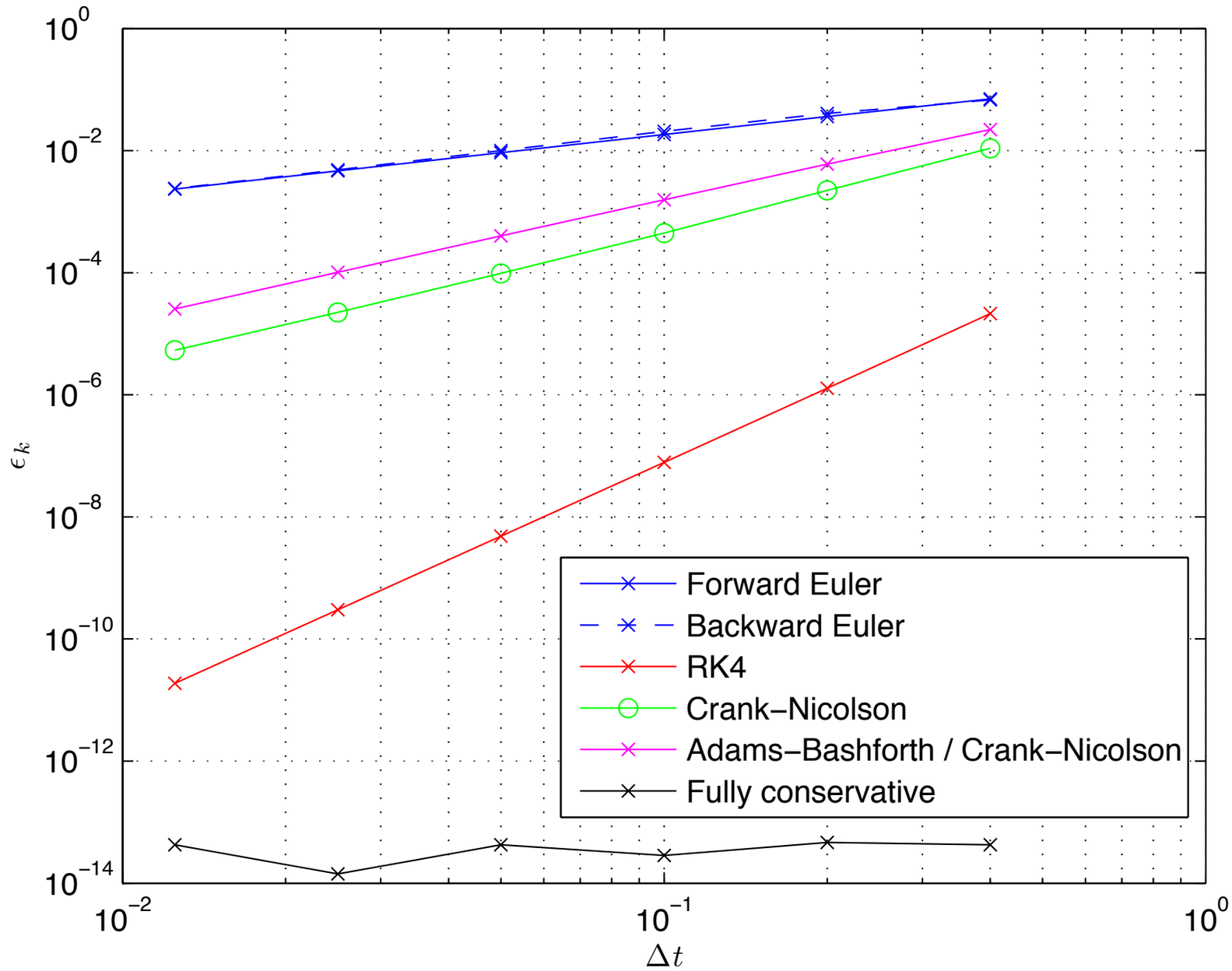


Runge-Kutta 4



Energy conserving




10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
ϵ_k
10^{-2}
10^{-1}
10^{0}
Δt
Forward Euler
Backward Euler
RK4
Crank–Nicolson
Adams–Bashforth / Crank–Nicolson
Fully conservative

Next steps

- Higher order accuracy in space and time
- Turbulence model
- Turbine model
- Inflow model
- Solution of very large systems of equations; parallelization