A more advanced turbulence model for RANS simulations of wind turbine wakes: the WJ-EARS model

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Technical University of Denmark (DTU)
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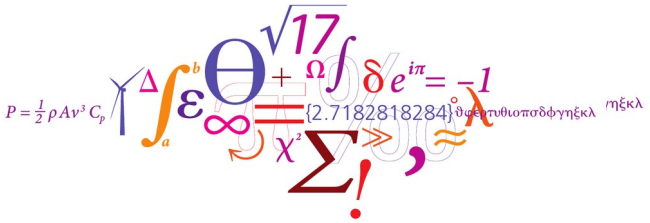
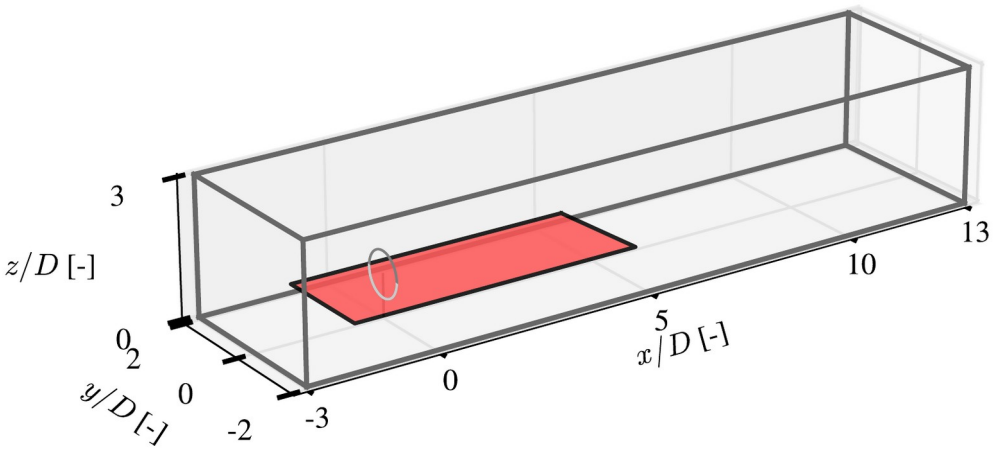
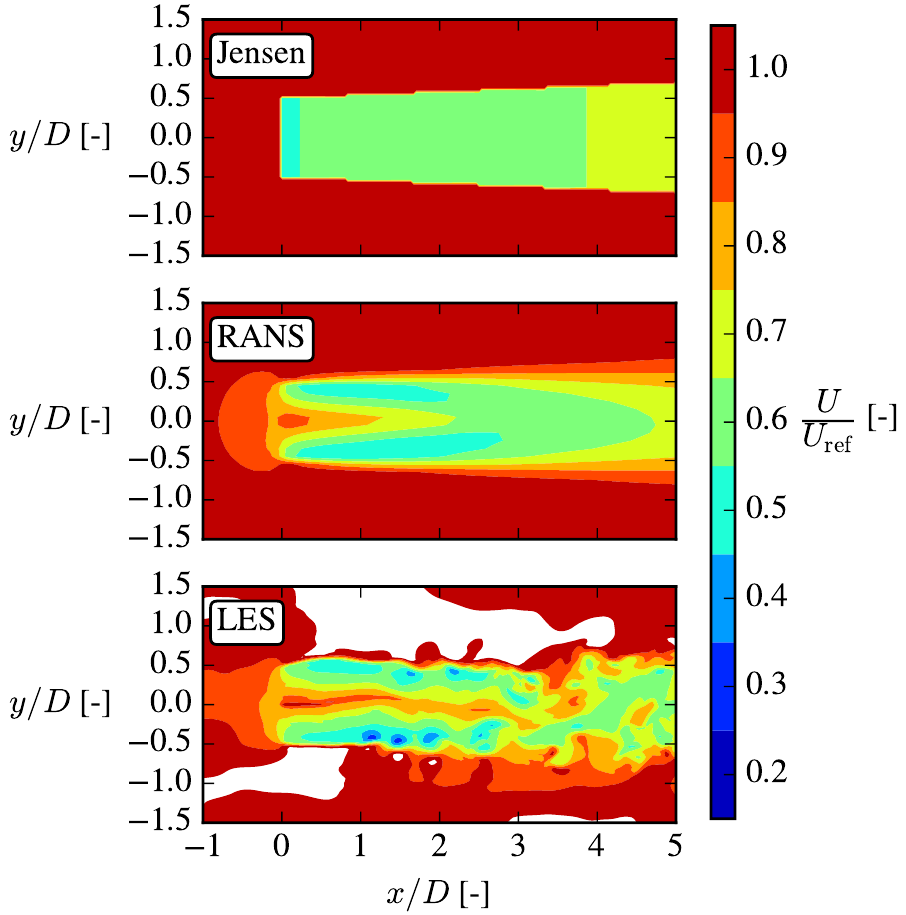


Different simulation methods

- Trade-off between flow details and computational cost





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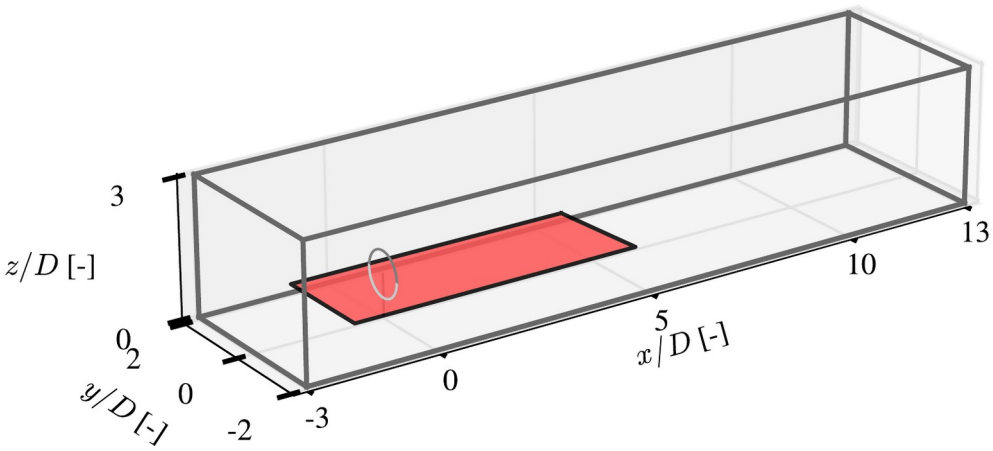

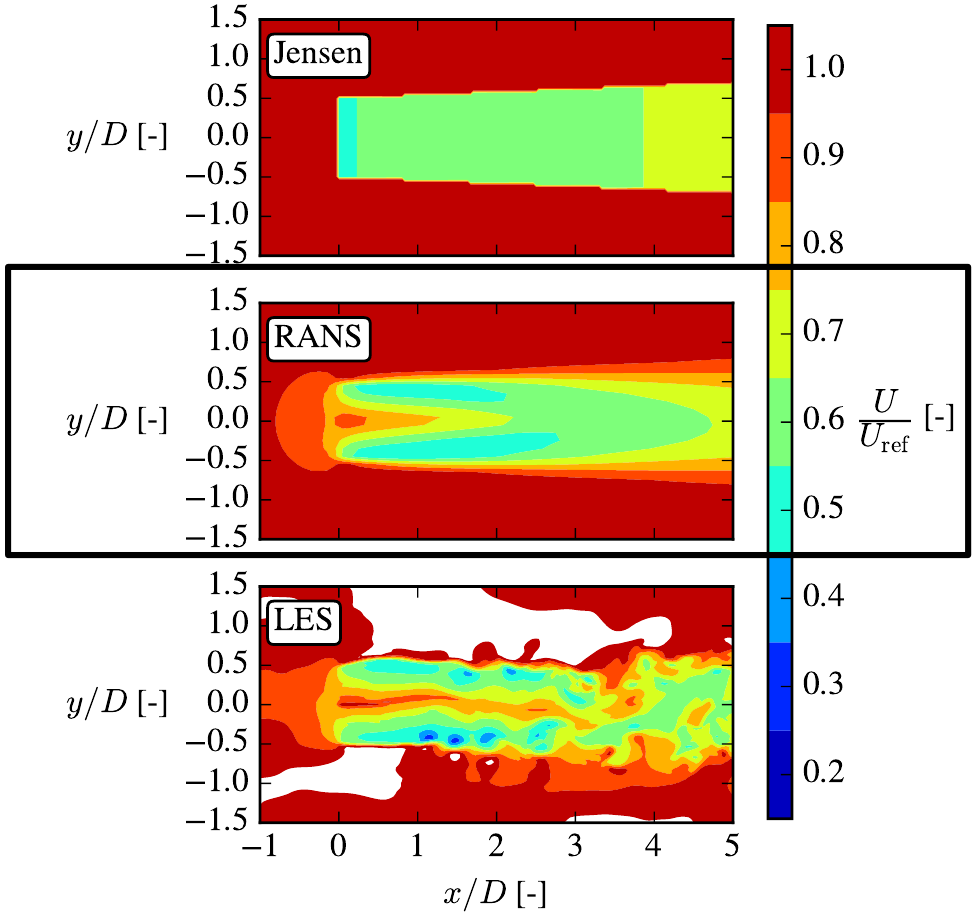

RANS turbulence modeling

“How do we get the Reynolds stress tensor?”

Reynolds-Averaged Navier-Stokes (RANS):

$$\frac{DU_i}{Dt} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}(2\nu S_{ij} - \overline{u_i' u_j'}) + f_i$$

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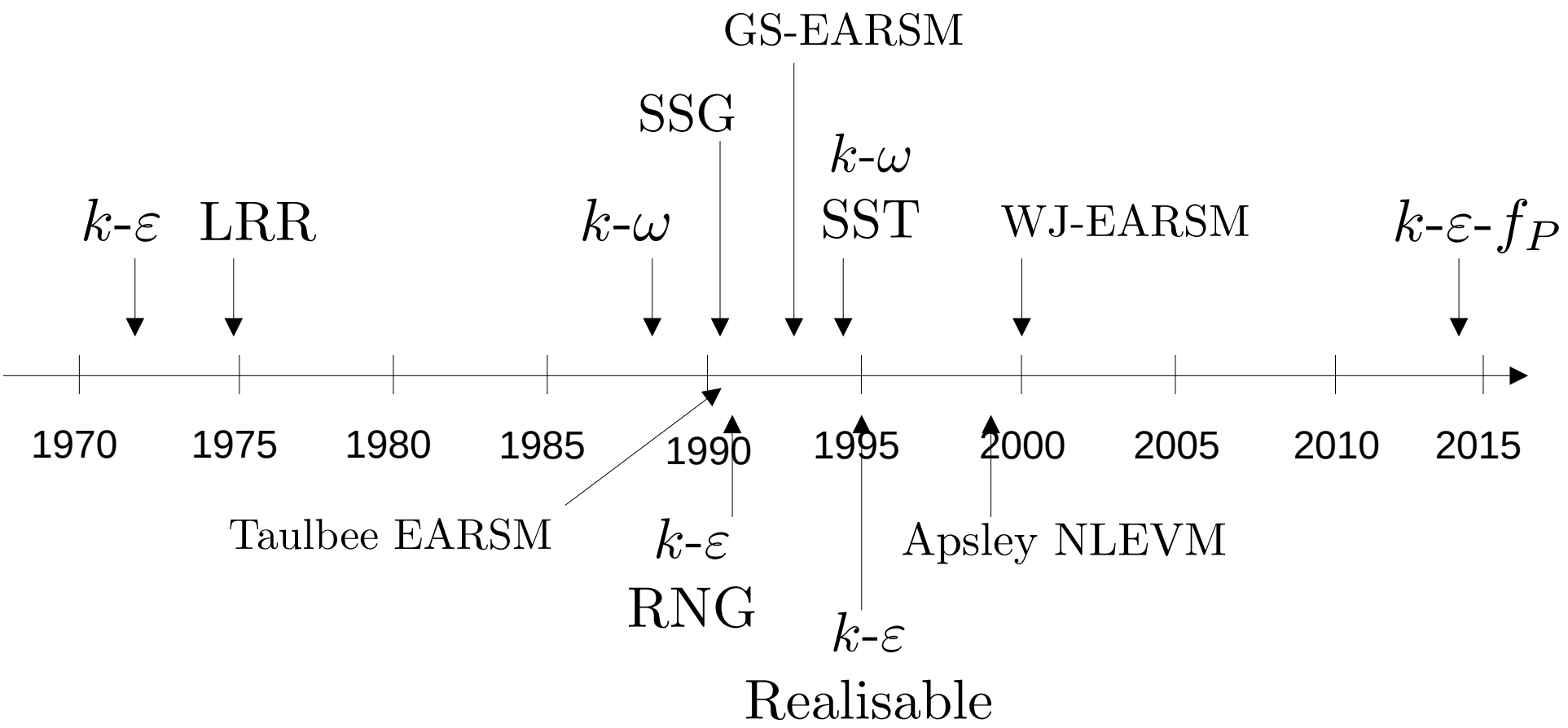
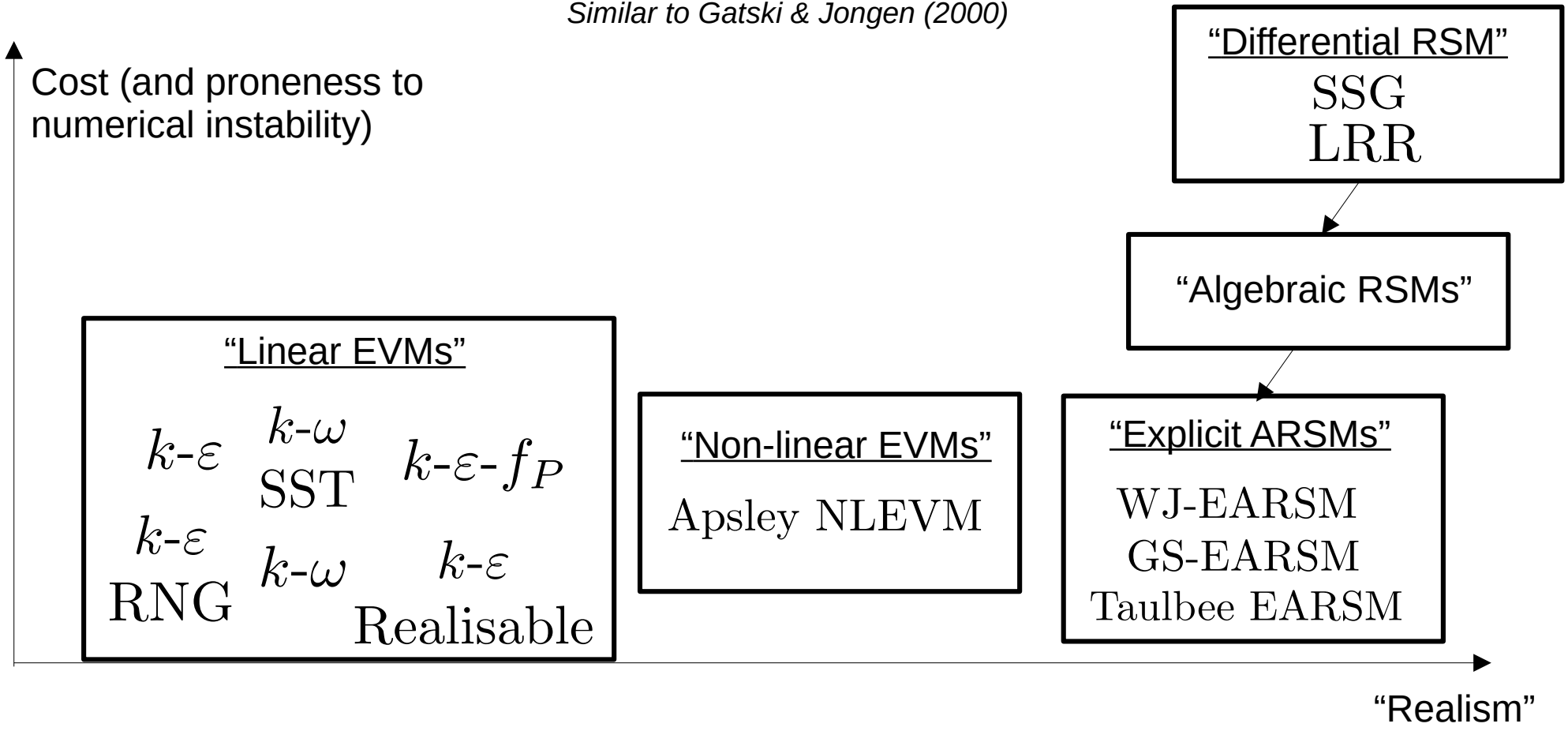
Very important for getting good results!

History of RANS turbulence models



Categories of RANS turbulence models

Similar to Gatski & Jongen (2000)



Wallin & Johansson (WJ) EARSM

- What are the advantages of WJ-EARSM?

	Linear EVM	WJ-EARSM
Anisotropic freestream turbulence	❌	✅
Secondary flows	❌	✅
Counter-gradient heat flux	❌	✅
Realizable turbulence	Some	✅
Sensitive to rotation	Very few	✅

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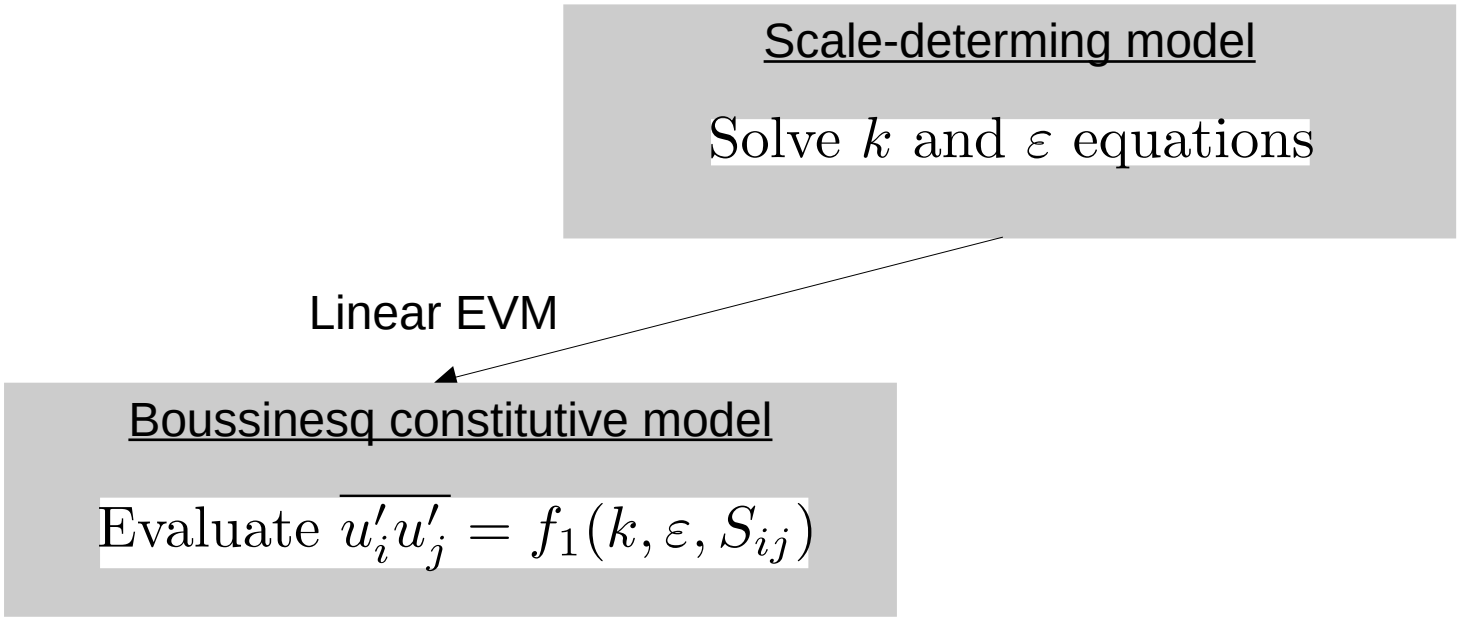
Linear EVM vs WJ-EARSM



Linear EVM vs WJ-EARSM

Scale-determing model

Solve k and ε equations

WJ-EARSM

~~Boussinesq constitutive model~~

~~Evaluate $\overline{u_i' u_j'} = f_1(k, \varepsilon, S_{ij})$~~

EARSM constitutive model

Evaluate $\overline{u_i' u_j'} = f_2(k, \varepsilon, S_{ij}, \Omega_{ij})$

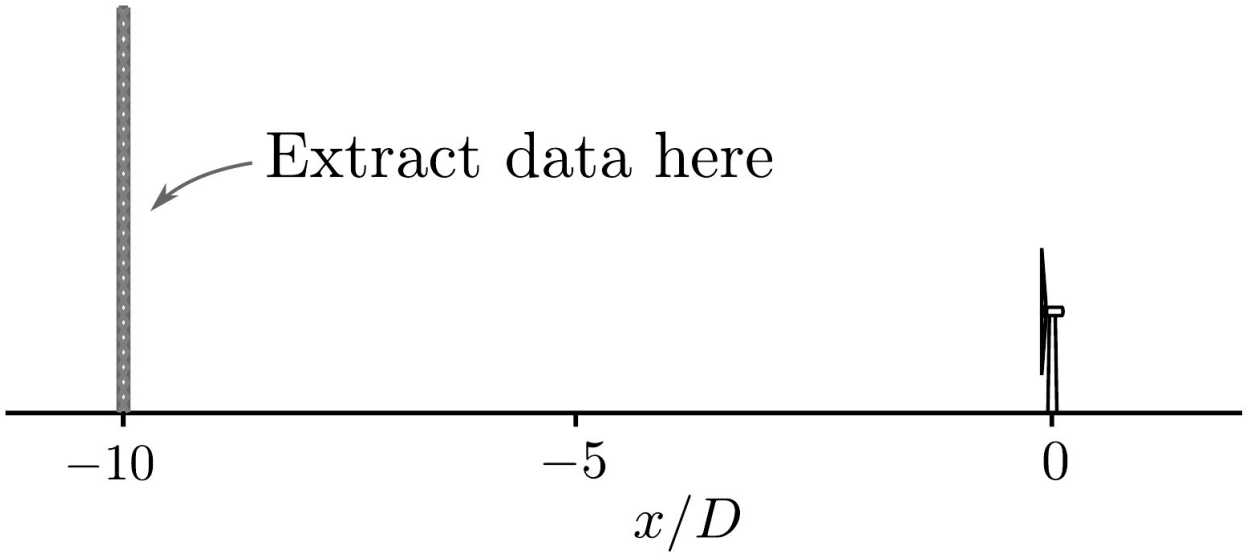
The function, f_2, in EARSM:

- Wallin & Johansson (2000)
- Baungaard, Wallin, van der Laan and Kelly (2022)

Anisotropic freestream turbulence

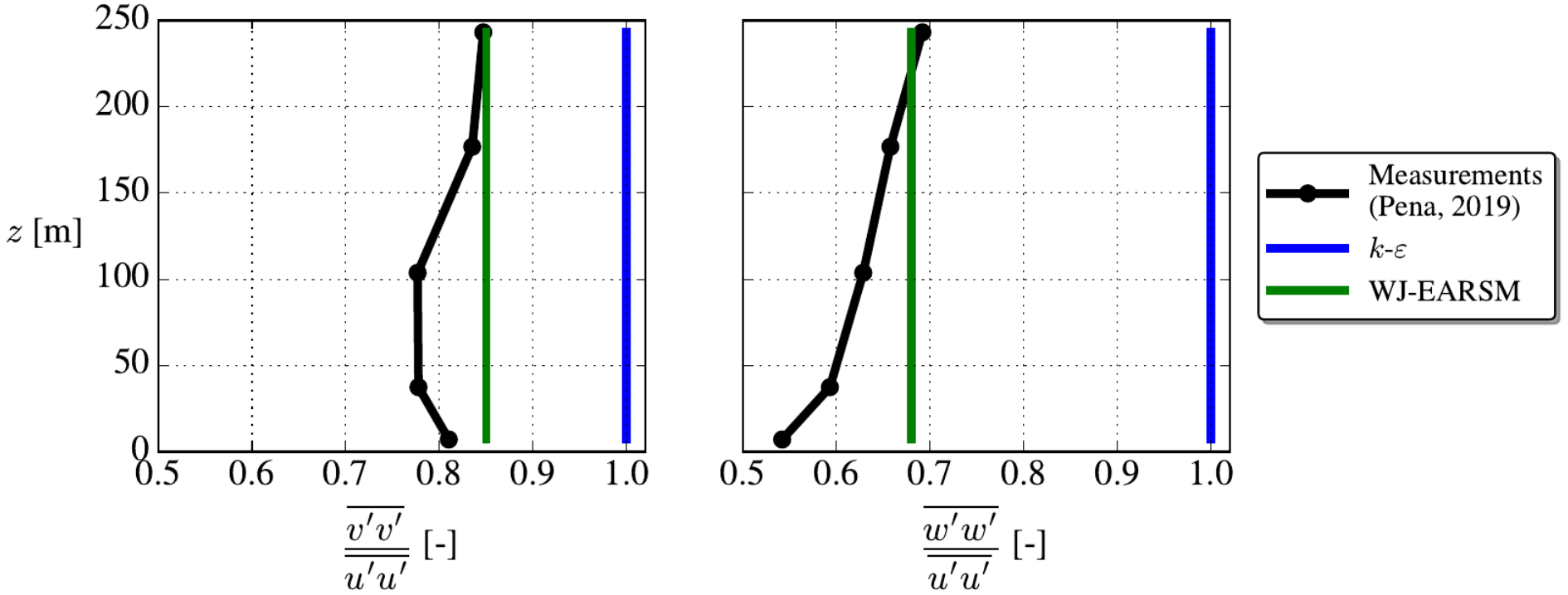
$$k \equiv \frac{1}{2}(\overline{u'u'} + \overline{v'v'} + \overline{w'w'})$$

Anisotropy: *What is the distribution of TKE among its components?*



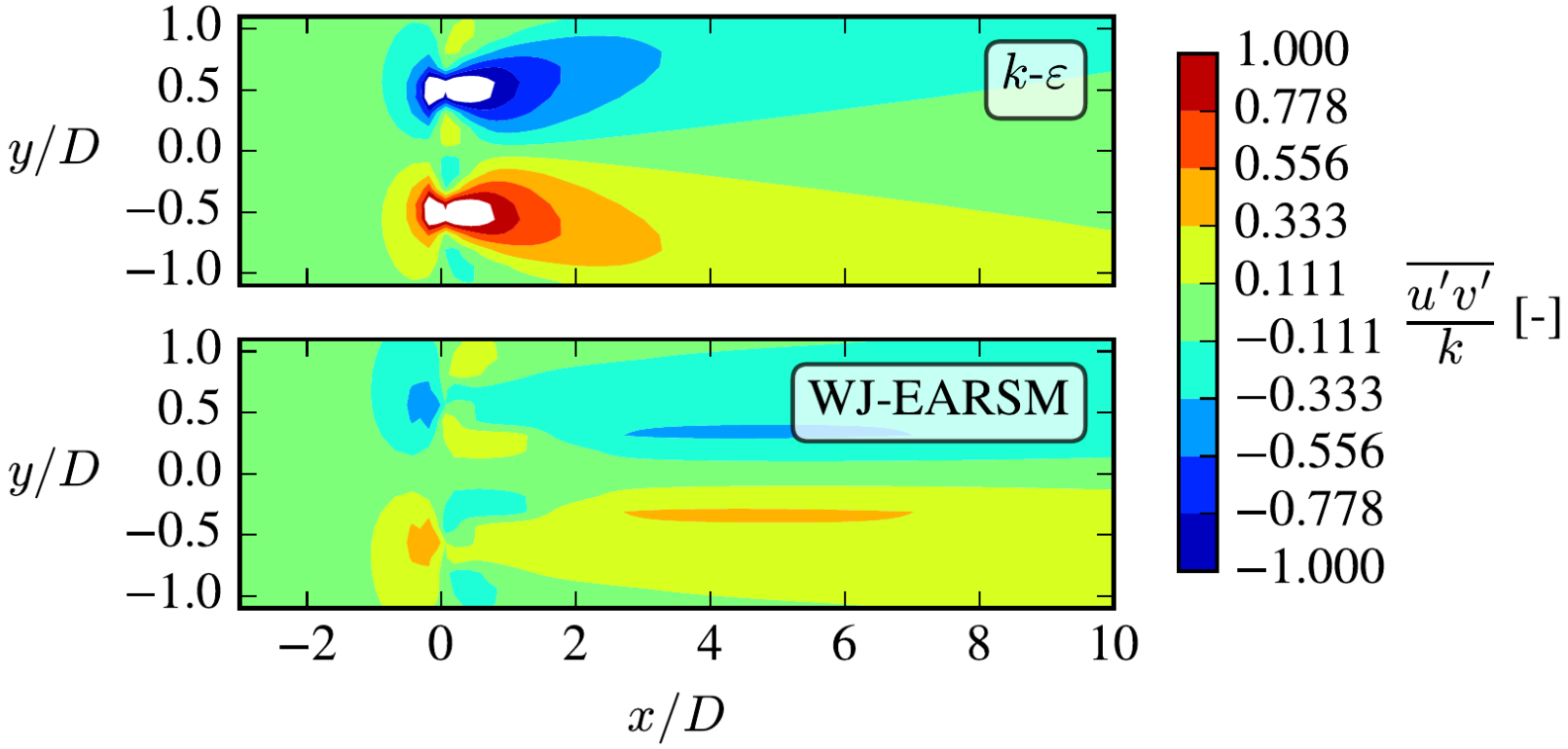
Anisotropic freestream turbulence

In the ABL, $\overline{u'u'} > \overline{v'v'} > \overline{w'w'}$



Realizable turbulence

Realizable: *The Reynolds stress tensor has limits.*



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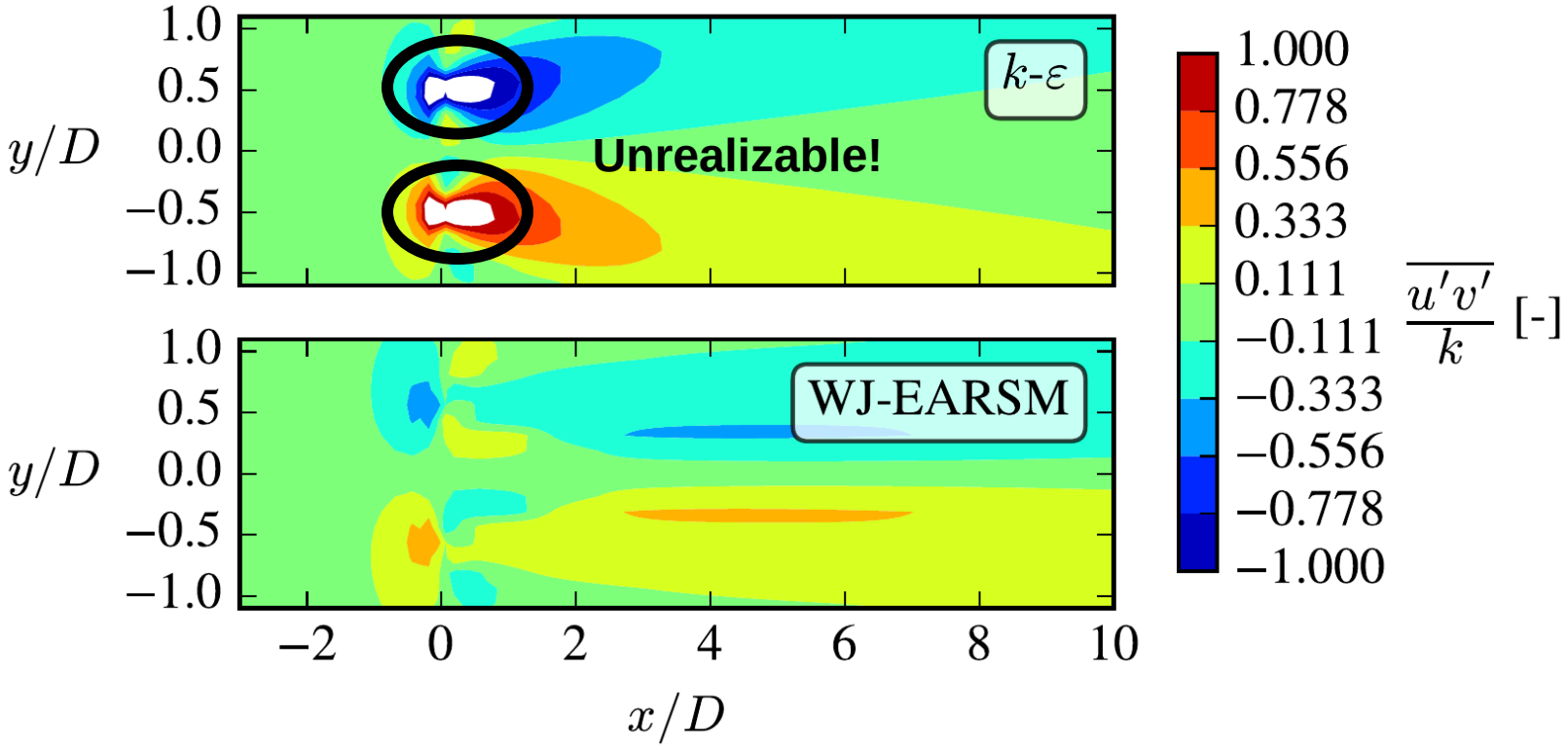

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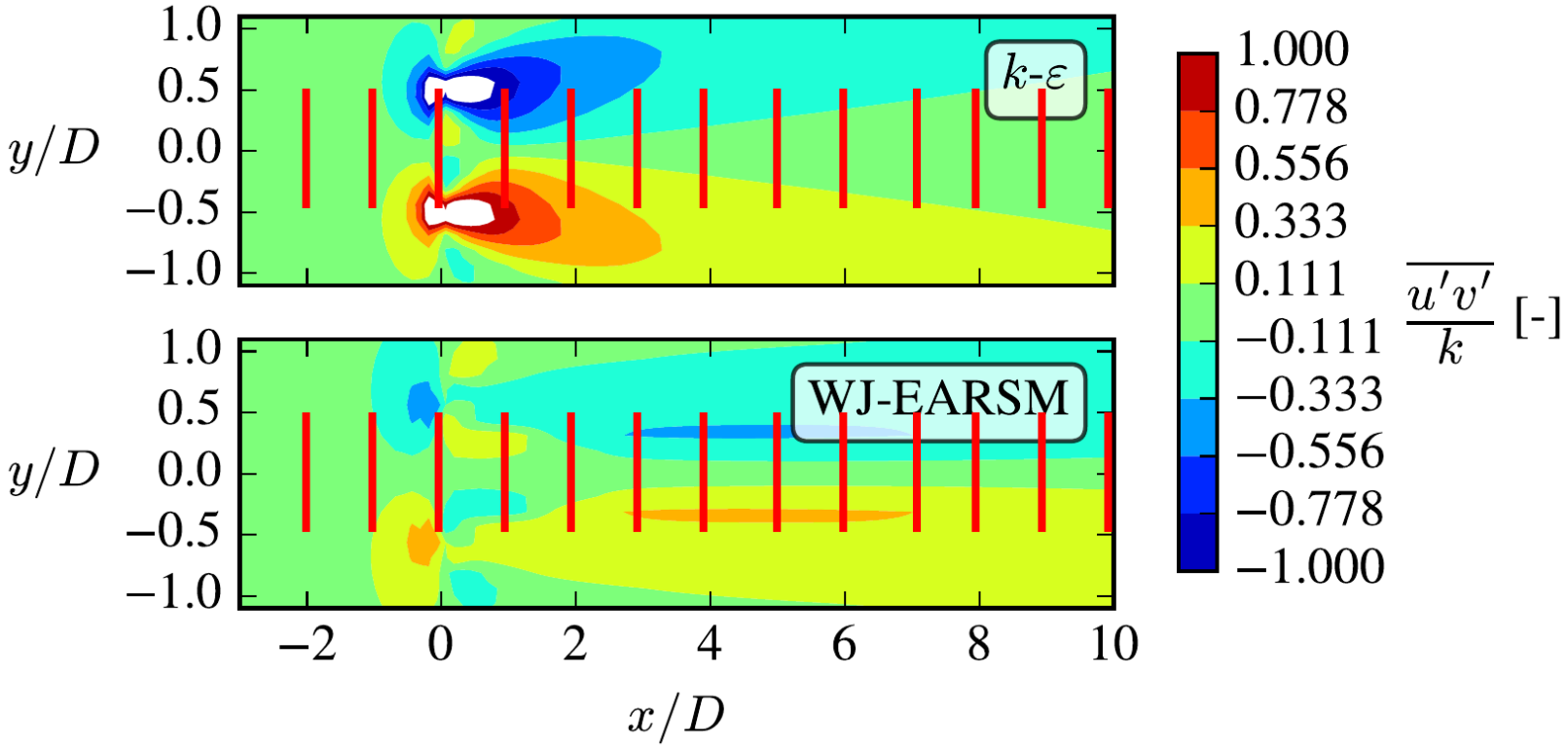
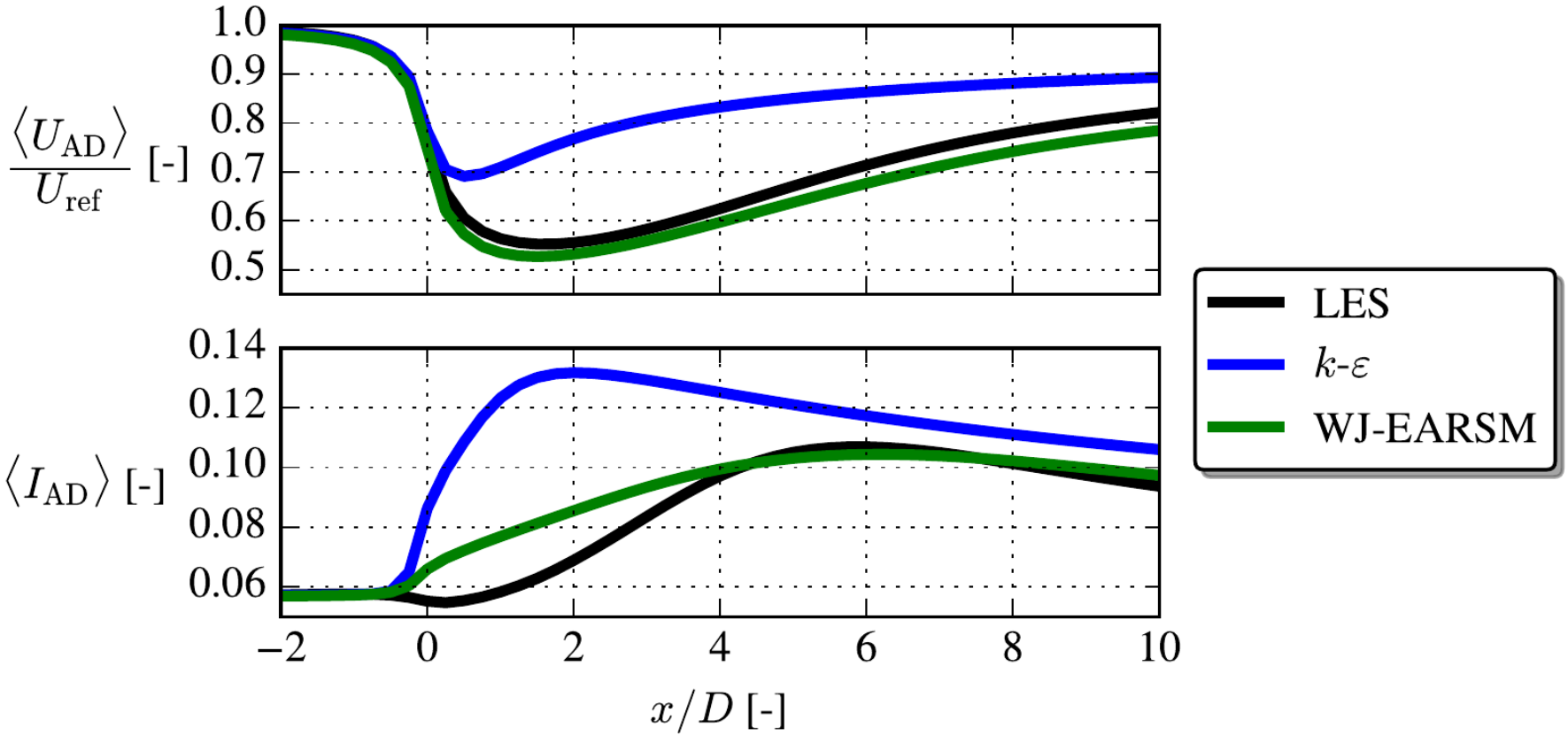
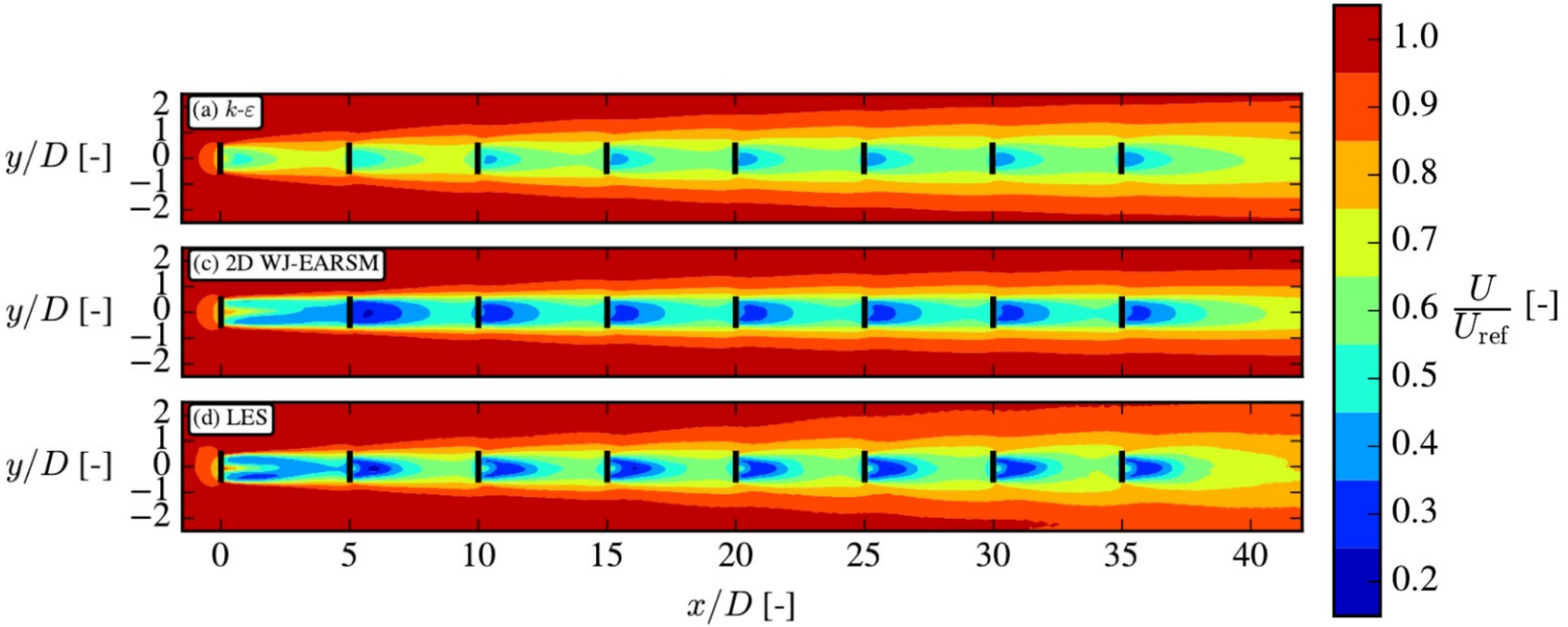


Disk-averaged recovery (single turbine)

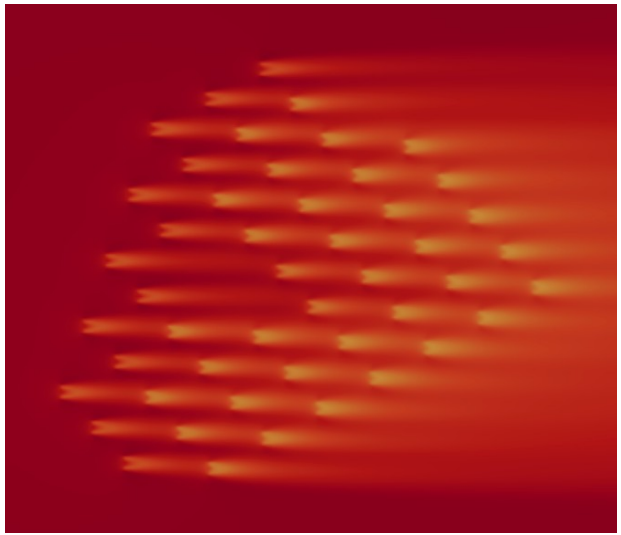


A row of turbines

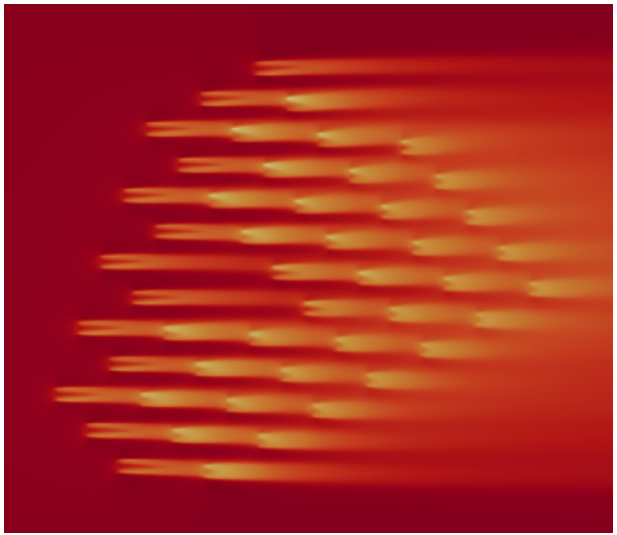


Lillgrund wind farm

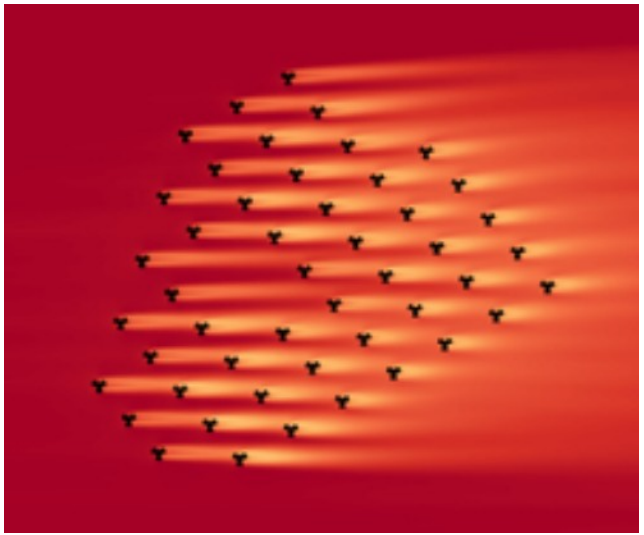
RANS (k-ε)



RANS (WJ-EARSM)



LES (Sood et al. 2022)



Conclusions and perspectives

- The WJ-EARS model can be used for wind farm simulations
  - ✅ More physical effects can be captured
  - ✅ Small computational overhead
  - ✅ Numerically stable
  - ✅ Easy to implement
  - ❓ Model coefficients
  - ❓ Validation

$$\text{Linear EVM: } \overline{w\theta} = -\kappa_1 \frac{d\Theta}{dz}$$
$$\text{WJ-EARSM: } \overline{w\theta} = -\kappa_2 \frac{d\Theta}{dz} + \Phi$$

- There exists an extension of WJ-EARSM for non-neutral atmospheric conditions