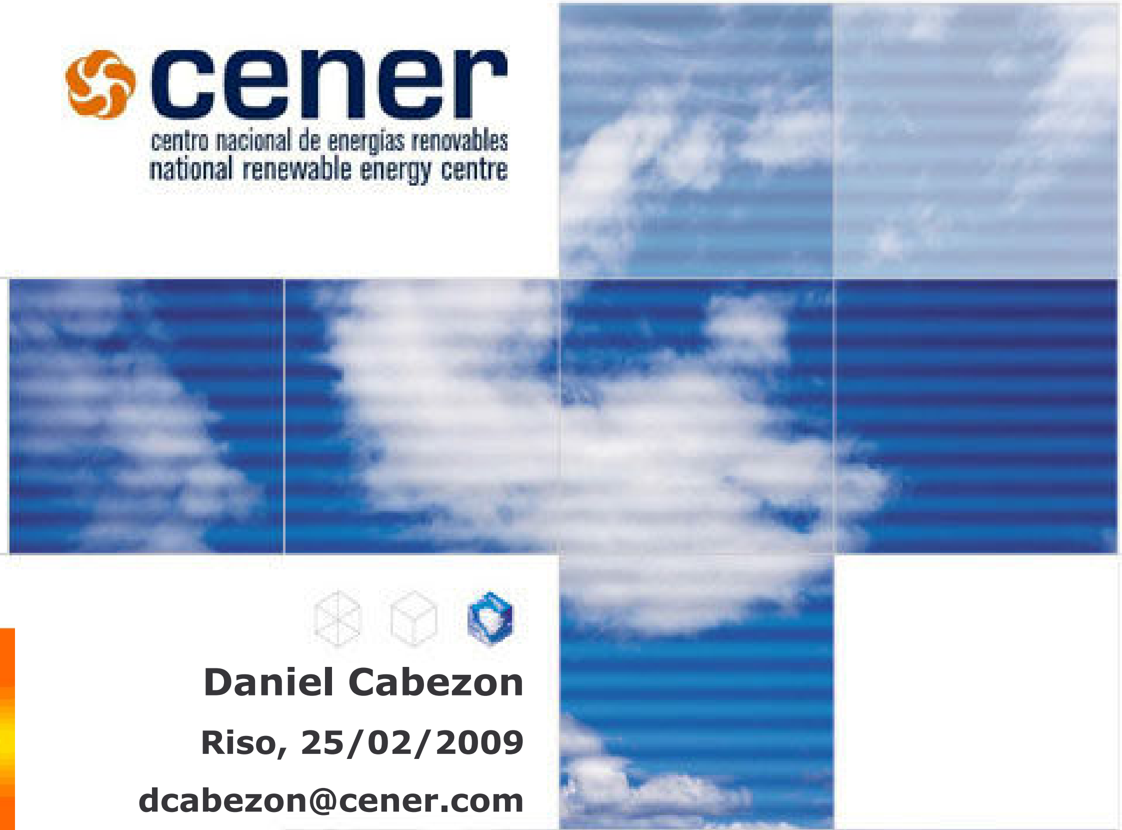
CFD modeling of the interaction between the Surface Boundary Layer and rotor wake

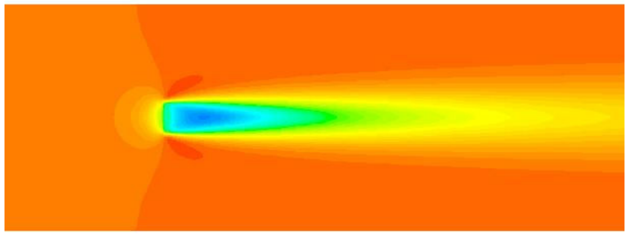
Turbulence models and mesh strategies



Wind Energy Department

CFD area

Wind Resource Assessment and Forecasting Service



Daniel Cabezon

Riso, 25/02/2009

dcabezon@cener.com

National Renewable Energy Centre - CENER
Madrid (SPAIN)

INDEX

1. Introduction

2. Sexbierum experiment

3. Actuator Disk Model

4. Results

    A. Mesh strategies. Grid independency analysis

    B. Turbulence modeling. Validation and sensibility analysis

5. Conclusions. Further work

1. Introduction

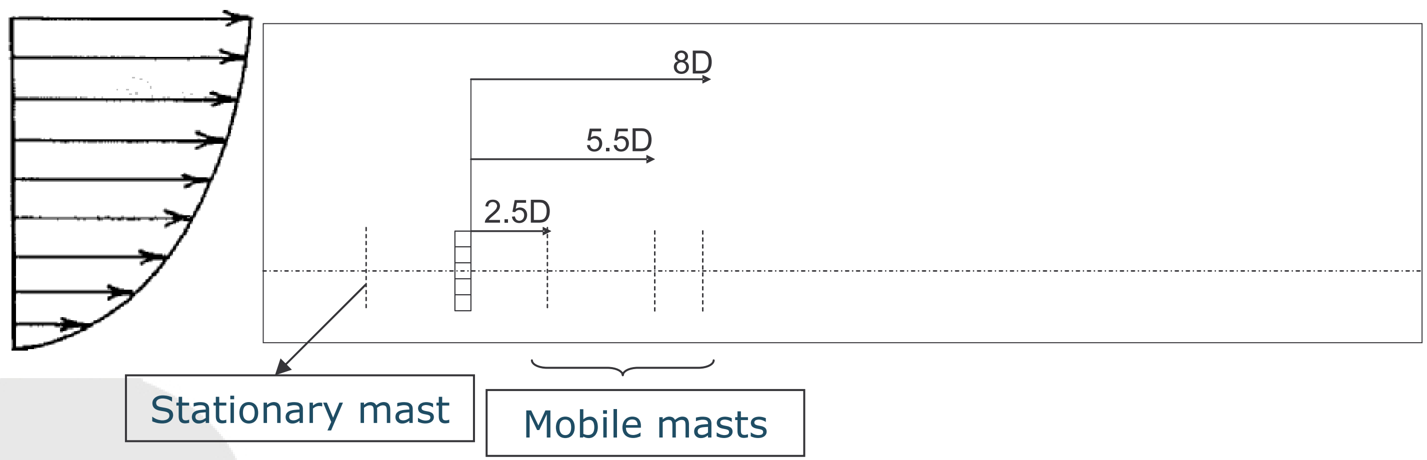
- New wake models are needed for facing challenging environments: Complex Terrain and Offshore
- 'Back to the basics' concept
- CFD wake model based on coupling:

  Actuator Disk Technique + Wind flow model
- Get knowledge on the interaction between ABL and rotor wakes
- Validation and adjustment on:
  - ❑ Turbulence modelling
  - ❑ Meshing strategies

  } Sensitive topics!

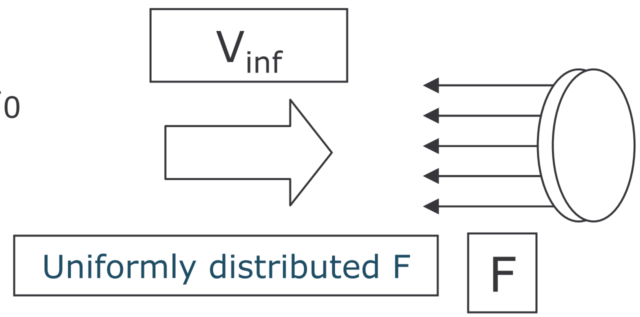
2. Sexbierum experiment

- Experiment: Single rotor configuration
  - Hub height, H = 35m
  - Rotor diameter, D = 30m
  - Thrust coefficient, C_t=0.75
- Measurements of WS_Def and TI upwind and downwind
- Freestream conditions:
  - Wind speed: logarithmic flow, U_0 (H) = 10 m/s
  - Turbulence intensity, TI_x (H) = 10%

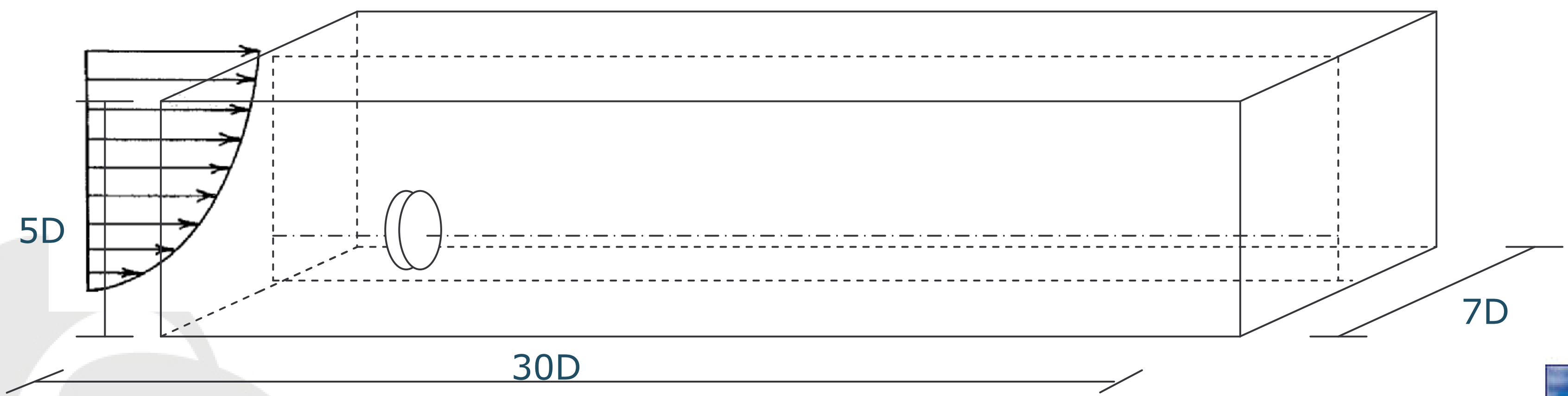


3. Actuator disk model

- Actuator disk model:
  - Based on the linear momentum theory
  - Momentum sink term: $F[N/m^2]=-0.5 \cdot \rho \cdot C_t \cdot U^2_0$
  - "Relaxed BEM model"

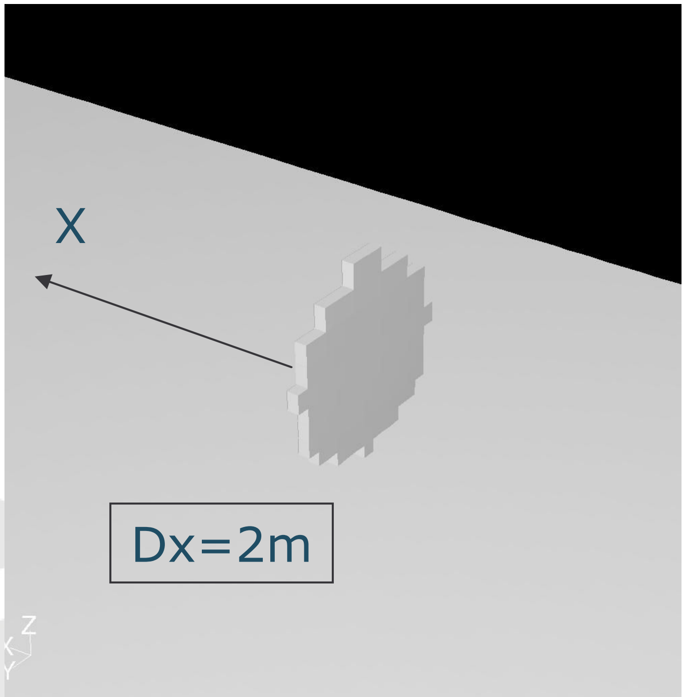


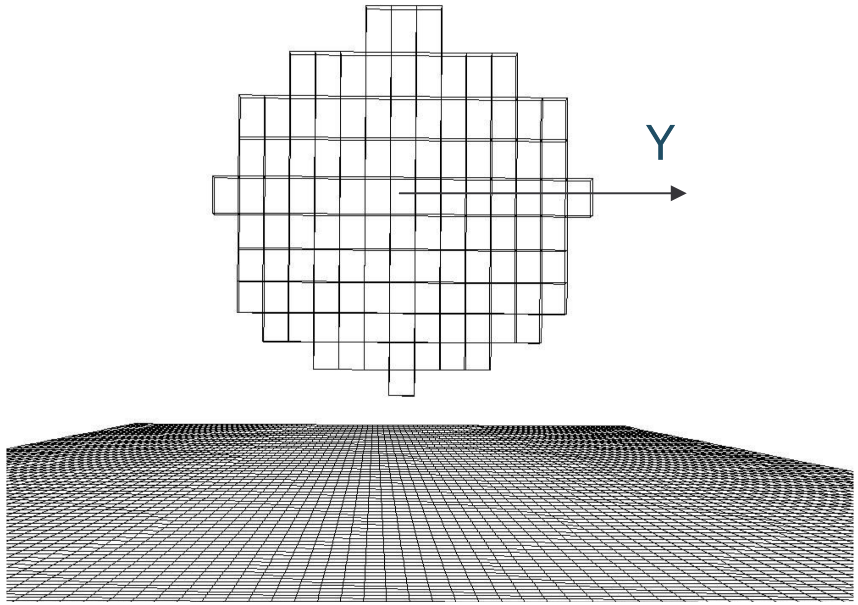
- Computational domain. Set-up:
  - Domain Size: 30D x 7D x 5D
  - Mesh: Structured - 100,000 Hexas
  - Discretization scheme: 2nd order upwind



4. RESULTS. MESH STRATEGIES

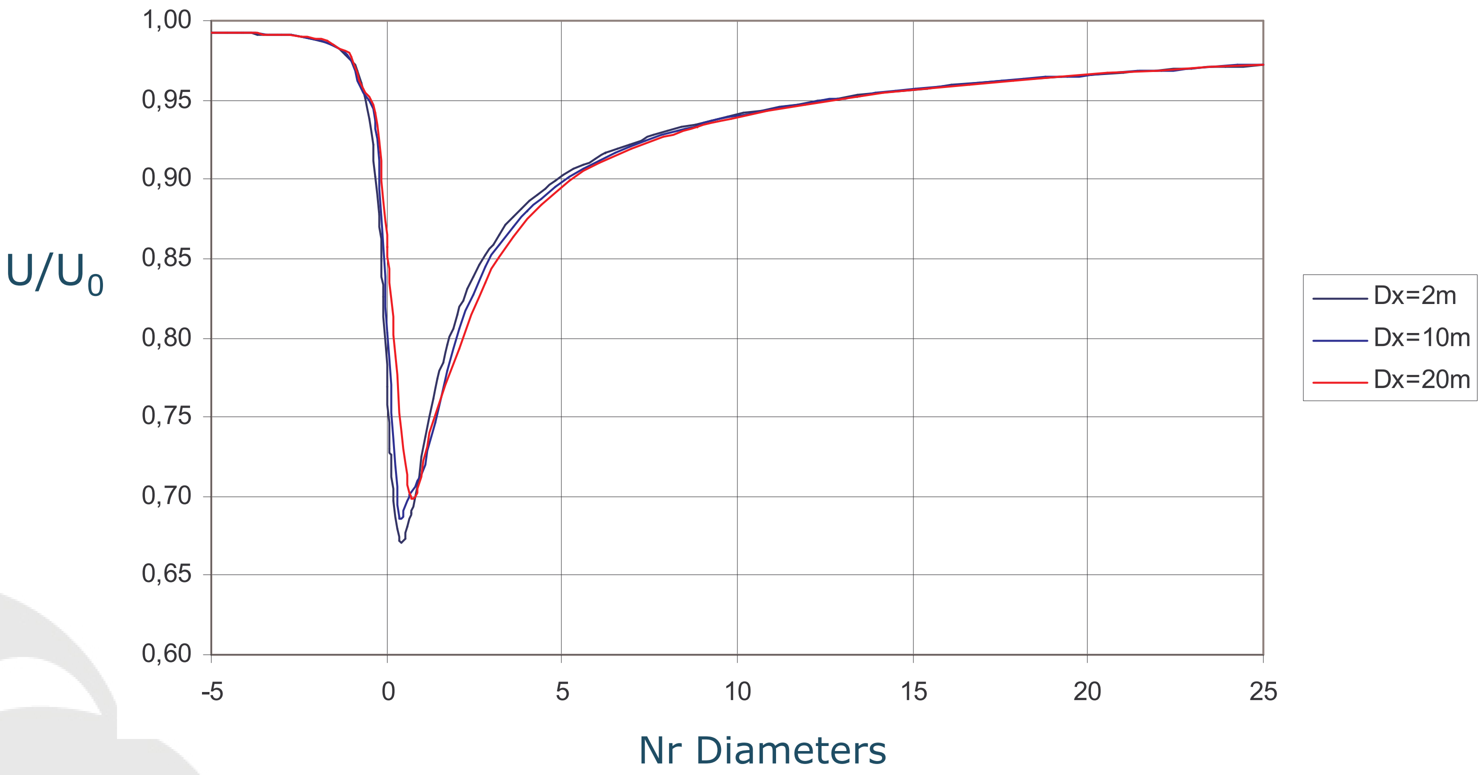
- Uncertainty on the discretization of actuator disk
- X=axial, Y=lateral, Z=vertical
- Minimum number on CVs to reach independency
- Initial mesh for Sexbierum:





4. RESULTS. MESH STRATEGIES

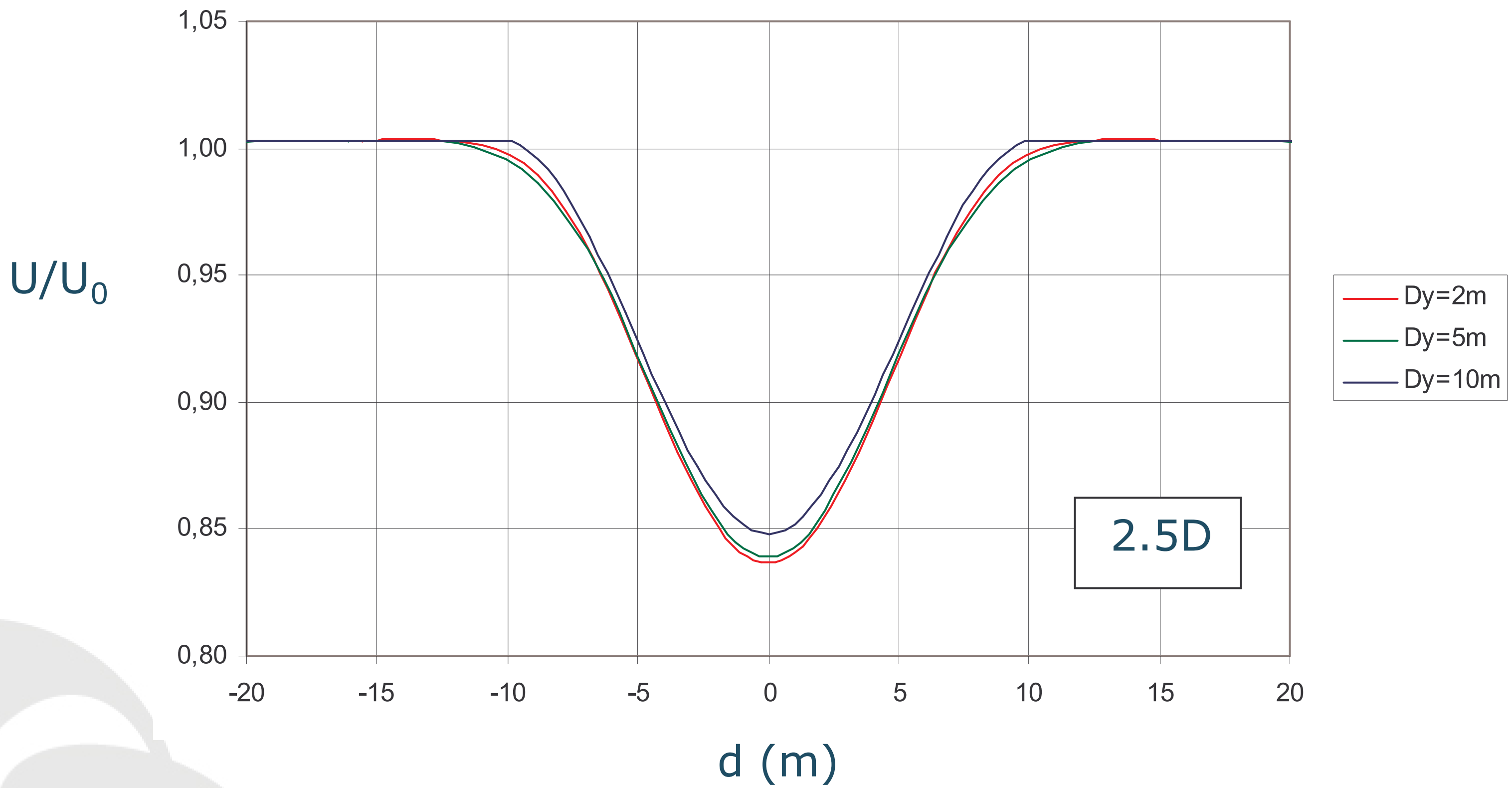
- Independency on X – axial direction:
  - Sensitivity for thickness -> Dx=2m, 10m and 20m
  - Discrepancies for X<7D-8D



4. RESULTS. MESH STRATEGIES

- Independency on Y – lateral direction:
  - ❑ Sensitivity for -> Dy=2m, 5m and 10m
  - ❑ Significant difference for Dy=10m

~30-40 CVs

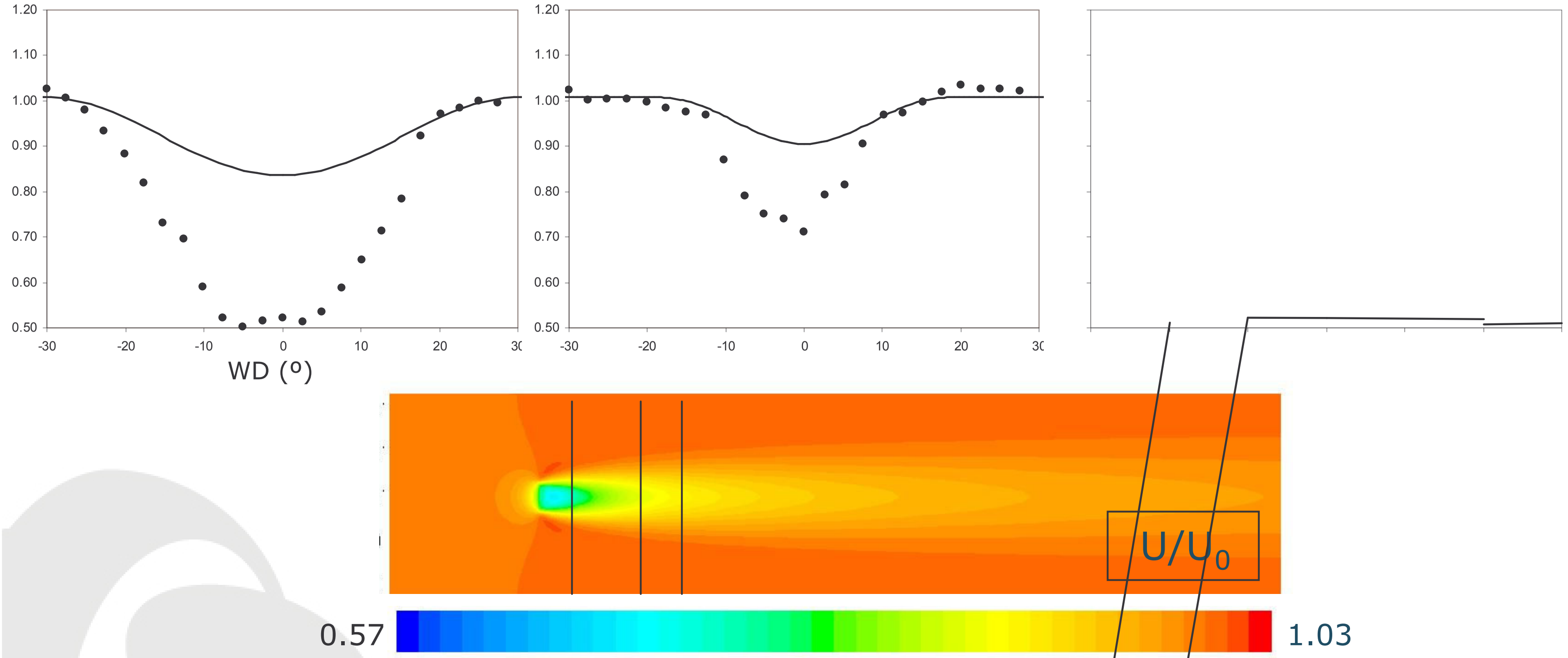


cener
centro nacional de energías renovables
national renewable energy centre

4. RESULTS. TURBULENCE MODELING

ISOTROPIC kε Standard. Default parametrization for ABL

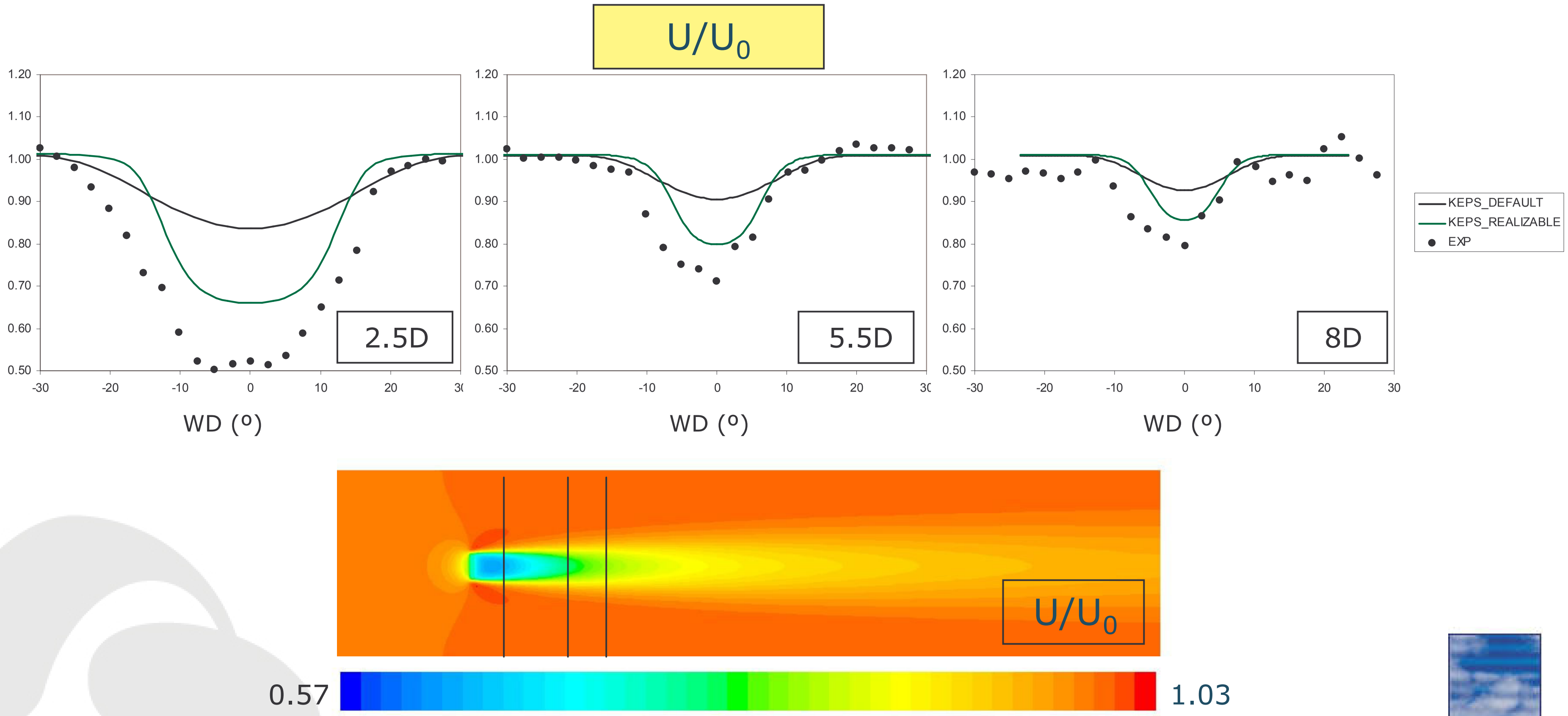
- Default parametrization for modeling flow in the ABL
- Very diffusive especially in the near wake sections
- Tunning / Corrections needed for increasing local dissipation



4. RESULTS. TURBULENCE MODELING

ISOTROPIC kε Realizable

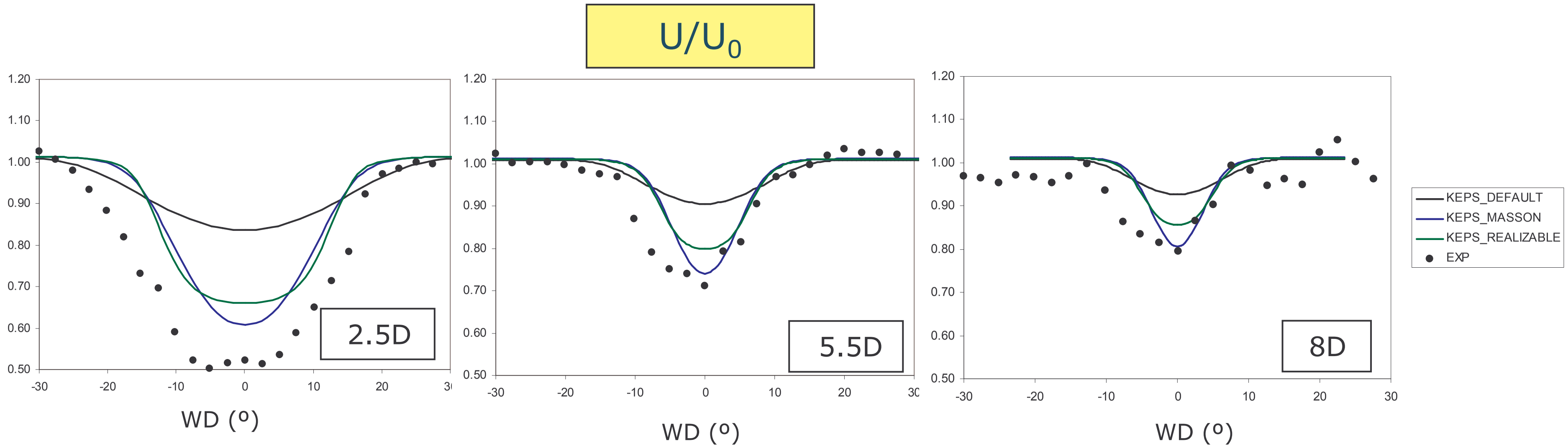
- A new eddy-viscosity formula involving a variable C_μ with WS gradient
- A new model equation for dissipation affecting $C_{1\varepsilon}$ constant
- Increase ε in areas of strong mean strain

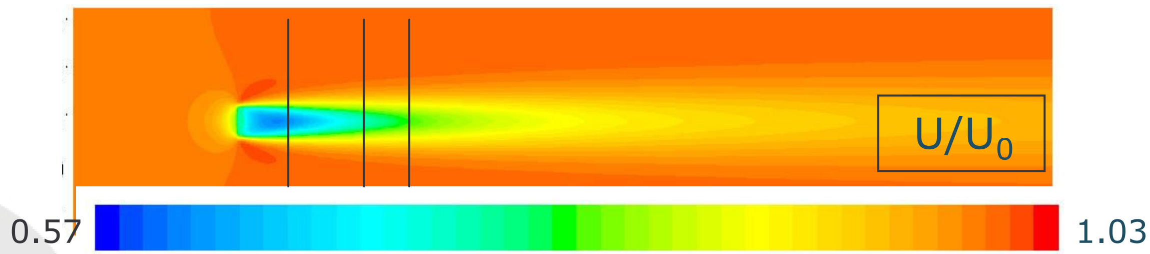


cener
centro nacional de energías renovables
national renewable energy centre

4. RESULTS. TURBULENCE MODELING

- ISOTROPIC kε Standard corrected in ε equation (C. Masson*)
  - ❑ New source term on ε production in a volume adjacent to the rotor
  - ❑ Constants recalibrated to get equilibrium at the wall region
  - ❑ Similar results in the far wake





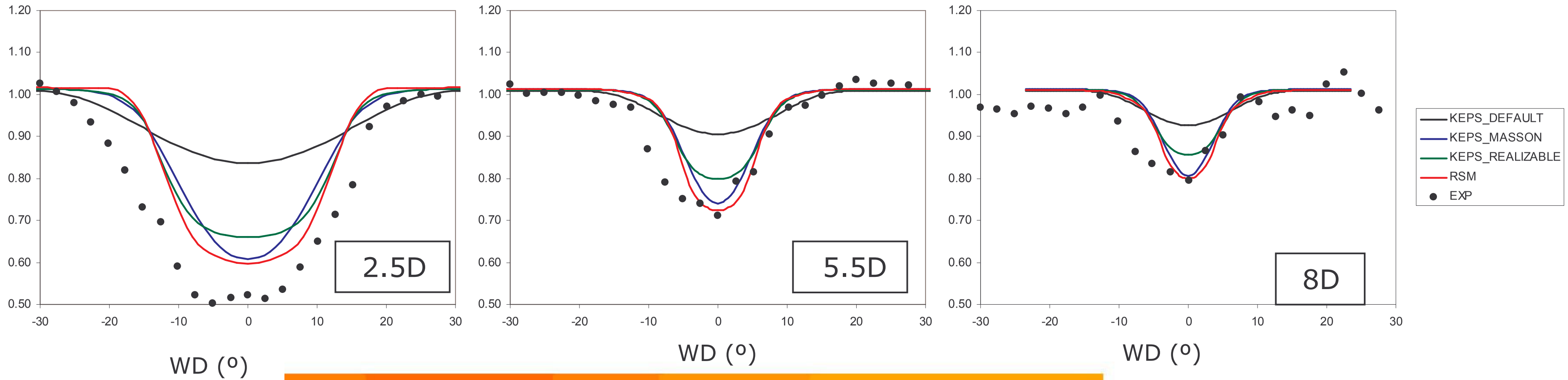
(*) El Kasmin, Masson C., An extended k-ε model for turbulent flow through horizonta-axis wind turbines,J. Wind Engineering and Industrial Aerodynamics 96 (2008), 103-122

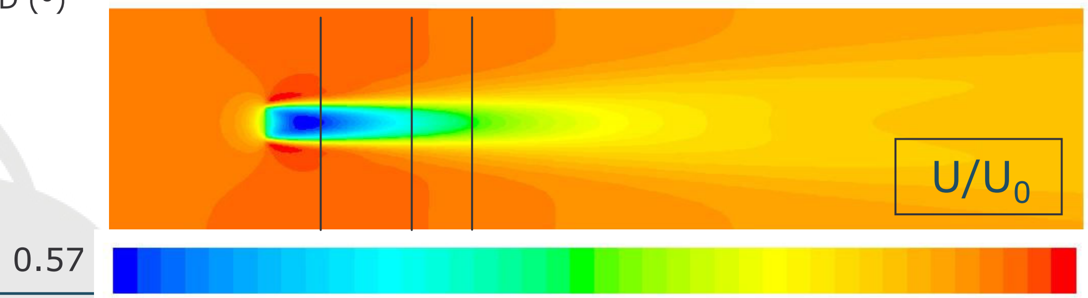
4. RESULTS. TURBULENCE MODELING

ANISOTROPIC RSM (Reynolds Stress Model). Preliminar results

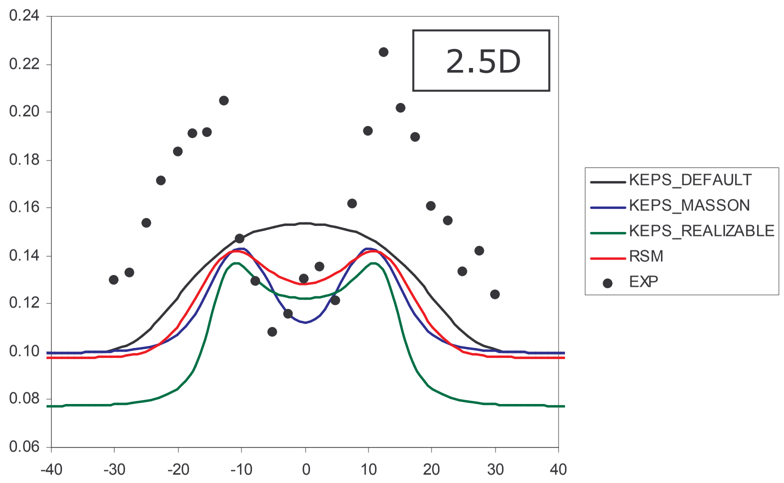
- Modelization of Reynolds stress tensor (7 extra equations)
- Inlet profiles of ABL stress values
- Increase of computing time in the order of 2-3

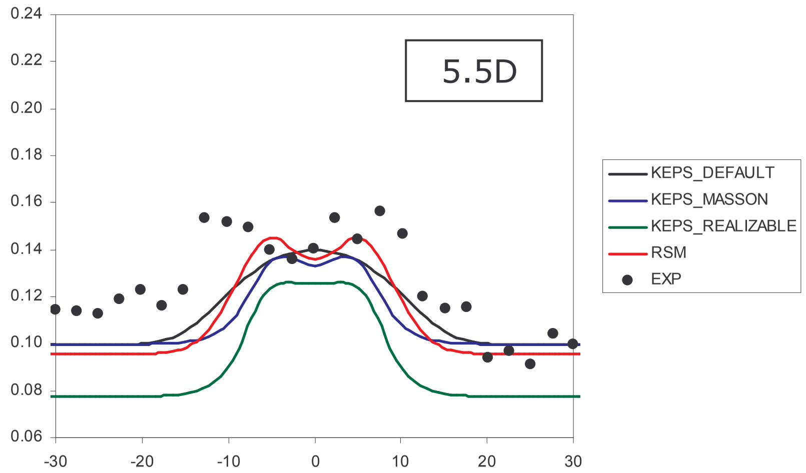
U/U_0

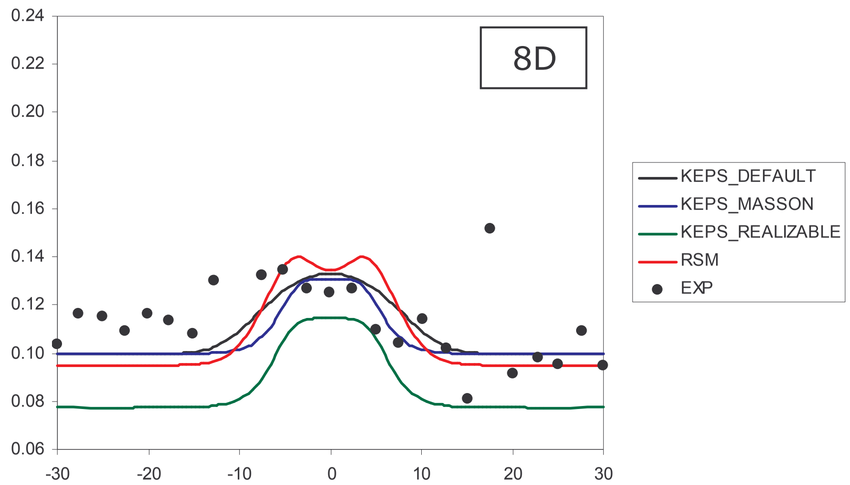




TURBULENCE INTENSITY







4. CONCLUSIONS

- **Mesh resolution** not particularly necessary to be extremely high
- Results sensitive to **turbulence model** parametrization
- Standard $k\varepsilon$ turbulence models (on stand alone WT) by default too diffusive
  - ❑ Wind speed deficit underestimated
- Suitable modifications to be done:
  - ❑ Increase local turbulent dissipation rate ε in areas of strong gradients
  - ❑ Use higher order turbulence closure
  - ❑ Decrease inflow turbulent length scale
- Anisotropic RSM: preliminar results show good agreement in comparison to isotropic models

4. FURTHER WORK

- Extend validation to:
  - Additional 1WT cases
  - WTs in a row
  - Wind farms
- Automate the creation of rotor areas
- Observe the behavour of the proposed modifications/corrections on wind farm models (wakes merging)
- Additional sensitivity analysis on:
  - Turbulence model parametrization + RSM
  - Meshing strategies for CFD wake models: refinement on shear layer
  - Influence of atmospheric stability on wake evolution
- POSTER+PAPER to be produced for the next EWEC 2009 (Marseille)

Cabezón D., Sanz J., Martí I., Crespo A., CFD modeling of the interaction between the Surface Boundary Layer and rotor wake. Comparison of results obtained with different turbulence models and mesh strategies

Avda. Ciudad de la Innovación, nº 7
31621 Sarriguren. Navarra (Spain)

Tel. +34 948 25 28 00
Fax. +34 948 27 07 74
Email. info@cener.com

www.cener.com

cener
centro nacional de energías renovables
renewable energy national centre