IEA WakeBench

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IEA Task 31
WAKEBENCH

Objectives:

1) Validate various wind farm power simulation tools in IEA Task 31 “Benchmarking of Wind Farm Flow Models”.
2) Establish guidelines for test cases; which can be used to validate and compare wind farm flow models.

IEA Task 31
WAKEBENCH – Working Groups

- WG1 Flow over flat terrain
- WG2 Flow over hills in wind tunnel
- WG3 Flow over hills in the field
- WG4 Flow in and above forest canopies
- WG5 Flow over Mountains

- WG6 WT Wakes. Theoretical verification
- WG7 WT Wakes. Wind tunnel experiments
- WG8 Small wind farms / Individual WT
- WG9 Large wind farms

IEA Task 31: WAKEBENCH – Initial benchmarks

ABL	*Models*	*Participants*	*Misc*
WG1: Flow over flat terrain 1. Monin-Obukhov Quasy-steady surface layer profiles at different stabilities 2. Leipzig Quasy-steady ABL in neutral conditions			
WG2: Flow over hills in wind tunnel 2.1 POSTECH 2D hills; Isolated 2D hills with and without flow separation 2.2 POSTECH 2D hills; Hill-hill interaction using the same hill geometries of previous			
WG3 Flow over hills in the field 3.1 Askervein 210. Isolated hill, historical reference 3.2 Askervein different wind directions 3.3 Bolund Revisit blind test simulations, now calibration is allowed			
WG4 Flow in and above forest canopies 4.1 CSIRO homogeneous forest 1D profile in and above modeled forest canopy. 4.2 CSIRO 2D Furry hill Isolated 2D hill covered by modeled forest canopy. 4.3 Bradley's roughness change Smooth <--> Rough transition in the field.			
WG5 Flow over Mountains	N.A.		

IEA Task 31: WAKEBENCH – Initial benchmarks

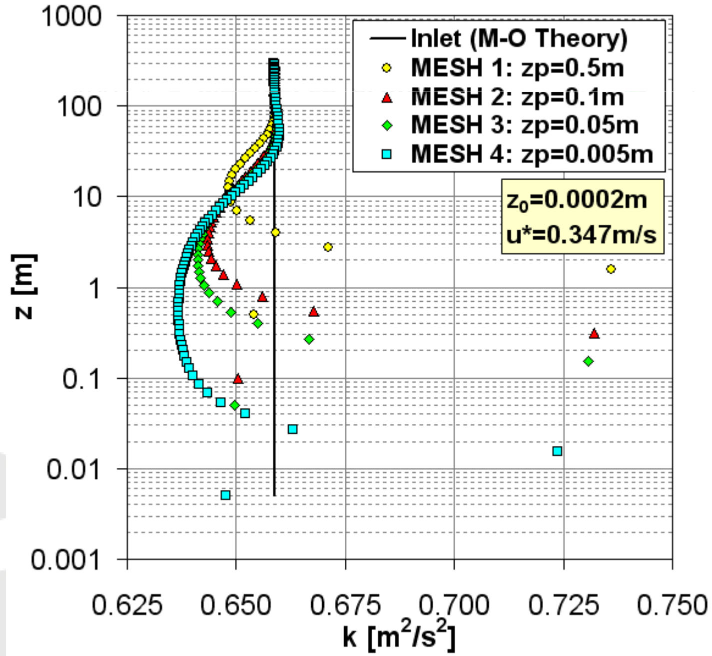
Wind turbine wakes	*Models*	*Participants*	*Misc*
WG6 WT Wakes. Theoretical verification **6.1 Theory Self-similar turbulent circular wake (possibly with swirl)** **6.2 Theory Infinite wind farm**			
WG7 WT Wakes. Wind tunnel experiments **7.1 University of Minnesota Single or multiple turbines with different stability**			
WG8 Small wind farms / Individual WT **8.1 Sexbierum Single WT in flat terrain and neutral atmosphere**	**WASP**		
WG9 Large wind farms **9.1 Lillgrund Offshore, 48x2.3MW, 3.3Dx4.3D, gap in the middle**	**FUGA**		

- Basic working group for any wind farm model since it includes the physics of the background flow
- Neutral conditions, simulation in empty domains

Surface layer: Monin-Obukhov

1km-long empty domain

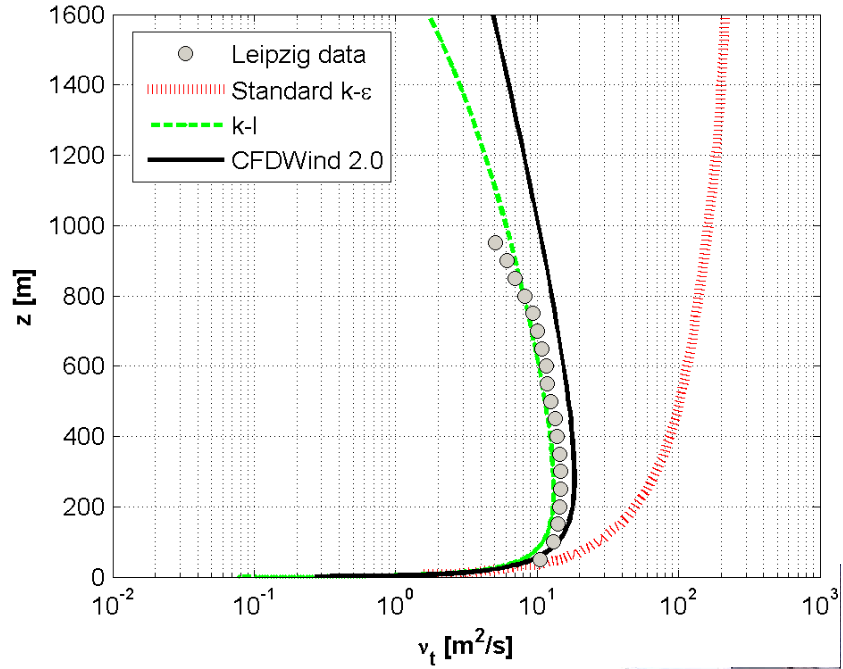
u*=0.35m, z_0=0.0002m



Atmospheric Boundary Layer

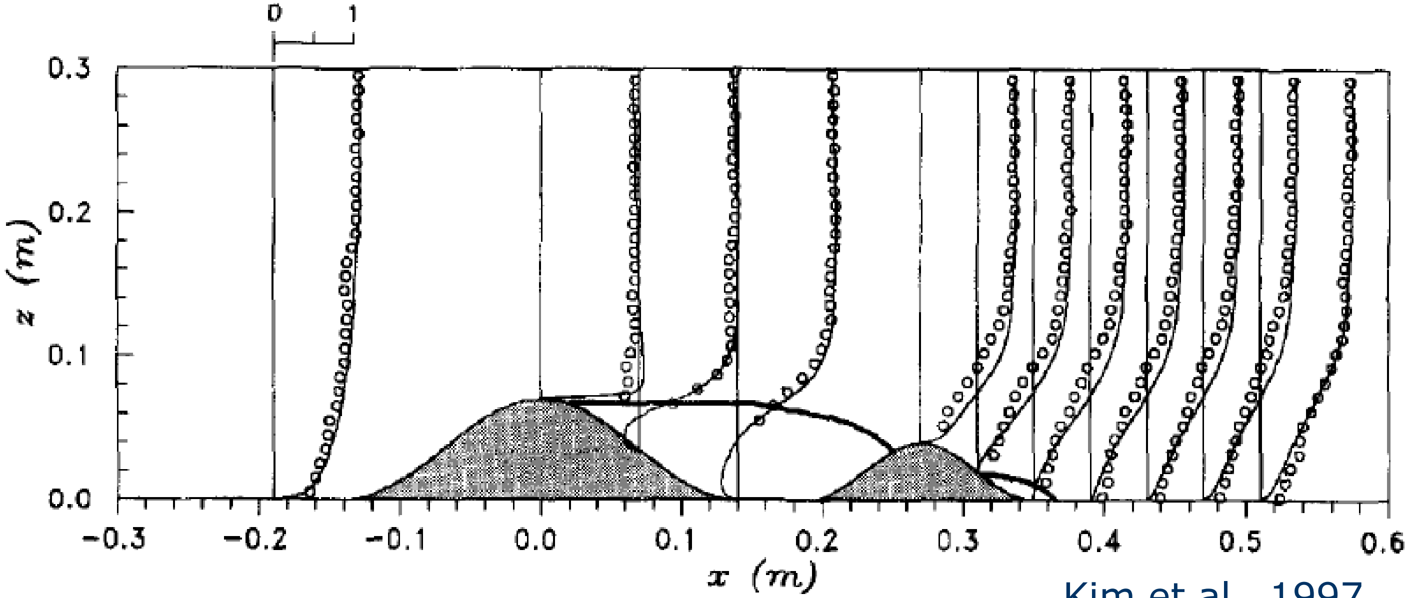
Leipzig Profile (Lettau, 1950)

u*=0.65m, z_0=0.3m, S_g=17.5ms^{-1}



WG2: Flow over hills in wind tunnel

- Basic experiments to study turbulence models
- Model validation at wind tunnel scale
- Isolated and double hills: POSTECH 2D hills in neutral conditions
  - Slopes: 0.3 and 0.5; Heights: 4 and 7 cm
  - Geometries: Isolated [S3H4, S3H7, S5H4 and S5H7]; Double hills [S3H4-S3H7, S3H7-S3H4, S5H4-S5H7 and S5H7-S5H4]
  - Mean profiles of velocity, turbulence and surface pressure

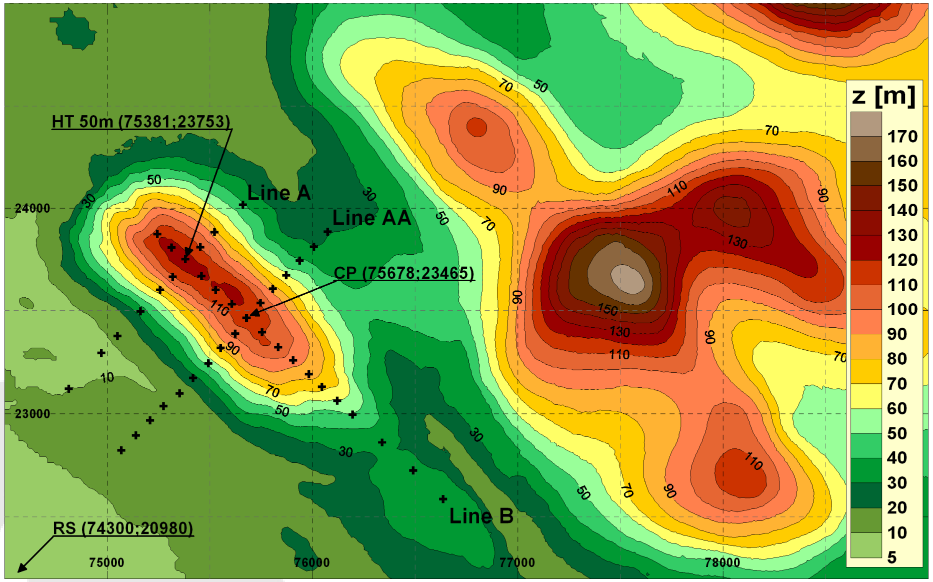


Kim et al., 1997

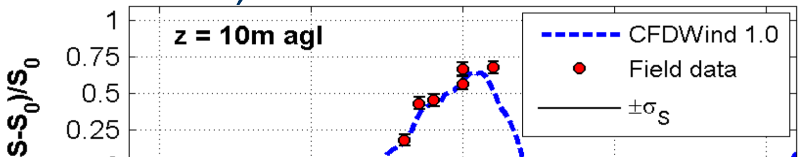
WG3: Flow over hills in the field

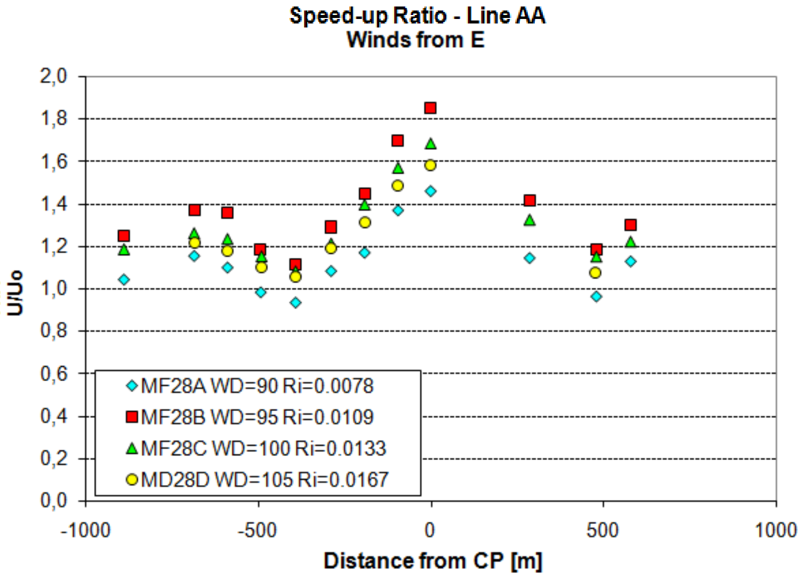
- Basic test cases for flow over hills in wind energy
- Connection with wind tunnel experiments to be developed

- Askervein (1982-83):
  - ❑ 210º case: historical reference
  - ❑ New runs: 180º, 130º, 90º
  - ❑ FSR and tke profiles



210º, Line AA

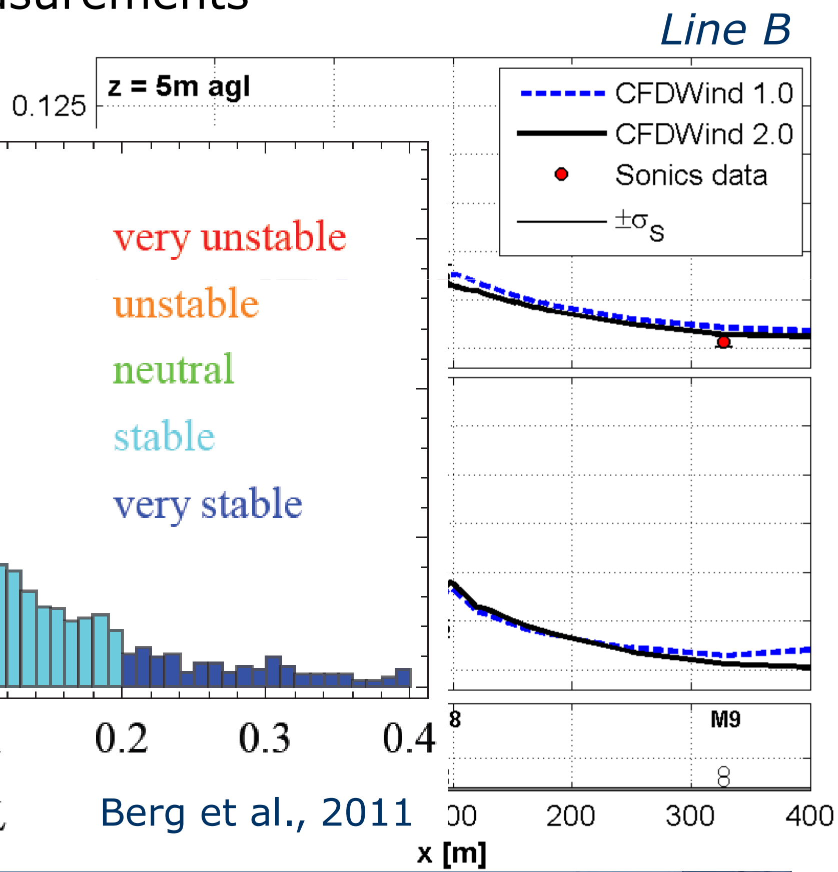


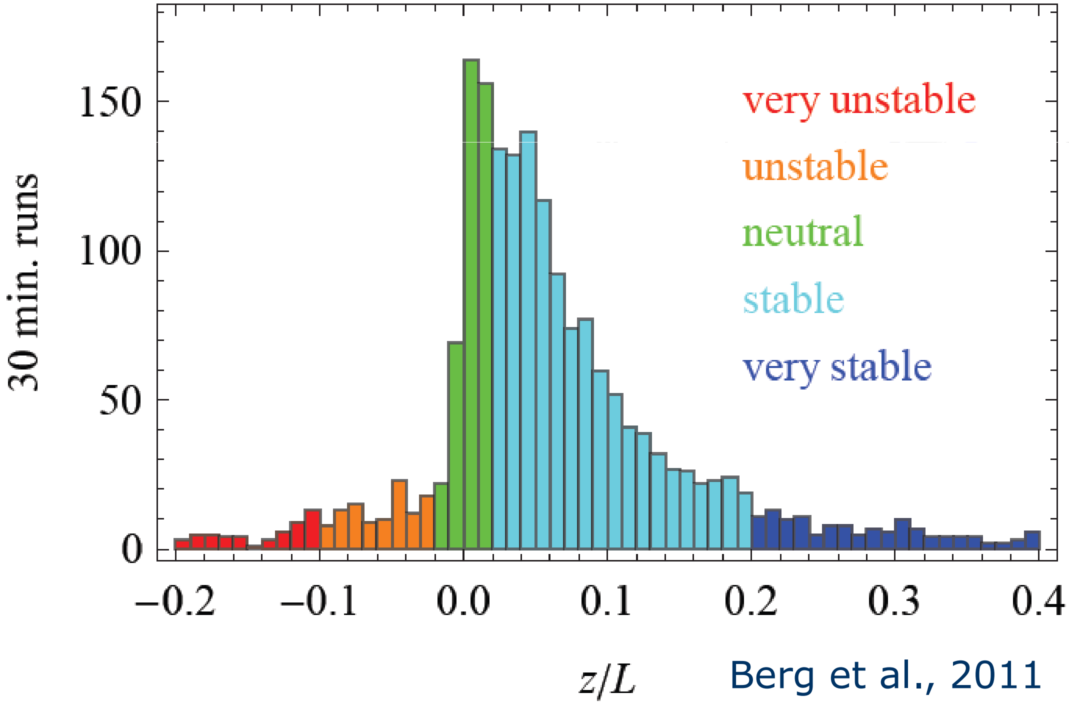


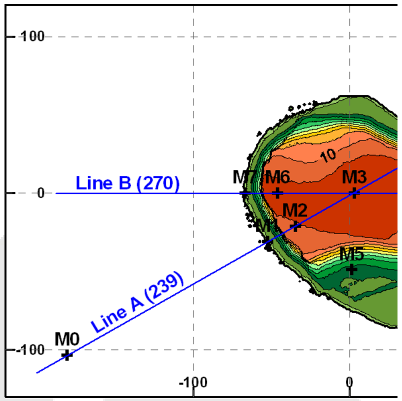
Sanz Rodrigo et al., 2011

WG3: Flow over hills in the field

- Bolund (2008): latest reference in benchmarking of flow models
  - Blind test 2009: simulations can be directly uploaded
  - Revisit the same benchmark runs but now allowing for model calibration based on available measurements
  - Stratification not that important







Berg et al., 2011

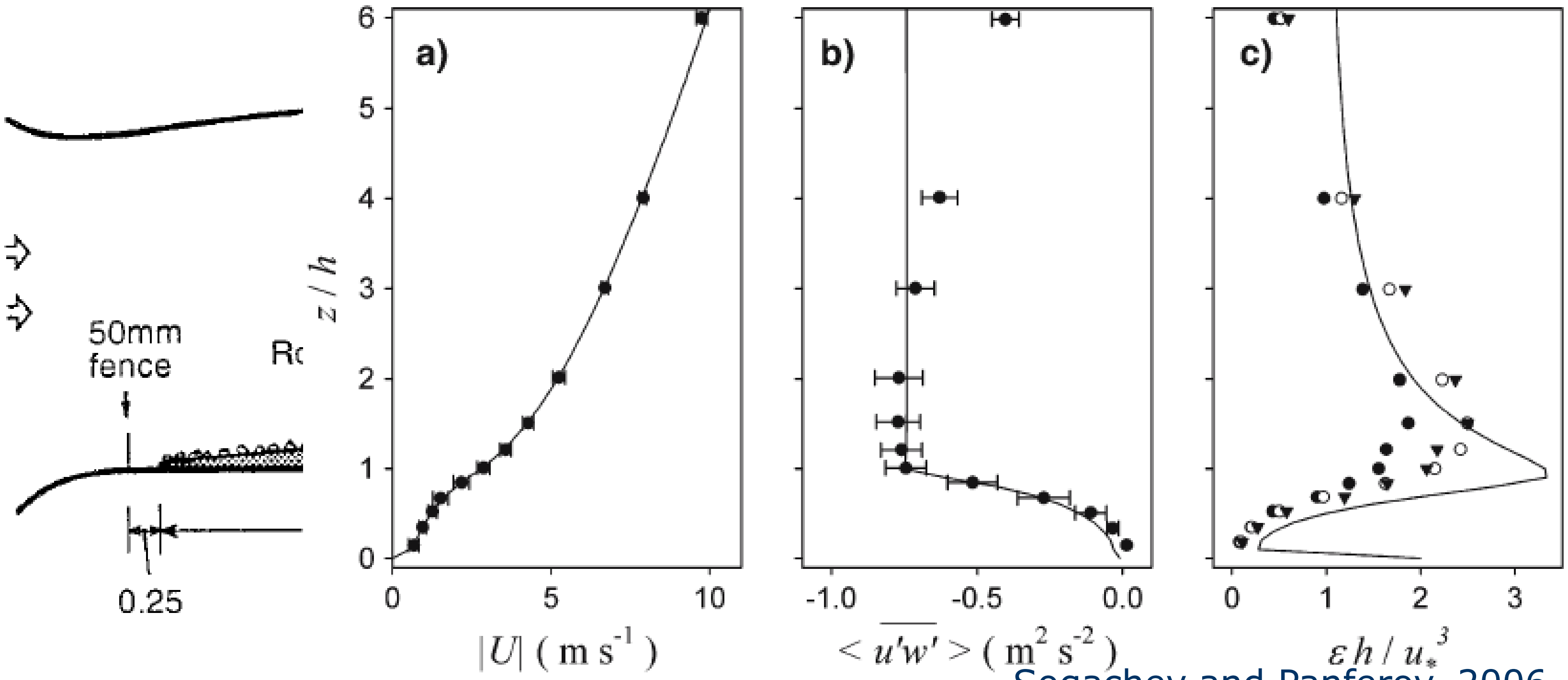
cener centro nacional de energías renovables national renewable energy centre

iea wind

WG4: Flow in and above forest canopies

- Very complex flow modeling

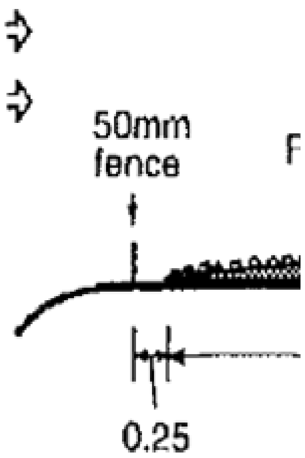
- CSIRO homogeneous wind tunnel forest
  - ❑ Waving weat crop model, h=47mm
  - ❑ 1D profiles (infinite forest) of velocity and turbulence

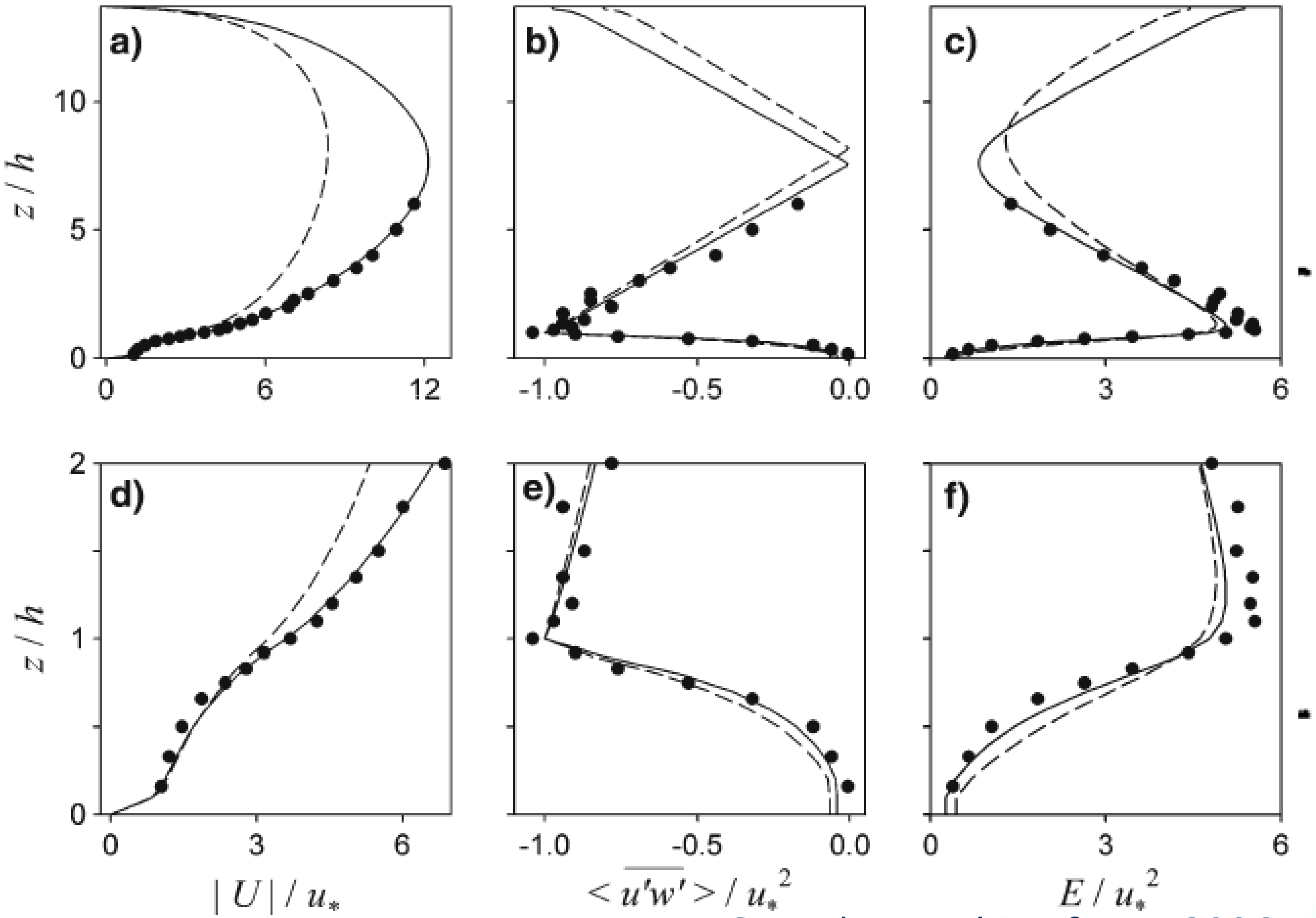


Sogachev and Panferov, 2006

WG4: Flow in and above forest canopies

- Isolated hill covered by forest: Furry Hill (CSIRO)
  - Hill: H=0.15m, L=0.42m
  - Canc
  - Mear

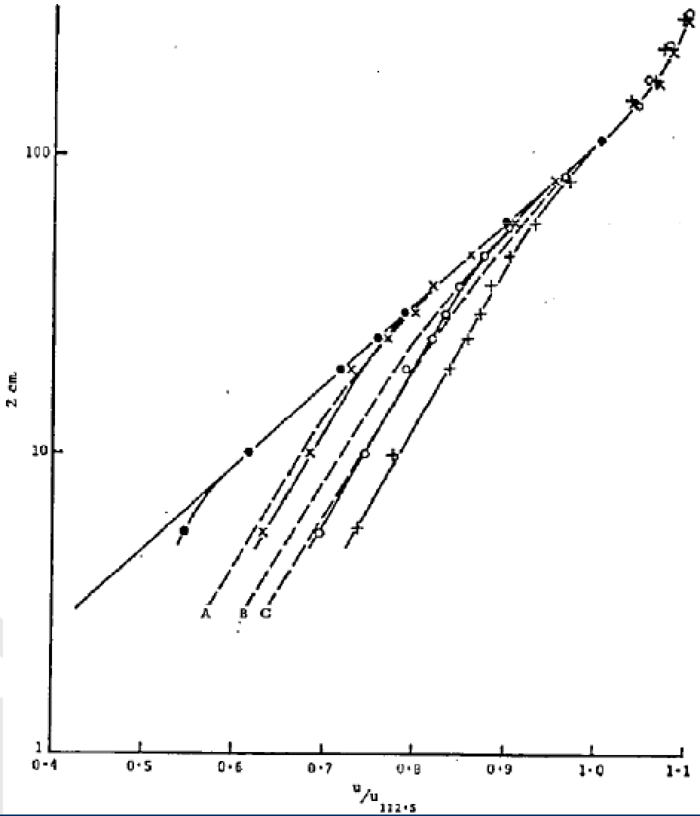


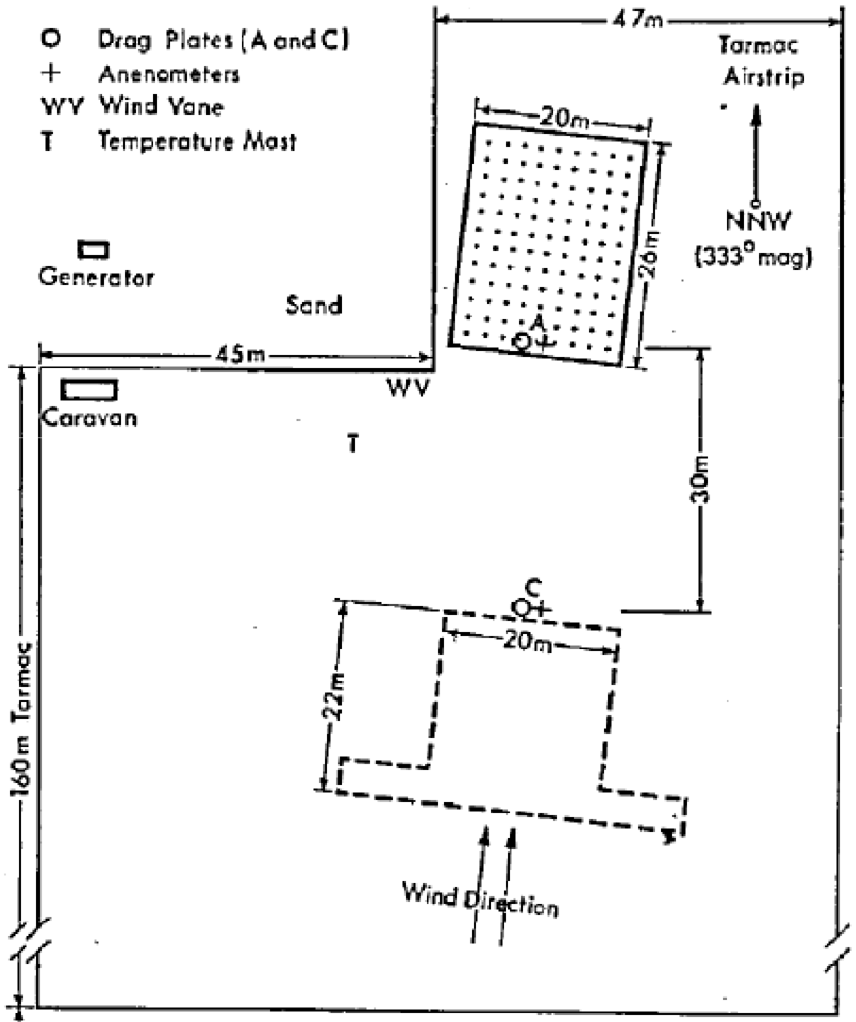


Sogachev and Panferov, 2006

WG4: Flow in and above forest canopies

- Bradley's roughness change (1964)
  - ❑ z0=0.002cm ←→ z0=0.25cm
  - ❑ Surface shear stress and velocity profiles up to 3m





WG 6 – Theoretical Test Cases

Self similar axisymmetric wake (9/23)

- Does wake model follow trends with downstream distance?
- $Width \sim x^{\frac{1}{3}} \quad \Delta u \sim x^{-(\frac{2}{3})}$

Infinite wind farm (8/23)

- Number of rows 1→∞
- At what row does velocity/power deficit asymptote

Other Suggestion

- Self Similar Turbulent swirling wake

Suggested Test Cases for First 6 months

WG-6 Theoretical

- Self similar axisymmetric wake (possibly with swirl)
  - Does wake model follow trends with downstream distance?
  - $Width \sim x^{\frac{1}{3}} \quad \Delta u \sim x^{-(\frac{2}{3})}$
- Infinite wind farm
  - Number of rows 1→∞
  - At what row does velocity/power deficit asymptote

WG-7 Wind Tunnel Tests

University of Minnesota (9/23)

Johns Hopkins (9/23)

University of Orleans and Surrey (8/23)

Chalmers University (6/23)

Other Suggestions

- Wyoming swirling wake
- NREL Phase IV
- MEXICO
- Portland State wind tunnel
- WAUDIT wind turbine wake experiments

Suggested Test Cases for First 6 months

WG-7 Wind tunnel

- University of Minnesota (Chammaro et al. 2009)
- Scale rotating turbines
- Variable atmospheric stability
- Flat terrain

WG-8 - Single Wakes & Small Farms

ECN Wieringermeer Test Wind Farm (EWTW) (10/23)

NREL TWICS (10/23)

Nibe (8/23)

Sexbierum (8/23)

ECN Scale Wind Farm (ESWF) (8/23)

MOD-2 Medicine Bow (5/23)

Other Suggestions

- Risø Nordtank
- Risø NM80
- Generic Model Comparison

Suggested Test Cases for First 6 months

WG-8 Individual and Small Wind Farms

EWTW and TWICS most popular, but may be IP issues

Sexbierum

- Onshore flat terrain, Neutral ABL
- Wakes of one or two 300kW tubrines
- 30m diameter, 35 hub height
- Masts at -2.8D, 2.5D, 5D and 8D

Generic model development

- Tuning of important properties, relative to known cases at different scales
- Sensitivity to turbine properties
- Identify bias from “real” configurations – relative model comparison just

WG-9 Large Wind Farms

Egmond aan Zee (12/23)
Lillgrund (12/23)
Nysted (11/23)
Horns Rev (10/23)
CWEX 11/12 (10/23)
UpWind Complex Terrain (9/23)
Middlegrunden (9/23)
Vindeby (9/23)
San Gorgonio (5/23)
Other Suggestion

- UpWind Complex Terrain 2

Suggested Test Cases

WG- 9 Large Wind Farms

- Lillgrund (Dhalberg and Thor 2009)
  - Offshore
  - 1 met tower
  - 48x2.3 MW Siemens machines
  - Close spacing
- Possible delay for IP clearance (true for all large farms)
- Or use scaled generic model instead