# Downscaling of Wind Resources From Mesoscale Tendencies with URANS

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# The NEWA Model-Chain

✓ **Blending of mesoscale and microscal models**
✓ **Systematically validated** with high-fidelity experiments over a range of conditions
✓ **Uncertainty quantification**

**@mesoscale**

➢ NEWA database of wind resource characteristics
➢ 30-year WRF down to 3 km resolution
 + downscaling to 100 m using WAsP
 (generalized wind methodology)
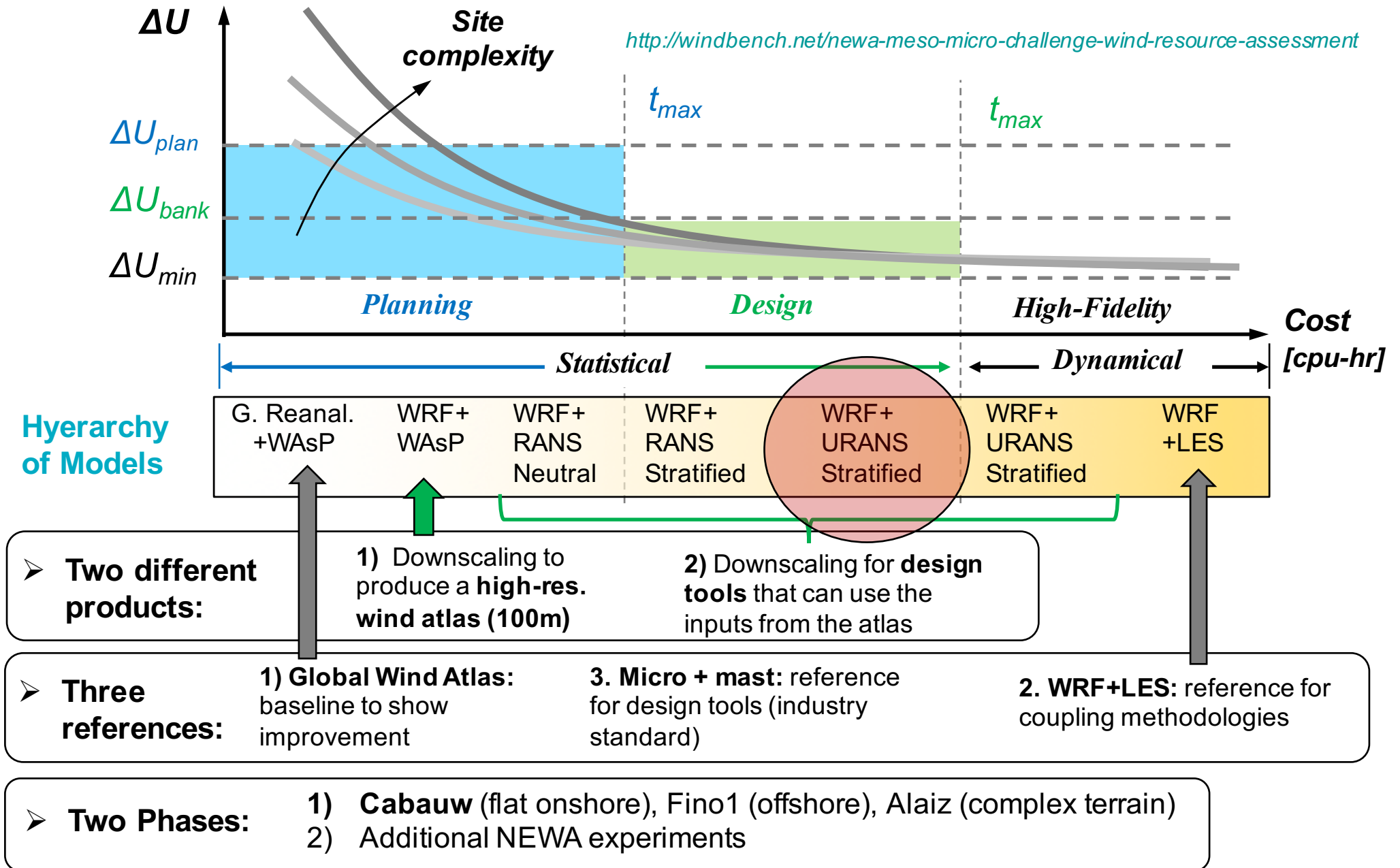➢ Mesoscale multiphysics ensemble (UQ)

**@microscale**

➢ Design tools based on CFD (RANS or LES)
➢ Driven by (mesoscale) wind atlas inputs
➢ Include diurnal-cycle thermal stratification
➢ Surface-layer characterization based on aerial lidar scans of vegetation canopy
➢ **Open source** model built on OpenFOAM (NEWAfoam)

http://www.neweuropeanwindatlas.eu/
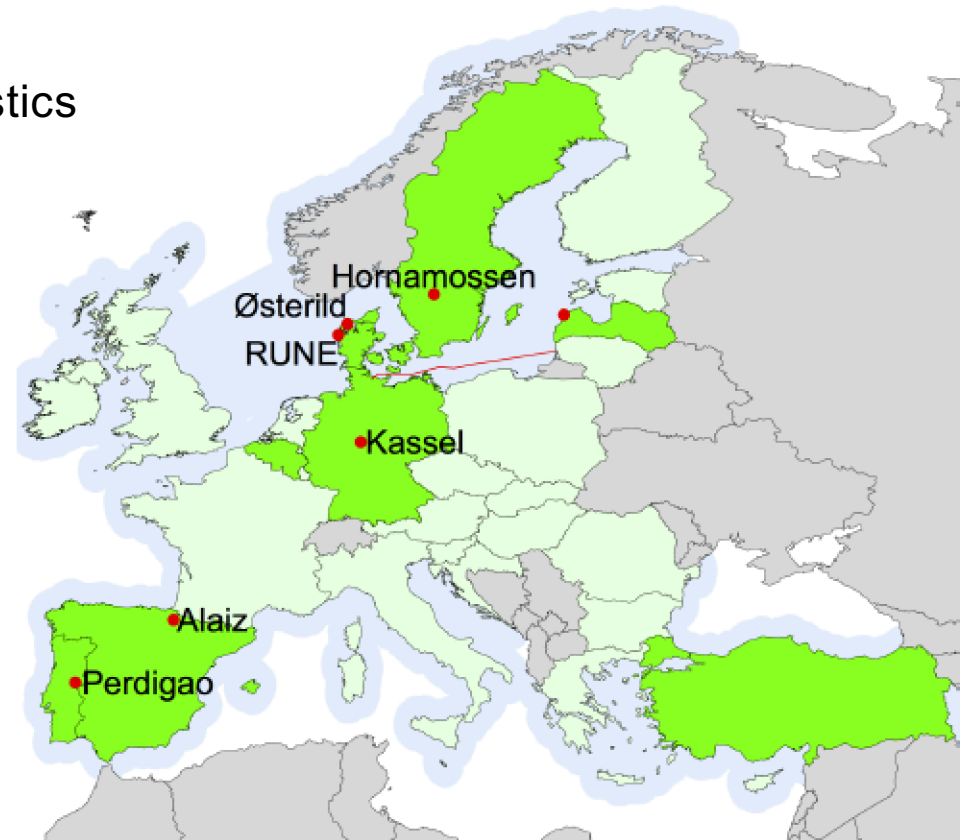
# NEWA Meso-Micro Challenge

➢ Determine the applicability range of meso-micro methods for the NEWA validation domain



*http://windbench.net/newa-meso-micro-challenge-wind-resource-assessment*

➢ **Two different products:**

1) Downscaling to produce a **high-res. wind atlas (100m)**

2) Downscaling for **design tools** that can use the inputs from the atlas

➢ **Three references:**

1) **Global Wind Atlas:** baseline to show improvement

3. **Micro + mast:** reference for design tools (industry standard)

2. **WRF+LES:** reference for coupling methodologies

➢ **Two Phases:**

1) **Cabauw** (flat onshore), Fino1 (offshore), Alaiz (complex terrain)
2) Additional NEWA experiments

# Design of the ABL model for Wind Energy applications

➢ Add 1$^{st}$-order physics to the flow model
  ▪ Turbulence closure through a modified k-eps as proposed by Sogachev et al. 2012
  ▪ Thermal stratification through energy eq.
  ▪ Transient model
  ▪ Inspired in Bass et al. 2010, instead of Idealized forcing, Sanz-Rodrigo et al. 2014 proposed to include large-scale "**tendencies**"

➢ Avoid adding physical complexity if this is not justified by improved performance
  ▪ No humidity equation
  ▪ No heat transfer by radiation or phase changes
  ▪ No land-surface modeling

➢ Make best use of onsite measurements to calibrate the model
  ▪ **Nudging at microscale** using typical wind energy measurements

• *Bass P, Bosveld FC, Lenderink G, van Meijgaard E and Holtslag AAM . Q J R Meteorol Soc (2010) 136 671-684*
• *Sanz-Rodrigo et al. J. Physics Conf. Ser. (2014) 753.*
• *Sogachev A, Kelly MC, Leclerc MY. (2012) Bound. Layer Meteorol ;145(2):307-327*

# Momentum Budget at Mesoscale: "Tendencies"

$$\frac{1}{f_c}\frac{\partial U}{\partial t} = -\frac{1}{f_c}\left(U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} + W\frac{\partial U}{\partial z}\right) + V - V_g - \frac{1}{f_c}\frac{\partial \overline{u'w'}}{\partial z}$$

$$\frac{1}{f_c}\frac{\partial V}{\partial t} = -\frac{1}{f_c}\left(U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} + W\frac{\partial V}{\partial z}\right) - U + U_g - \frac{1}{f_c}\frac{\partial \overline{v'w'}}{\partial z}$$

Tendency | Advection | Coriolis | Horizontal Pressure Gradient | Turbulence

$$U_{tend} \approx U_{adv} + U_{cor} + U_{pg} + U_{pbl}$$

Coriolis parameter:

$$f_c = 2\Omega\sin\phi$$

*Sanz-Rodrigo J, Matthew Churchfield, and Branko Kosovic. Wind Energ. Sci.(2017), 2, 35-54*

# SCM with Large-Scale Tendencies and Data Assimilation

- **Mesoscale forcing**
- Solved at microscale
- **Data assimilation at microscale**

$$\frac{1}{f_c}\frac{\partial U}{\partial t} = U_{adv} + V + U_{pg} - \frac{1}{f_c}\frac{\partial \overline{uw}}{\partial z} + U_{nud}$$

$$\frac{1}{f_c}\frac{\partial V}{\partial t} = V_{adv} - U + V_{pg} - \frac{1}{f_c}\frac{\partial \overline{vw}}{\partial z} + V_{nud}$$

$$\frac{\partial \Theta}{\partial t} = \Theta_{adv} - \frac{\partial \overline{w\theta}}{\partial z} + \Theta_{nud}$$

$$\delta_{nud} = \frac{\omega_z}{f_c}\frac{(\delta_{obs} - \delta)}{\tau_{nud}}$$

$\tau_{nud}$ = 10min : 1hr
$\omega$ = 1 within measurements

- M-O at the surface based on mesoscale inputs

$$\Theta_2 = \Theta_0 + \frac{\theta^*}{\kappa}\left[\lg\left(\frac{2}{z_{0t}}\right) + \Psi_h\left(\frac{2}{L_0}\right)\right]; \quad \theta^* = -\frac{\overline{w'\theta'}}{u^*}$$

*Sanz-Rodrigo J, Matthew Churchfield, and Branko Kosovic. Wind Energ. Sci.(2017), 2, 35-54*

# GABLS 3 (GEWEX Atmospheric Boundary Layer Studies)

- Stationary synoptic
- Clear skies
- No fog
- Substantial LLJ
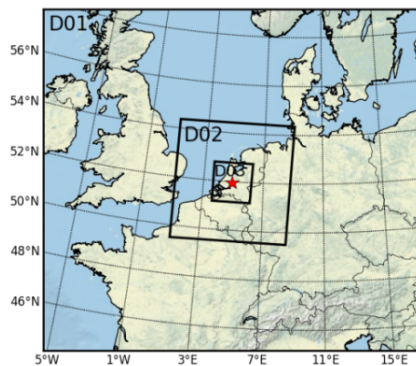- 6 years → 9 days →
  night of 1–2 July 2006

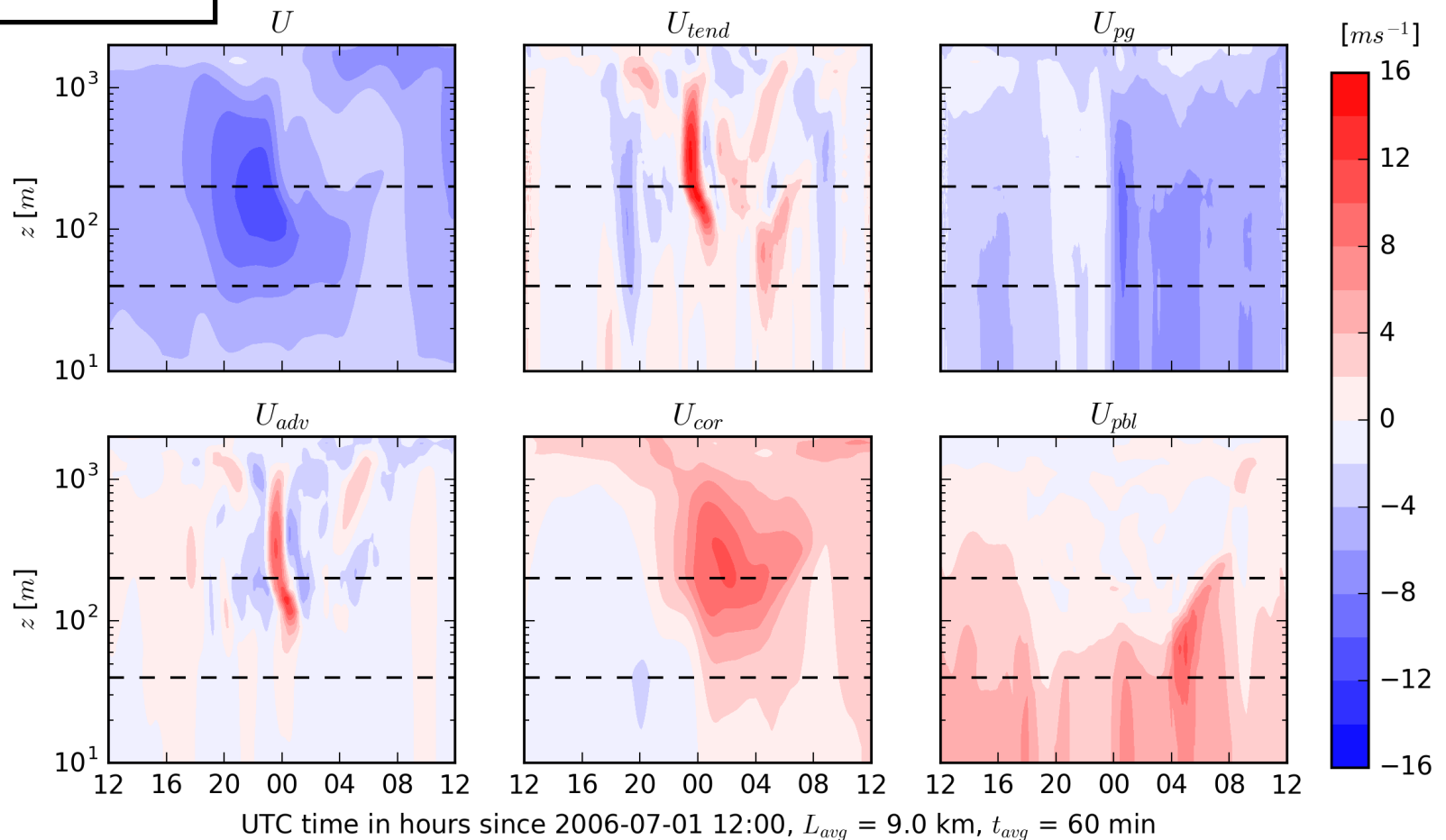Credit: Panoramio ©
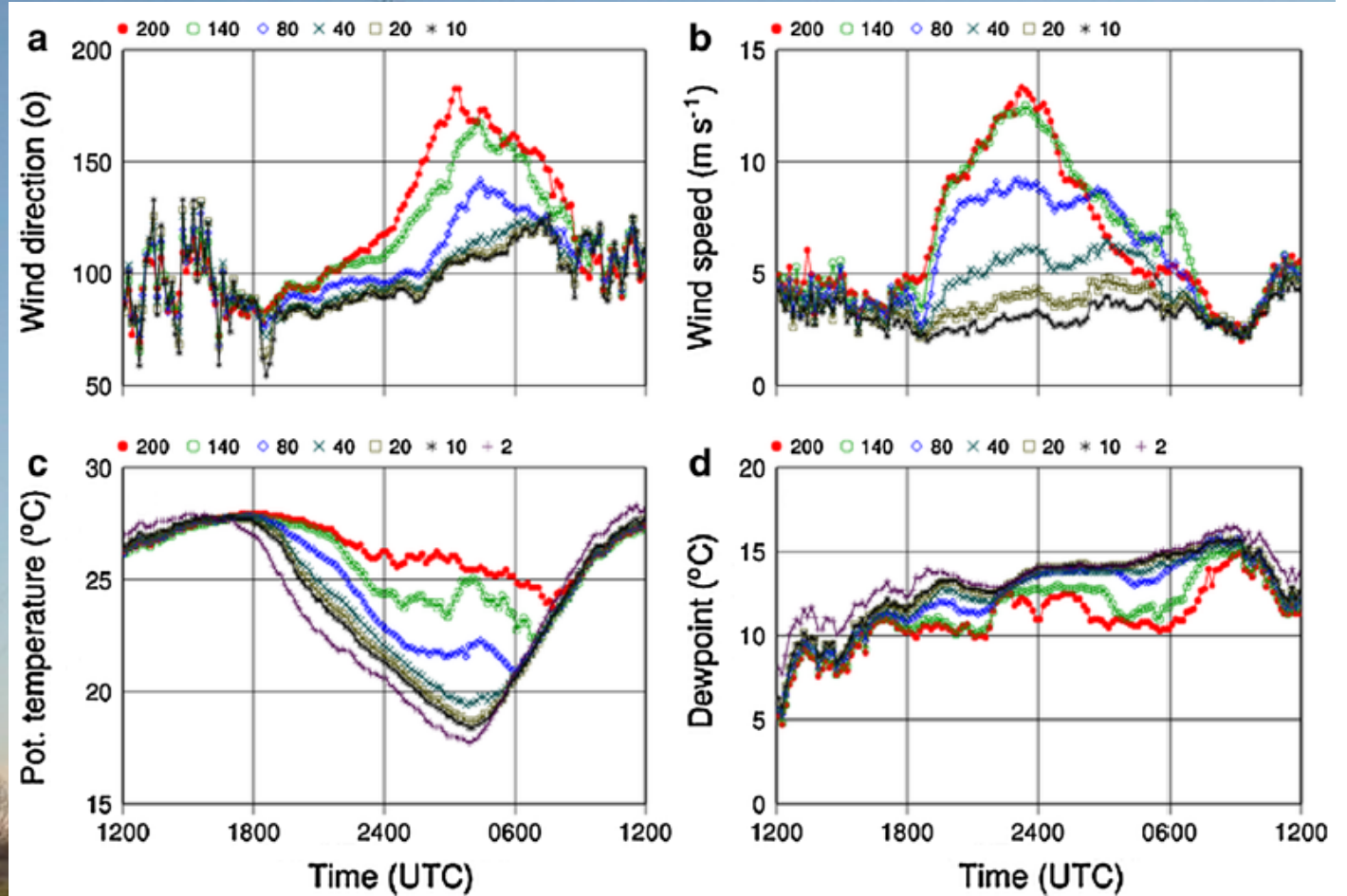
# Mesoscale Tendencies from WRF during GABLS3

**WRF-YSU**
- ERA Interim
- 9 > 3 > 1 km
- 24 hr spin-up
- Tendencies from d02 (3 km)
- $L_{av}$ = 3x3 = 9 km
- $t_{av}$ = 60 min (rolling average)

$$U_{tend} \approx U_{adv} + U_{cor} + U_{pg} + U_{pbl}$$

D = 160 m
$z_{hub}$ = 120 m



UTC time in hours since 2006-07-01 12:00, $L_{avg}$ = 9.0 km, $t_{avg}$ = 60 min

# GABLS3 Benchmark revisited for Wind Energy ABL models

**Table 1:** Summary of model simulations. Monin-Obukhov similarity theory (MOST) surface boundary conditions use either heat flux ($H$), 2-m ($T_2$) or skin temperature ($T_{SK}$) from WRF

| Name | Input | Turbulence | $z$-Levels | Surface B.C. |
|---|---|---|---|---|
| WRF-YSU (ref) | ERA Interim | YSU | 46 | Noah |
| WRF | ERA Interim, GFS | MYJ, MYNN, QNSE, TEMF, YSU | 46 | Noah |
| WRF-YSU_LES | ERA Interim | LES-TKE | 101 | Noah |
| WRF-VentosM_ke | ERA Interim | YSU/$k$-$\varepsilon$ | 70 | MOST, $H$ |
| CFDWind1D_ke | WRF (ref) | $k$-$\varepsilon$ | 301 | MOST, $T_2$ |
| Alya-CFDWind1D_ke | WRF (ref) | $k$-$\varepsilon$ | 500 | MOST, $T_2$ |
| Ellipsys1D_ke | WRF (ref) | $k$-$\varepsilon$ | 512 | MOST, $T_{SK}$ |
| Ellipsys3D_ke | WRF (ref) | $k$-$\varepsilon$ | 192 | MOST, $T_{SK}$ |
| Ellipsys3D_LES | WRF (ref) | Smagorinsky | 128 | MOST, $T_{SK}$ |
| SP-Wind_LES | WRF (ref) | LES-TKE | 500 | MOST, $T_2$ |

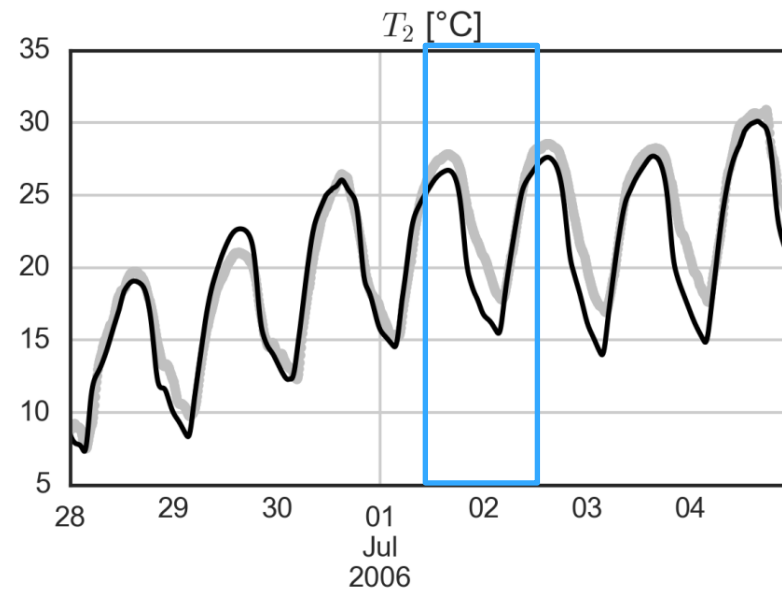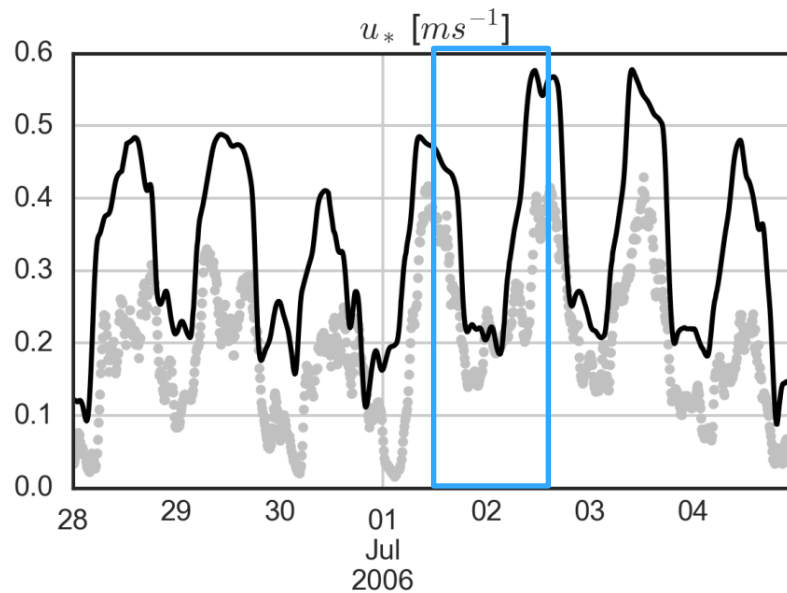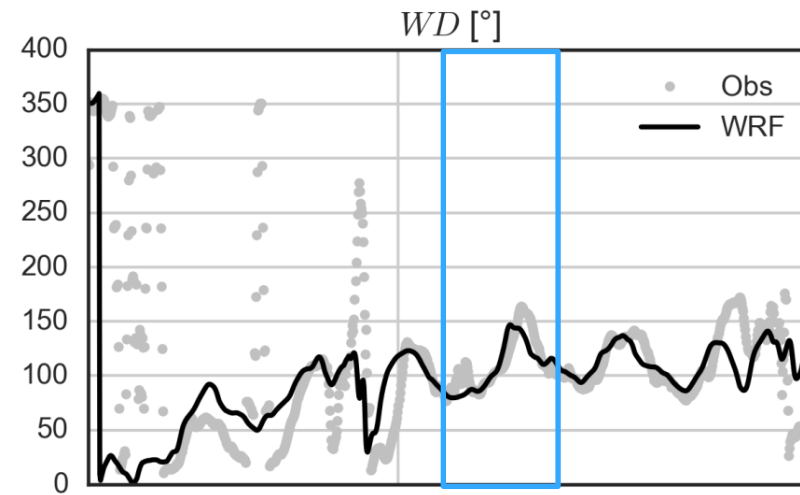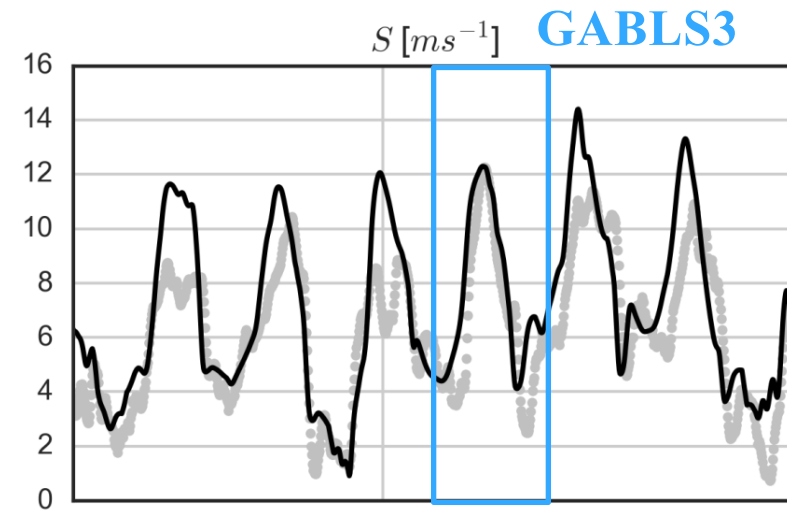- A fare agreement among all models with the implementation of the tendencies.

Almost all RANS models in the benchmark are based on the modified k-eps proposed by Sogachev et al. 2012

- *Sanz Rodrigo J, et al. (2017). J. Phys: Conf. Ser. 854 012037*
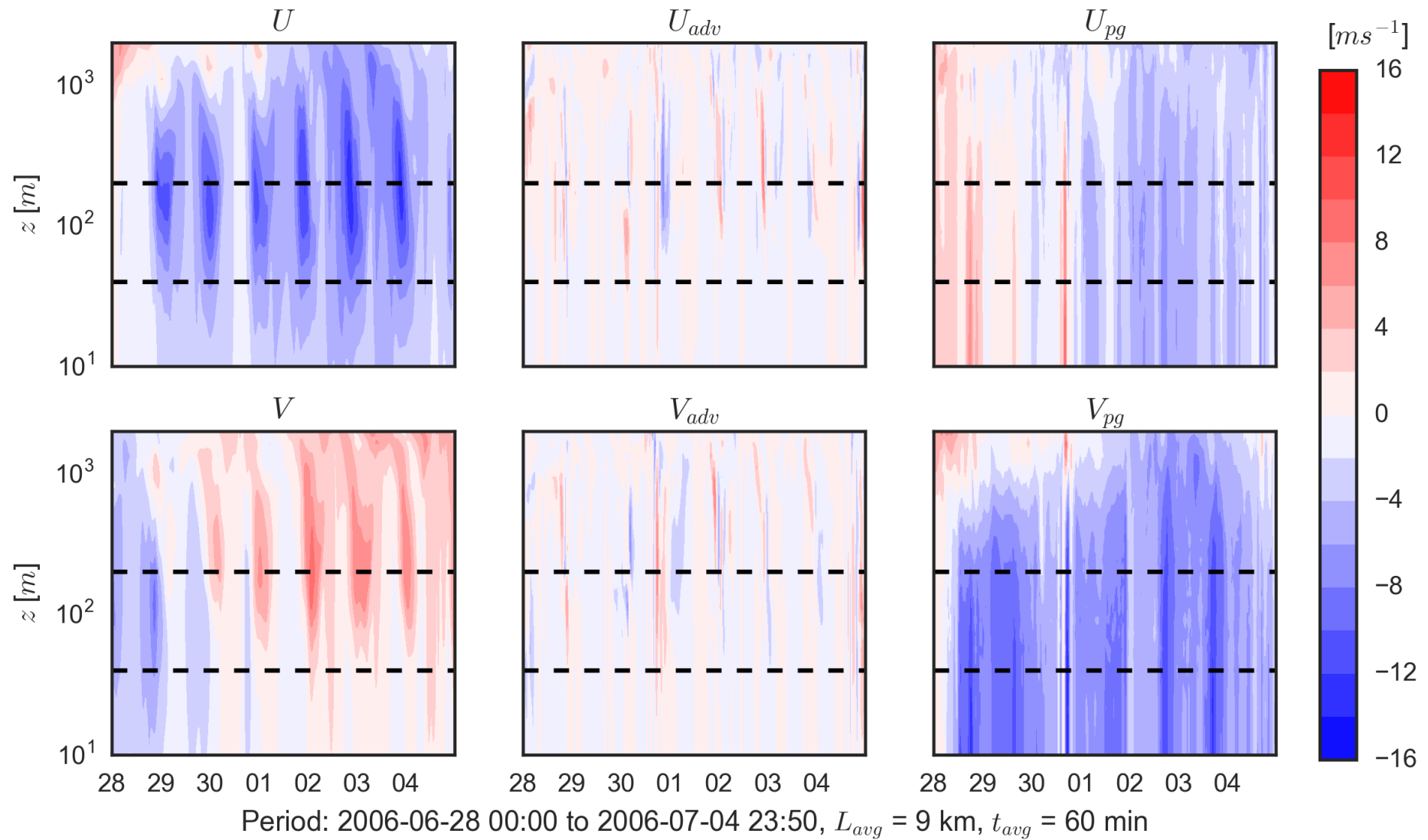- *Sogachev A, Kelly MC, Leclerc MY. (2012) Bound. Layer Meteorol ;145(2):307-327*
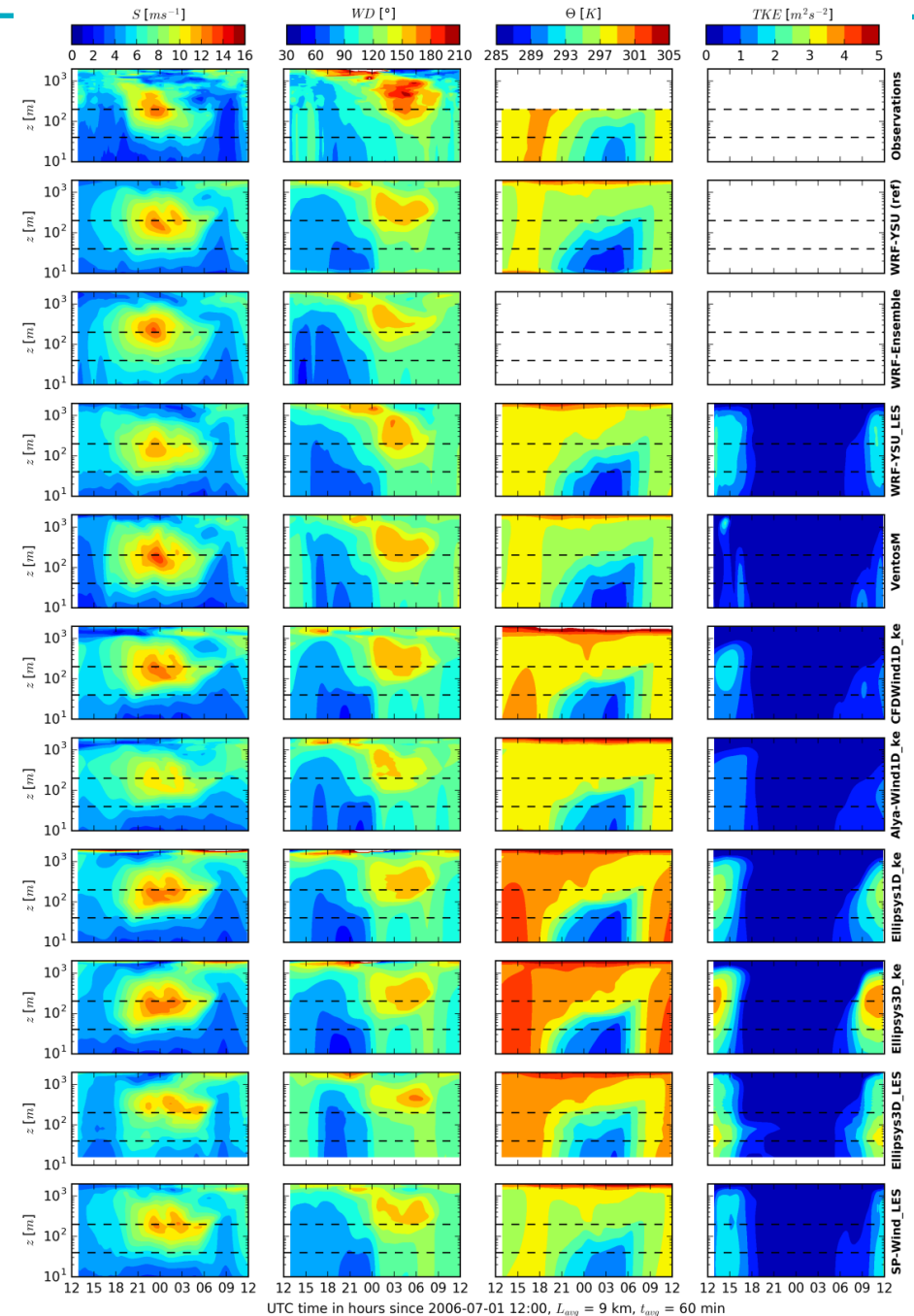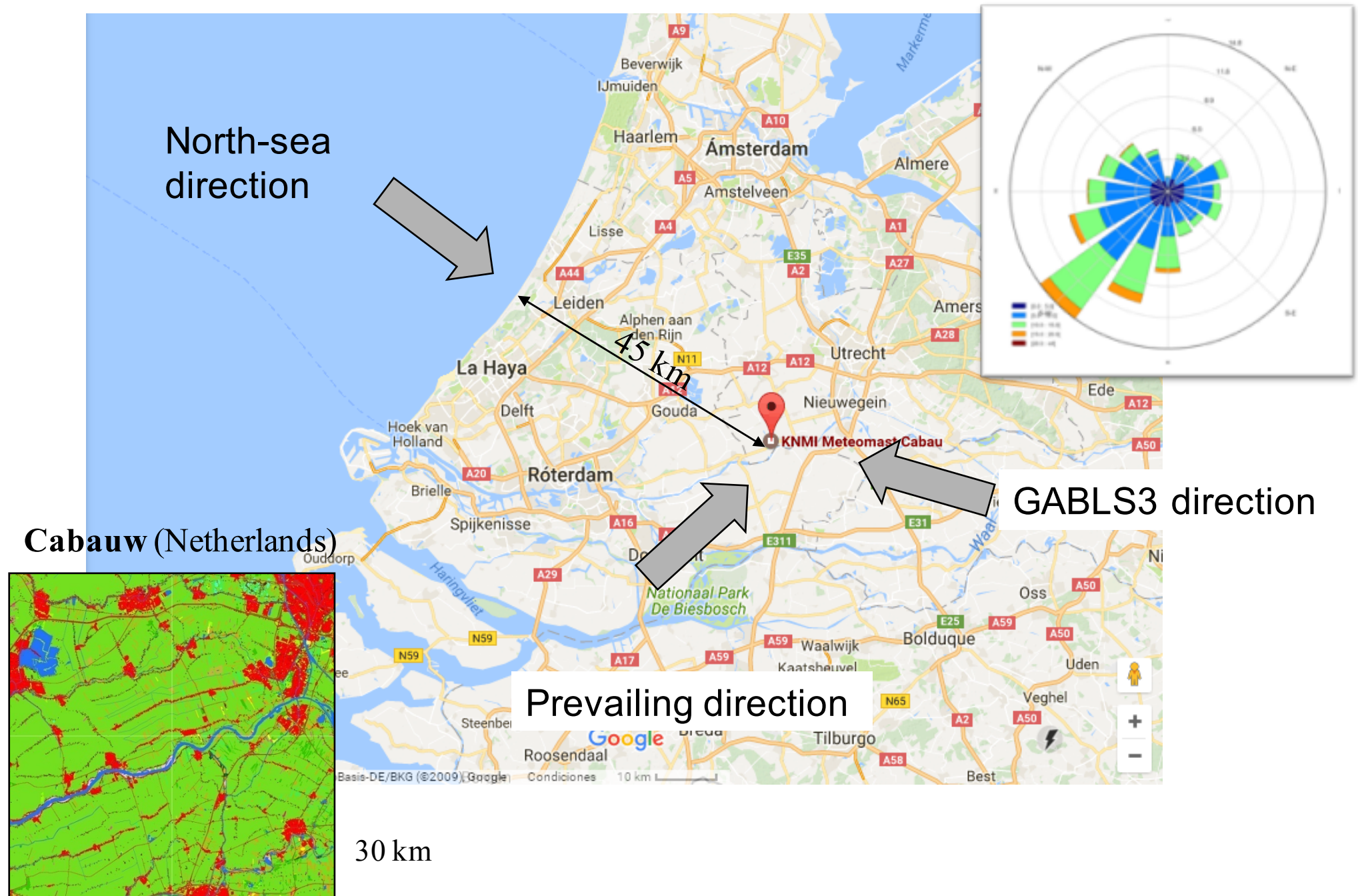
# A typical week: GABLS3 direction

Period: 2006-06-28 00:00 to 2006-07-04 23:50, $L_{avg}$ = 9 km, $t_{avg}$ = 60 min

# Cabauw year 2006: From flow case to wind climate characterization



North-sea direction

GABLS3 direction

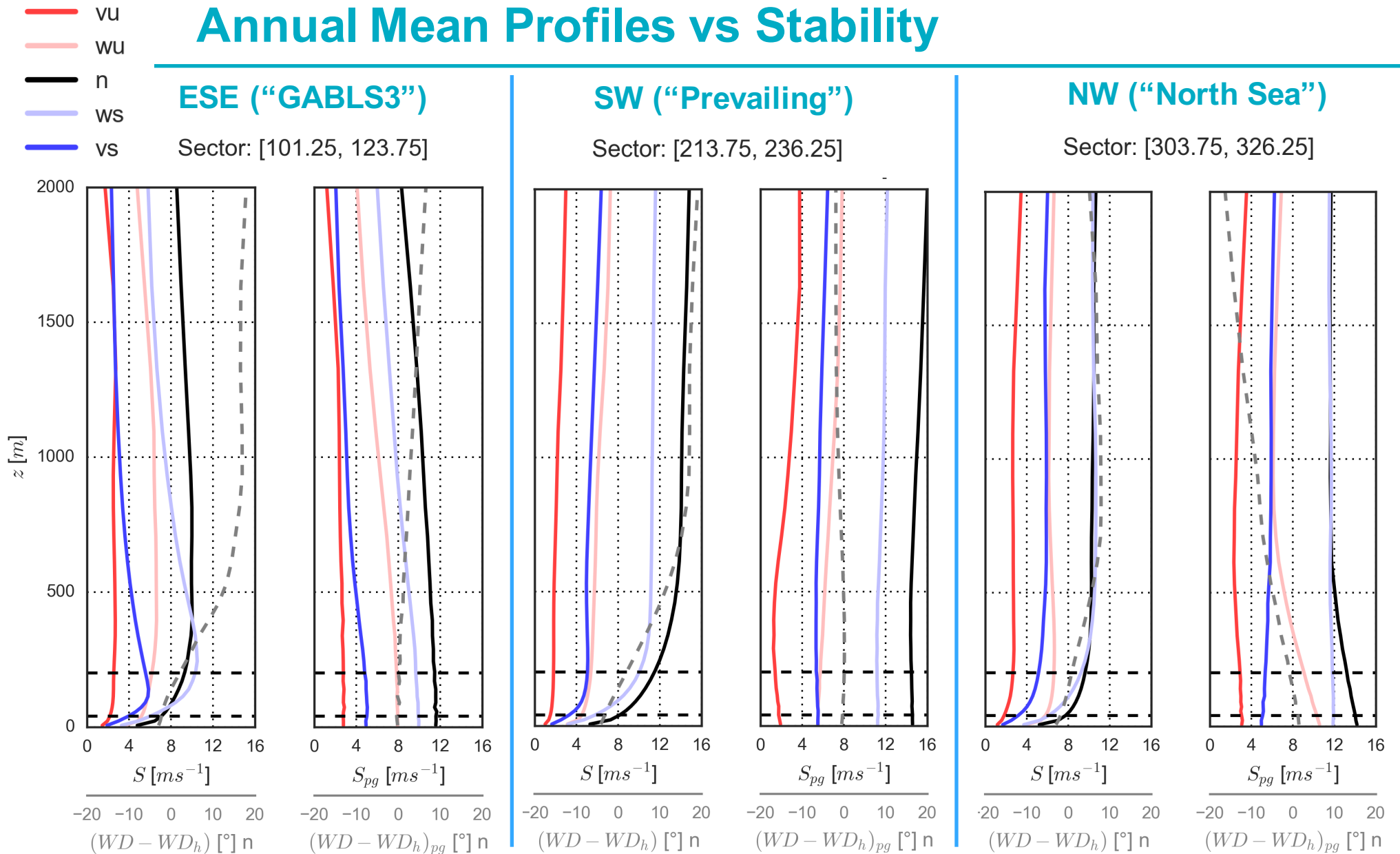Cabauw (Netherlands)

Prevailing direction

45 km

30 km

# Wind Climate Classification: the common approach

Based on *z/L* at 10 m & velocity @ 140m  *(classification as used in Sanz-Rodrigo et al. 2014)*
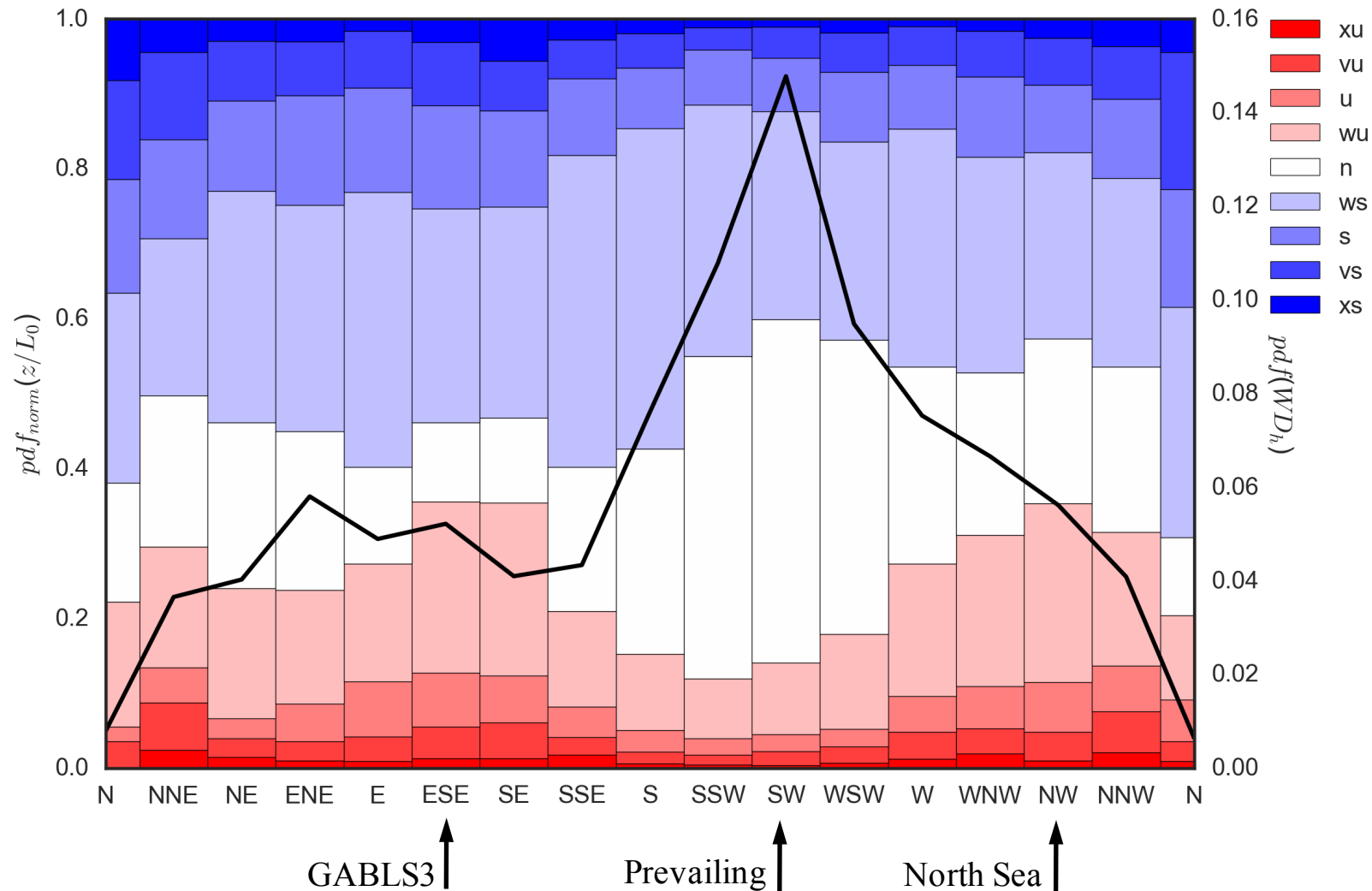
# Annual Mean Profiles vs Stability

- As expected, mesoscale pressure gradient significantly change with direction.
- Its value changes significantly with stability and height.
- Therefore, it can provide important information missed by the microscale.

# Sector-wise Annual Mean Diurnal Cycle

➤ However, bining has several drawbacks
- We should be able to produce pseudo-stationary profiles consistent with the bined tendencies
- Loss of time-dependent information from previous cycles

➤ Alternative to binning by stability (steady approach) to retain diurnal cycle dynamics (unsteady approach)
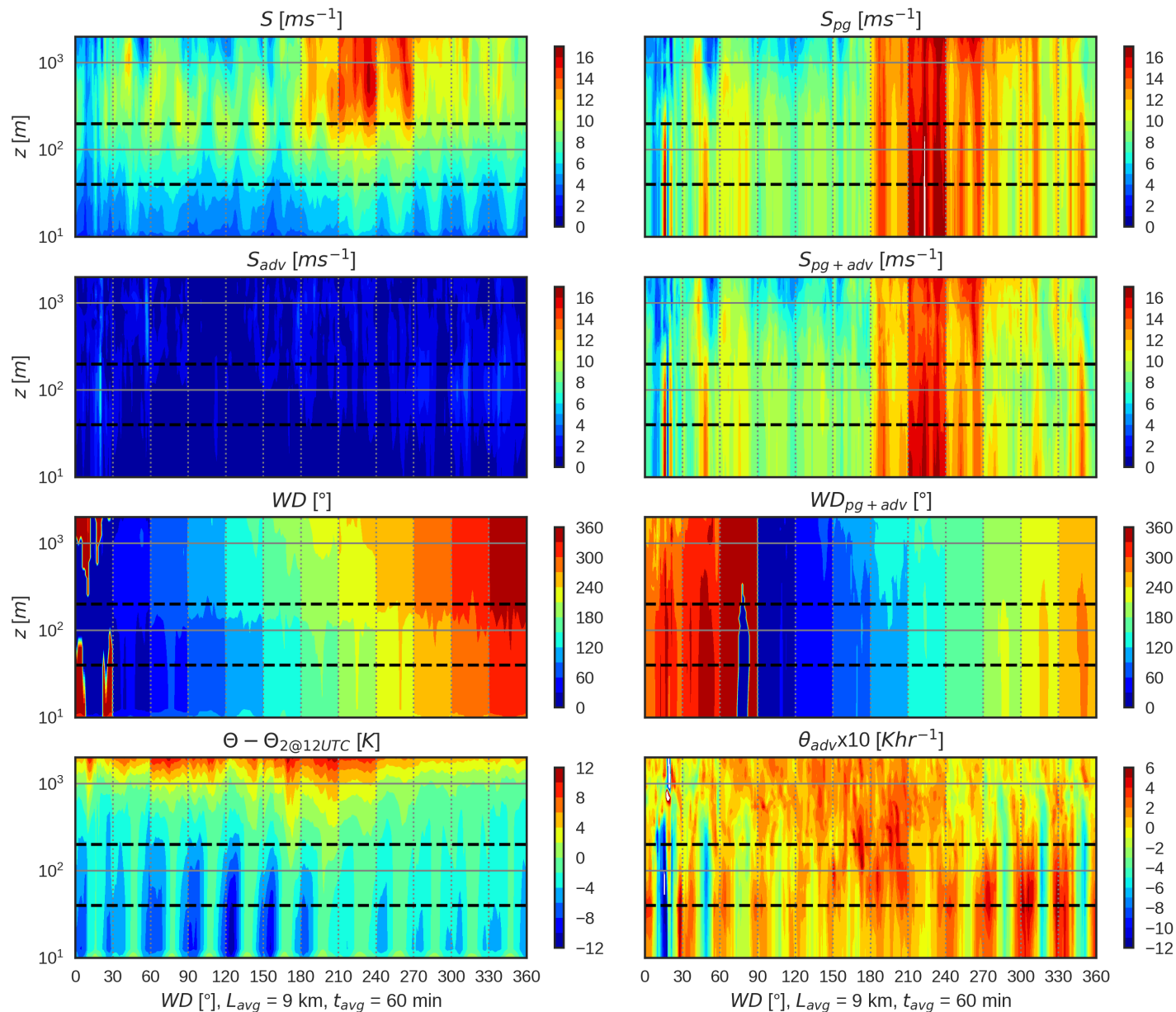


$z_{ref}$ = 140 m

30º bins

$S_{140}$ > 4 m/s

T = 12x24 = 288 h
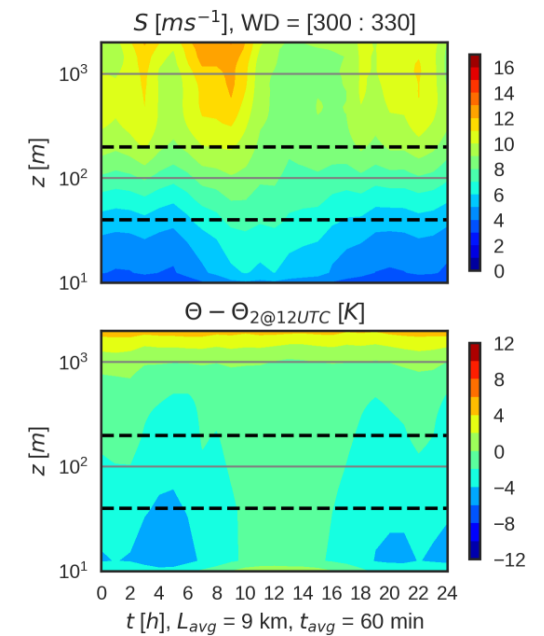
# Sector-wise Annual Mean Diurnal Cycle
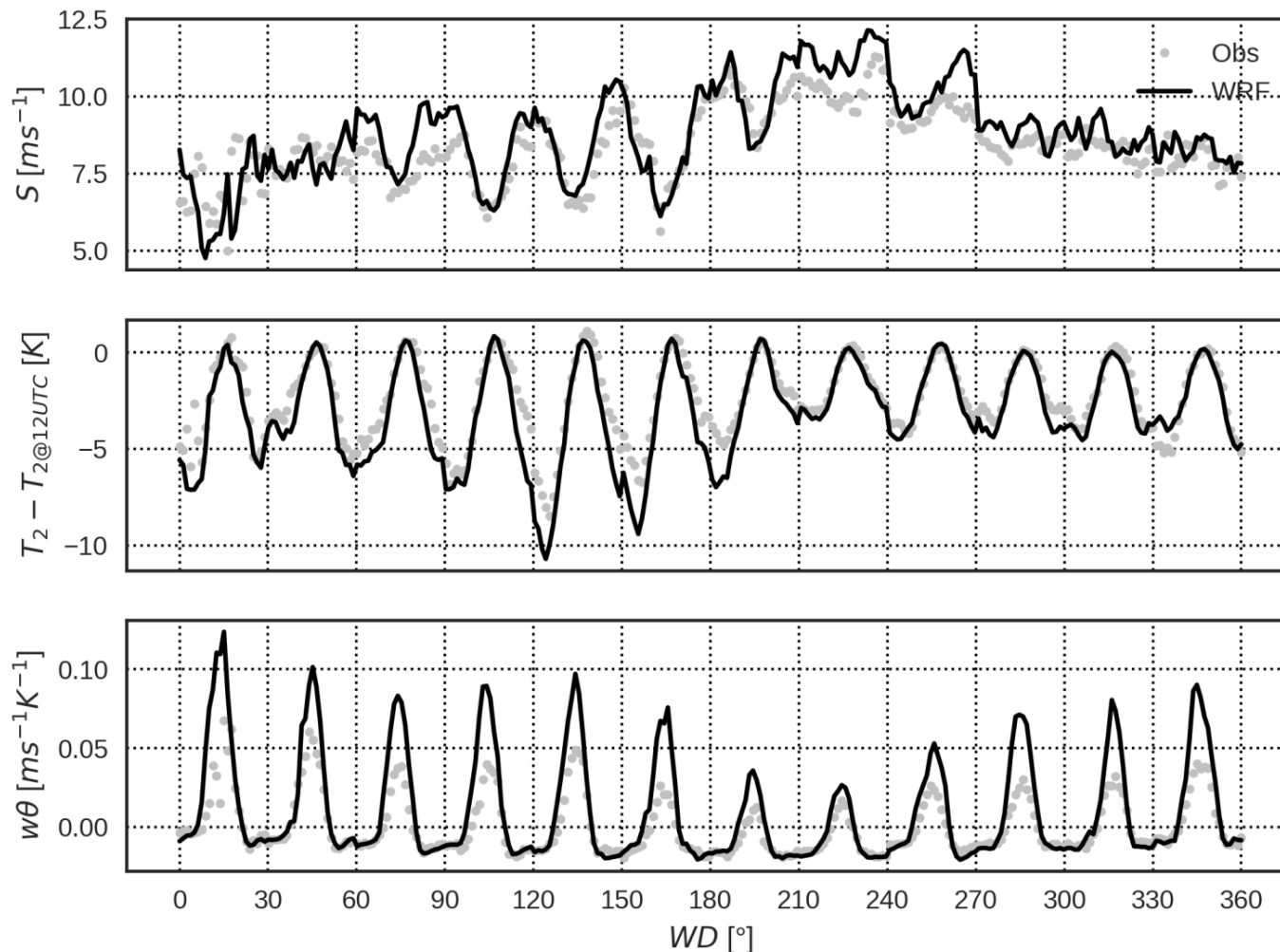


$z_{ref} = 140$ m
30° bins
$S_{140} > 4$ m/s

"North Sea"

# Conclusions & Outlook

So far…

Under NEWA framework a :

- Meso-micro offline coupling method verified with GABLS3
- Methodology for annual wind resources based on 1D sector-wise mean diurnal cycles now under development for the "NEWA Meso-Micro Challenge"

Outstanding Challenges

- From statistics to "suitable" model forcings (smoothing, nudging, etc)
- 3D methodology for complex terrain: nesting 3D tendencies and boundary conditions
- Optimization of 360 cycle using surrogate model and other statistical methods
- $k\text{-}\varepsilon$ model of Sogachev et al. (2012) seems to require a calibration ($l_{max}$ in complex terrain, etc)

# Acknowledgements

This work has been produced with support from the following projects:

- ***MesoWake***, European Comission FP7-PEOPLE-2013-IOF, 624562, http://www.windbench.net/mesowake-2014-2017
- ***NEWA***, European Comission FP7-ENERGY-2013.10.1.2, 618122, http://www.neweuropeanwindatlas.eu/; MINECO, Spain, PCIN-2014-011-C07-02
- ***IEA Task 31 Wakebench Phase 2***, International Energy Agency
- **PRACE-MesoWake**, PRACE 13th Call, MareNostrum, Barcelona
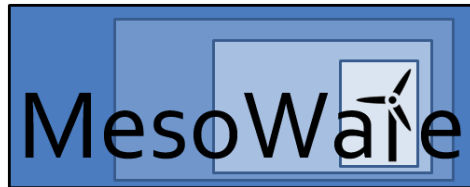
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