Optimization of the MYNN PBL scheme for wind resource assessment based on comparisons to mast and UAV measurements

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Motivation

- An accurate and reliable estimation of turbulence, shear and veer is necessary for the prediction of wind energy production and loads on wind turbines.
- The upper tip height of offshore wind turbines is in the order of 150 m and thus exceeds the height of currently existing measurement masts (e.g. FINO1: 103 m).
- Mesoscale model simulations can be a convenient tool to gain information on the wind conditions at these heights.

Mesoscale Simulation

We use the meso-scale model **WRF** [1] for the simulation of the lower atmosphere above the North Sea. Fifteen simulations of one year using the combination of three different reanalyses (**CFSR**, **ERA-Interim**, **MERRA**) and five PBL-schemes (**ACM2**, **MYJ**, **MYNN**, **QNSE**, **YSU**) were carried out. Comparisons to the offshore metmast **FINO1** showed best results for the combination of ERA-Interim data and the MYNN PBL-scheme:

Bias [m/s]	ERA	MERRA	CFSR
ACM2	-0.17	-0.45	-0.31
MYJ	-0.01	-0.18	-0.08
MYNN	0.05	-0.18	-0.11
QNSE	0.05	-0.14	-0.10
YSU	0.00	-0.26	-0.18

RMSE [m/s]	ERA	MERRA	CFSR
ACM2	1.51	1.63	1.60
MYJ	1.49	1.57	1.53
MYNN	1.46	1.62	1.55
QNSE	1.52	1.66	1.61
YSU	1.53	1.65	1.61

Table 1: Bias (left) and RMSE (right) of the wind speed compared to a sonic anemometer at 80 m.

Foreman and Emeis [2] showed that by the adaption of closure constants the calculation of TKE can be improved.

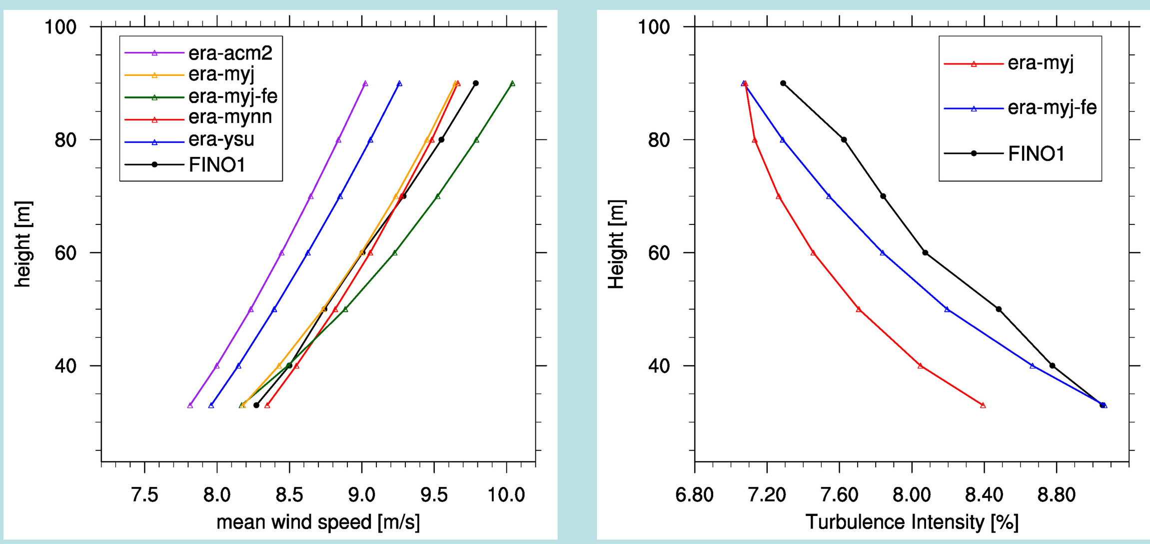

Figure 1 : Mean wind and TI profiles for stable conditions at FINO1 in 2007

However the improvement was limited to situations with stable stratification.

Governing Equations in MYNN

The parameterization of turbulent fluxes in the Mellor-Yamada model uses several constants.

Velocity:

$$\frac{D}{DT}U + \frac{\partial}{\partial z}\langle uw\rangle = -\frac{1}{\rho}\frac{\partial P}{\partial x} + fV$$

Turbulent kinetic energy (TKE):

$$\frac{D}{DT}\left(\frac{q^2}{2}\right) - \frac{\partial}{\partial z}\left[LqS_q\frac{\partial}{\partial z}\left(\frac{q^2}{2}\right)\right] = -\langle uw\rangle\frac{\partial U}{\partial z} - \langle vw\rangle\frac{\partial V}{\partial z} - \frac{q^3}{B_1 L}$$

Covariance u and w:

$$\langle uw\rangle = 3\frac{A_1 L}{q}\left[-\left(\langle w^2\rangle - C_1 q^2\right)\frac{\partial U}{\partial z} + (1-C_2)\beta g\langle u\theta_v\rangle\right]$$

Turbulent quantities are parameterized using constant factors and a stability dependent length scale L:

$$\frac{1}{L} = \frac{1}{L_S} + \frac{1}{L_T} + \frac{1}{L_B}$$

$$L_S = \begin{cases} \kappa z/3.7, & \zeta \geq 1 \\ \kappa z/(1+2.7\zeta), & 0 \leq \zeta < 1 \\ \kappa z(1-100\zeta)^{0.2}, & \zeta < 0 \end{cases}$$

$$L_T = \alpha_1 \int_0^\infty qz\,dz \Big/ \int_0^\infty q\,dz$$

$$L_B = \begin{cases} \alpha_2 q/N, & \frac{\partial\Theta}{\partial z} > 0, \zeta \geq 0 \\ \frac{\left[\alpha_2 q + \alpha_3 q (q_c/L_T N)^{1/2}\right]}{N}, & \frac{\partial\Theta}{\partial z} > 0, \zeta < 0 \\ \infty, & \frac{\partial\Theta}{\partial z} \leq 0 \end{cases}$$

LES Simulation

For the validation of constants a set of large-eddy simulations with different atmospheric situations were used. The simulations were performed with the LES model PALM [3].

The dissipation term in the equation for the TKE can be used to get the length scale from the LES:

$$\epsilon = \frac{q^3}{B_1 L} \quad \Rightarrow \quad B_1 = \frac{q^3}{\epsilon L}$$

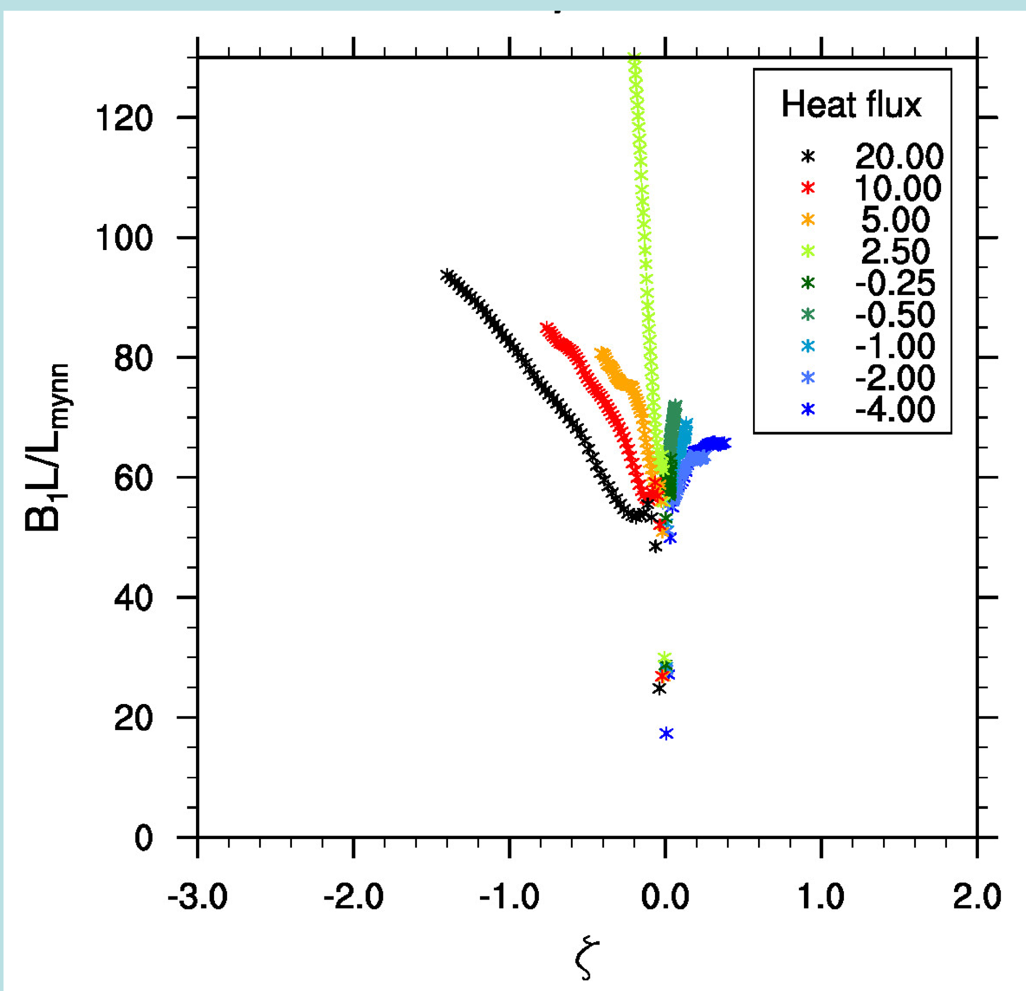

Figure 2 : Closure constant B_1 computed with L

However if B_1 is determined using L computed according to the MYNN scheme, it turns out that B_1 is not a constant but remains a function of ζ ($= z/L_M$, L_M: Monin-Obukhov Length).

A change of the constants that are used for the computation of L can lead to a considerably more constant behaviour of B_1:

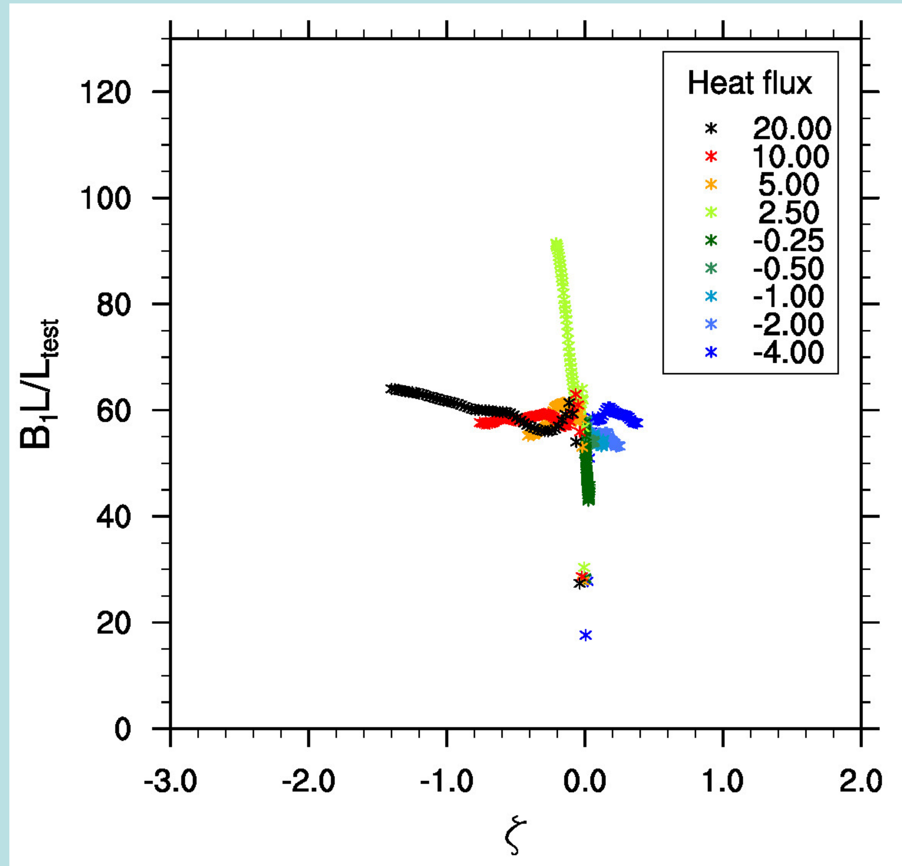

Figure 3 : Closure constant B_1 computed with an adapted L

Outlook

Within the project OWEA-Loads the working group Environmental Physics of Universität Tübingen performed measurements with an unmanned aerial vehicle (UAV) at the island Helgoland.

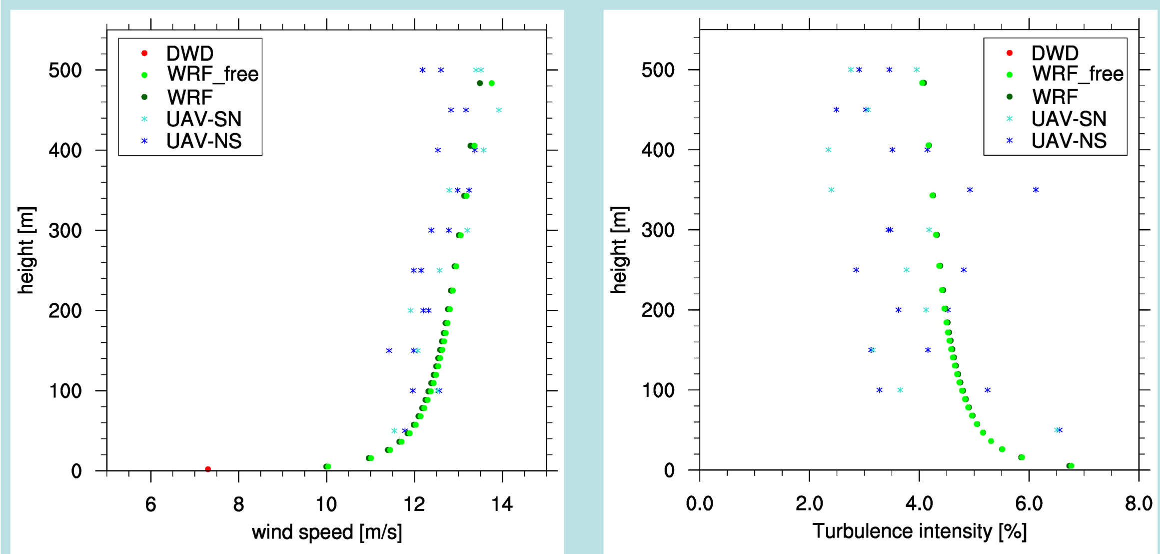

Figure 4 : Comparison of a WRF simulation to UAV measurements at Helgoland

These measurements provide valuable data for the verification of the simulations also above 100 m.

Conclusion

- The choice of constants can considerably improve the calculation of turbulence in mesoscale models.
- Further results indicate that a choice of generic constants is difficult. Thus more dependencies on stability and also roughness length in the formulation of the PBL-scheme might be necessary.

Literature

1. W. C. Skamarock, J. B. Klemp, "A time-split nonhydrostatic atmospheric model for weather research and forecasting applications." Journal of Computational Physics 227.7 (2008): 3465-3485.
2. Foreman, Richard J., and Stefan Emeis. "A Method for increasing the turbulent kinetic energy in the Mellor–Yamada–Janjić boundary-layer parametrization." Boundary-layer meteorology 145.2 (2012): 329-349.
3. Maronga, B., Gryschka, M., Heinze, R., Hoffmann, F., Kanani-Sühring, F., Keck, M., Ketelsen, K., Letzel, M. O., Sühring, M., and Raasch, S.: "The Parallelized Large-Eddy Simulation Model (PALM) version 4.0 for atmospheric and oceanic flows: model formulation, recent developments, and future perspectives", Geosci. Model Dev., 8, 2515-2551, doi:10.5194/gmd-8-2515-2015, 2015.

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