Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages
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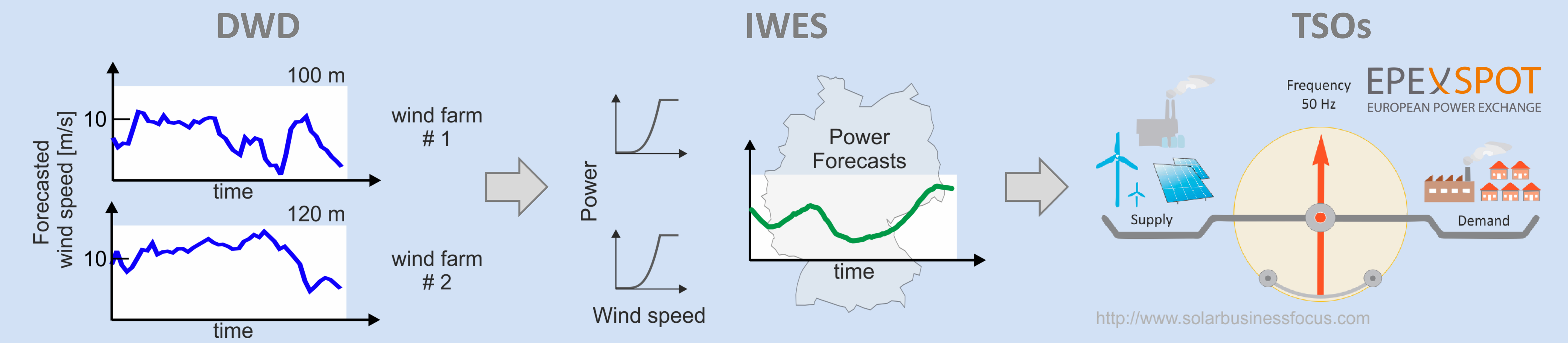
Towards a more accurate wind and solar power prediction by improving NWP model physics

EWeLiNE In the research project EWeLiNE, the DWD (German Meteorological Service) and Fraunhofer Institute IWES are working together with three german TSOs (transmission system operators) to improve weather and power forecasts for wind turbines and PV plants.



This poster focuses on the model physics of the regional NWP model COSMO-DE[1]. Critical weather situations where identified and first results on improving the physical parameterization are shown. The emphasis lies on wind forecasts.

COSMO-DE turbulence scheme[2]

For accurate forecasts of wind speeds in hub heights, turbulent processes in the atmosphere need to be parameterized correctly in NWP-models.

- The turbulence parameterization in COSMO is similar to the level 2.5 scheme of Mellor and Yamada[4]. It uses conservative variables instead of moisture and temperature, as well as the concept of scale separation, which leads to additional source terms for turbulent kinetic energy (TKE).
- The closure assumptions including the boundary layer approximation lead to a flux gradient representation:

$$\overline{\psi' w'} = -K \frac{\partial \overline{\psi}}{\partial z}$$

$$K = q \lambda S$$

$$K, S = \begin{cases} K_M, S^M, & \text{for } \psi = u, v \\ K_H, S^H, & \text{for } \psi = \theta_l, q_l \end{cases}$$

- A Blackadar-type turbulent length scale is used (asymptotic mixing length may be stability dependent)
- For computing q, the following prognostic equation is solved:

$$\frac{dTKE}{dt} = f_m + f_h + f_a - \epsilon + (p_{trans} + q_{diff})$$

On the right: vertical wind shear, buoyancy, additional shear by non-turbulent sub-grid scale (ss) flow structures (convective circulations, wakes induced by ss-orography, separated horizontal shear eddies, thermal circulations induced by surface inhomogeneity), dissipation, pressure transport, vertical TKE-diffusion.

- For computing the stability functions S, a special treatment for unstable stratifications is introduced in order to avoid numerical singularities. In the solution for the stability functions, a diagnostic representation of q is introduced, considering the departure from TKE equilibrium by using the prognostic q equation.
- Throughout the scheme, limiters assure numerical stability. Relevant for energy meteorology applications are the minimal values for the diffusion coefficients:

$$K_{M\_min} \leq K_M, \; K_{H\_min} \leq K_H$$

List of selected abbreviations:

TKE	Turbulent kinetic energy, $TKE = \frac{1}{2} q^2$
q	$q = \sqrt{2TKE}$
λ	Turbulent length scale
K_M, K_H	Diffusion coefficients (momentum, heat)
S^M, S^H	Stability functions (momentum, heat)

Critical weather situations

Wind:
- Frontal passages (lows)
- Pronounced diurnal cycles
- Winter (positive bias)[5]

Solar:
- Convective events
- Low stratus clouds
- Clear sky conditions

The daily cycle in wind speed

Especially in the summer, wind speeds in hub height exhibit strong daily cycles, challenging NWP-models. The German COSMO-DE model underestimates the amplitude of the daily wind speed cycle including Low Level Jets (LLJs) and additionally exhibits a temporal shift (transition from/to stable to/from unstable situations is too slow, see Fig. 1). Due to the nonlinearity of power curves such errors may have significant impact on wind power production (see Fig. 2).
Considering one example in August 2012 (stable situation), the LLJ in the model was underestimated and persisted for too long, even after sunrise (see Figure 3). By adjusting turbulence parameters in order to allow for more stable conditions during night and by artificially increasing vertical mixing after sunrise, better results are achieved (see Fig. 4). Further work will focus on how to implement a more realistic mixing after sunrise in the turbulence- and transfer-scheme of COSMO-DE.

Incoming solar radiation

On clear sky days shortwave radiation (SWR) is underestimated by the model, likely due to the high optical thickness of aerosols in the model (see Figure 5, yellow circle). Further work is conducted to improve SWR on cloudy days, where clouds appear to be too transparent (see Fig. 5, green circle).

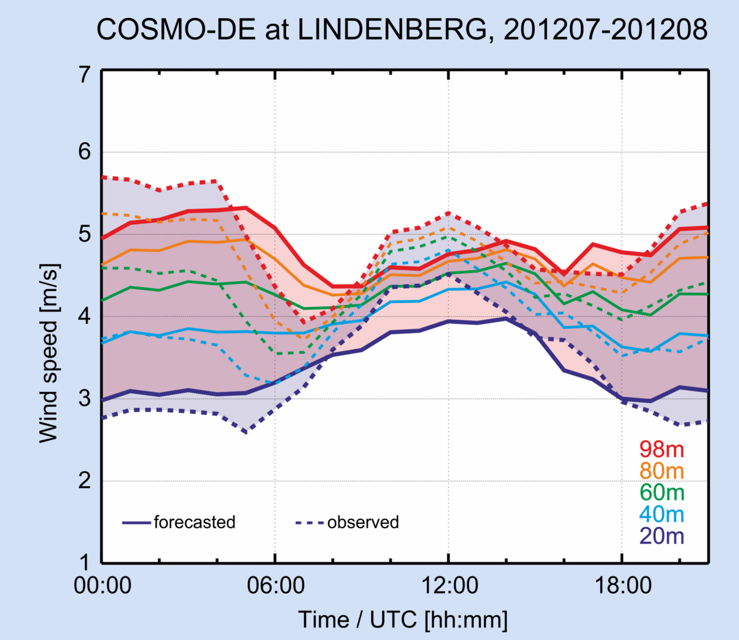


Fig.1) Mean daily cycle of observed (dotted) and forecasted (solid, 00:00 UTC forecast runs) wind speed at Lindenberg for July and August in 2012. Forecasted u and v values were carefully interpolated to measurement heights[5]. After sunrise, a strong decrease of wind speed aloft is observed, whereas the model fails to represent such sharp transition from stable to mixed conditions and vice versa.

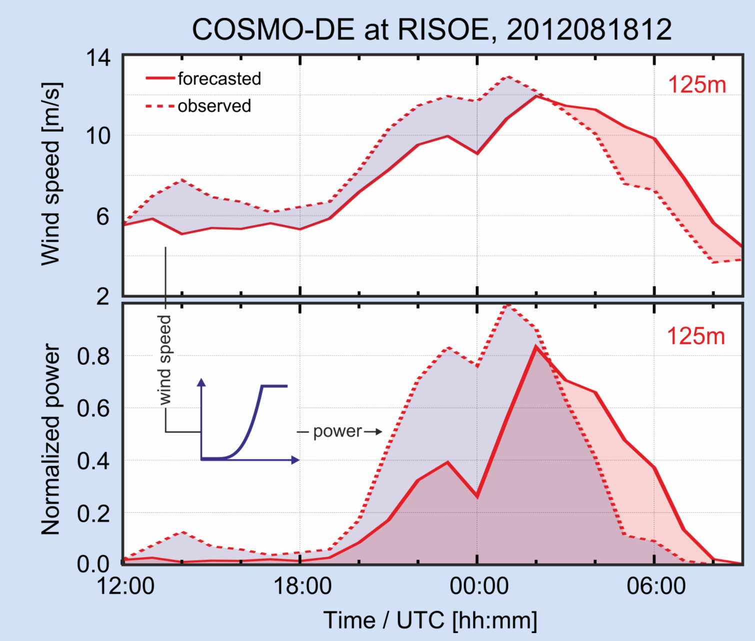


Fig.2) Risø, 18. August. 2012; Top: forecasted (solid) and observed (dotted) wind speed at 125 m. Note that the model simulates the Low Level Jet too weak and too late. Bottom: forecasted and observed wind speed converted to power. Within the critical range of the power curve, errors amplify significantly.

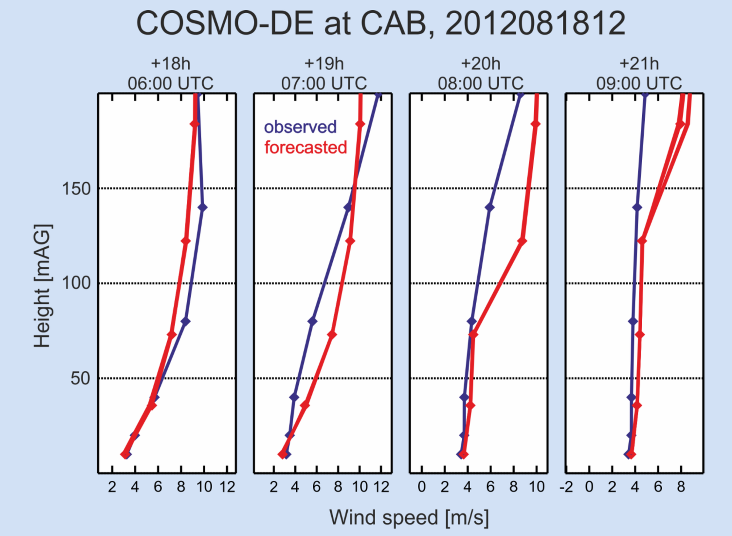


Fig.3) Cabauw, 18. August. 2012; Observed (blue) and forecasted (red) wind speed profiles for lead times +18 up to +21 hours, corresponding to 06:00 UTC up to 09:00 UTC. Note the persistence of a decoupled layer in the forecasted profiles after sunrise (04:30 UTC). Similar profiles can be found for Lindenberg and Risø for the same date.

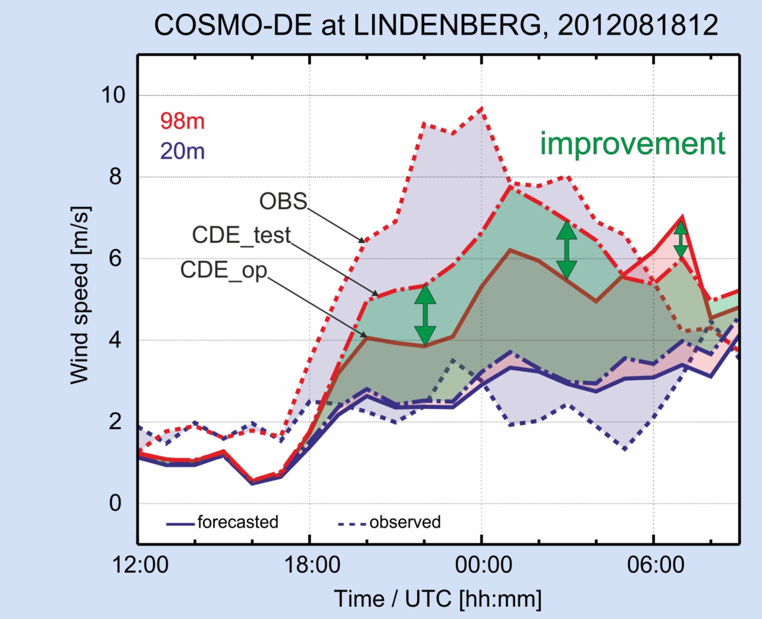


Fig.4) Lindenberg, 18. August. 2012; Observed (dotted) and operationally forecasted (solid) wind speed in 20 and 98 m. Note that the LLJ is too weak and too long-living in the model. A test run (dash dotted lines; momentum flux at the ground was slightly reduced, stability during night as well as mixing after sunrise were increased) shows better results. (namelist settings: tur_len=150, a_stab=1, pat_len=200, rlammom= 0.5, tk[h,m]min= 0.001, if sobs .gt. 5 tk[h,m]min=1.5)

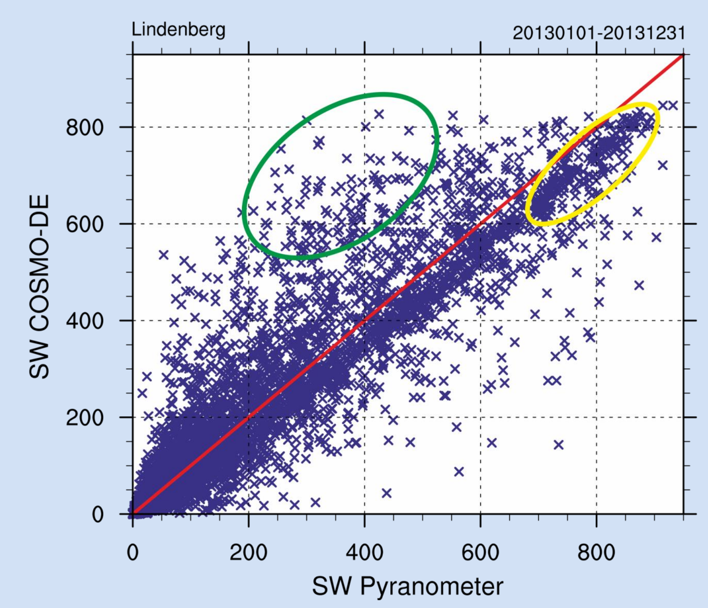


Fig.5) Lindenberg, 2013; Observed and operationally forecasted shortwave radiation (blue). Note the underestimation of high radiation values on clear sky days (yellow circle). The green circle markers the overestimated radiation of the model on cloudy days.

References

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5) Steiner, A., et al. 2013: Erste Ergebnisse zur Optimierung der NWV-Modelle des DWD im Hinblick auf die Windenergieertrags-prognose. Posterpräsentation, DACH-Tagung 2013 in Innsbruck.

All results are based on the NWP-model COSMO-DE, version 5.0.

Observations operated by:
Meteorologisches Observatorium Lindenberg
DTU Wind Energy
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