Modelling of the atmospheric boundary layer – Applications for wind energy

Astrid Ziemann, Manuela Starke, Valeri Goldberg and colleagues
Phenomenon during clear nights: low-level jet Measurement at forest clearing

→ Increase of wind speed over several hours

08.07.2016

SODAR

Starke, 2016

Ziemann, 2016

TU Dresden, Astrid Ziemann
Modelling of the atmospheric boundary layer – applications for wind energy
High Resolution Vegetation-Atmosphere Coupler (HIRVAC)

Scheme of 1D HIRVAC version

**Meteorological data:**
- geostrophic wind,
- temperature,
- radiation

**Auxiliary data:**
- Day Of Year (DOY)

**Canopy parameter:**
- plant area density,
- crown cover,
- height,
- drag coefficient

**Atmosphere**
- Vertical exchange between ABL and Vegetation

**Prognostic equations**
- for momentum, TKE, temperature

**Additional terms in prognostic equations**

**Soil**

Ziemann, 2017
HIRVAC2D – vegetation parameters and effects on the wind field

→ Height of vegetation (HP)
→ Profils of plant area density (PAD)
→ Horizontal wind speed in m/s

Ziemann and Wilson, 2015

Starke, 2017
Recent projects with HIRVAC applications \( \rightarrow \) wind field

Example 1: DFG priority program 1276 **Metström**

Project **TurbEFA** (Turbulent Exchange processes between Forested areas and the Atmosphere)

\( \rightarrow \) to investigate the effects of forest edges and inhomogeneities in forests on the turbulence of atmospheric flows and their representation in numerical models
Model results: dependence of wind speed on the vegetation structure

- Horizontal wind speed in m/s (lines), background: Plant Area Density (green area)
- HIRVAC2D simulation along a forest clearing
- Results from calculations with homogeneous (left) and measured (right) distribution of vegetation

→ Heterogeneous vegetation → more variable gradients of wind speed

Queck et al., 2014: DOI 10.1127/metz/2014/0567
Recent projects with HIRVAC applications → wind field

Example 2: BMWi 6. Energy Research Programme

Project QuWind100 (Quantitative wind climatology for wind energy applications at heights above 100 m)

→ to model a wind climatology for Germany for present and future climate and landuse
Project QuWind100

Meso scale

CCLM-Daten

Micro scale

HIRVAC2D

Sensitivity
LU-Classes

Landuse (LU)-Data

Grid-based wind atlas for heights between 100 m and 200 m

Adopted from Starke, 2019

TU Dresden, Astrid Ziemann
Modelling of the atmospheric boundary layer – applications for wind energy
Model results: nocturnal low-level jet

Low-level jet (LLJ) → important phenomenon of the wind field at typical hub heights of wind turbines:

- **Frequent phenomenon**: in 10-20% of all nights in Germany
- **Increasing wind speed** in comparison to the log. wind profile (dashed line)
- **Attention**: wind shear within the swept rotor area

HIRVAC simulation (morning hour) over grassland:

- **height and max wind speed** are dependent on day of the year

Ziemann, 2015
Model results: development of nocturnal low-level jet

→ **Maximum** wind speed about 1.3 $vg$
→ 6-7 hours after sunset

Ziemann et al., 2019: https://doi.org/10.5194/asr-16-85-2019
Model results: dependence of low-level jet on landuse

Vertical profiles at 4:00 local time on 19th June

vg=4 m/s

→ LLJ over grassland: lower height
→ More LLJ events for grassland

Adopted from Ziemann et al., 2019: https://doi.org/10.5194/asr-16-85-2019
Model results: dependence of wind speed on daytime

- Diurnal variations of wind speed at 100 m AGL induced by different wind speeds $v_g$ (colors), Vegetation: a 28 m high deciduous forest
- More LLJ events for smaller values of $v_g$

Starke et al., 2017
Model results: dependence of wind speed on vegetation parameters

- Daily averaged wind speed $v_h$ at different heights AGL (colors) and vegetation properties (height HP and leaf area index crown LAI$_{top}$)

$$y = -0.47 \ln(x) + 7.31$$  
$$R^2 = 0.98$$

$$y = -0.50 \ln(x) + 6.27$$  
$$R^2 = 0.97$$

$vg = 10 \text{ m/s}$

- 100 m
- 120 m
- 140 m
- 160 m
- 180 m
- 200 m

Log. (100 m)
Log. (200 m)

Starke et al., 2017
Wind atlas for Germany: exemplary results (only influence of LU, 100 m AGL)

Averaged wind speed (m/s) for winter season present time (left) und landuse (right)

Landuse data from Hoymann and Goetzke, 2014:

- Urban areas
- Grassland
- Farmland
- Mixed forest
- Coniferous for.
- Deciduous for.
- Water
- Sea

Starke, 2019

https://doi.org/10.1007/s13147-014-0290-y
Open questions

- **Heterogeneous environmental conditions** (terrain, landuse, vegetation parameters) → challenges for **wind power assessment**, estimation of **mechanical loads** and **short-term prediction** of wind fields

- **Evaluated models** and parametrizations (→ standardized models) are needed to simulate the wind field at hub heights with all important temporally and spatially variable features, especially **low-level jets**.

- **How the properties of low-level jets are modified by a complex terrain with a heterogeneous landuse?**

- Combination of suitable models for special process studies and enhanced parameter/sensitivity studies (wind climatology)

- Model comparison with adequate **measurements** (WindForS)
There are also experiences in meteorological measurements ;-)