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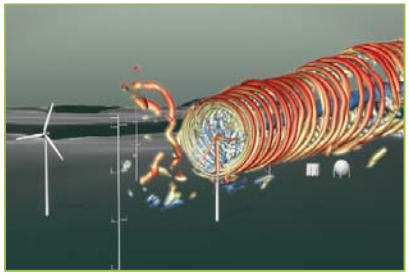

Untersuchung von Standorten für Windkraftanlagen im komplexen Gelände mit Hilfe hochaufgelöster, dreidimensionaler Strömungssimulation (CFD) am Beispiel des Windenergie-Testfelds des Forschungsclusters WindForS

Dr. Andrew Clifton, Director WindForS

Prof. Dr.-Ing. Hermann Knaus, Esslingen University of Applied Sciences

Prof. Dr. Jens Bange, University of Tuebingen

STORENERGY Congress, Offenburg

November 2017

Challenges for Wind Energy in Complex Terrain

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- How do we accurately measure wind resources?
- How do we predict ice?
- How do we use flow models?
- How do we optimize turbines?
- How do we minimize noise?
- How do we maximize acceptance?
- How do we forecast power generation?
- How do we integrate weather-driven generators into the grid?

Source: U. Stuttgart Wind Energy

WindForS Pools Expertise in Research and Teaching for Wind Energy

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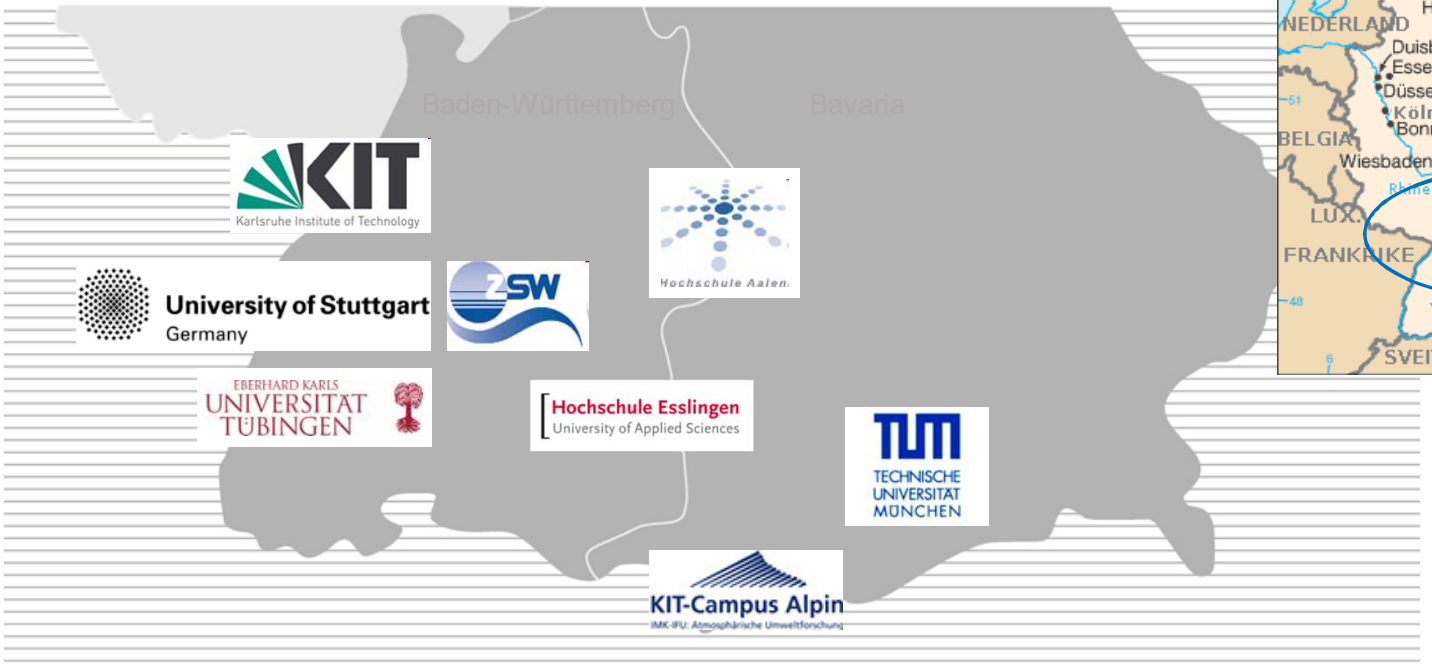
Süddeutschland



Do We Need Another Turbine Test Site?

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We need a research platform, not a test site!

WindForS Covers The Whole System

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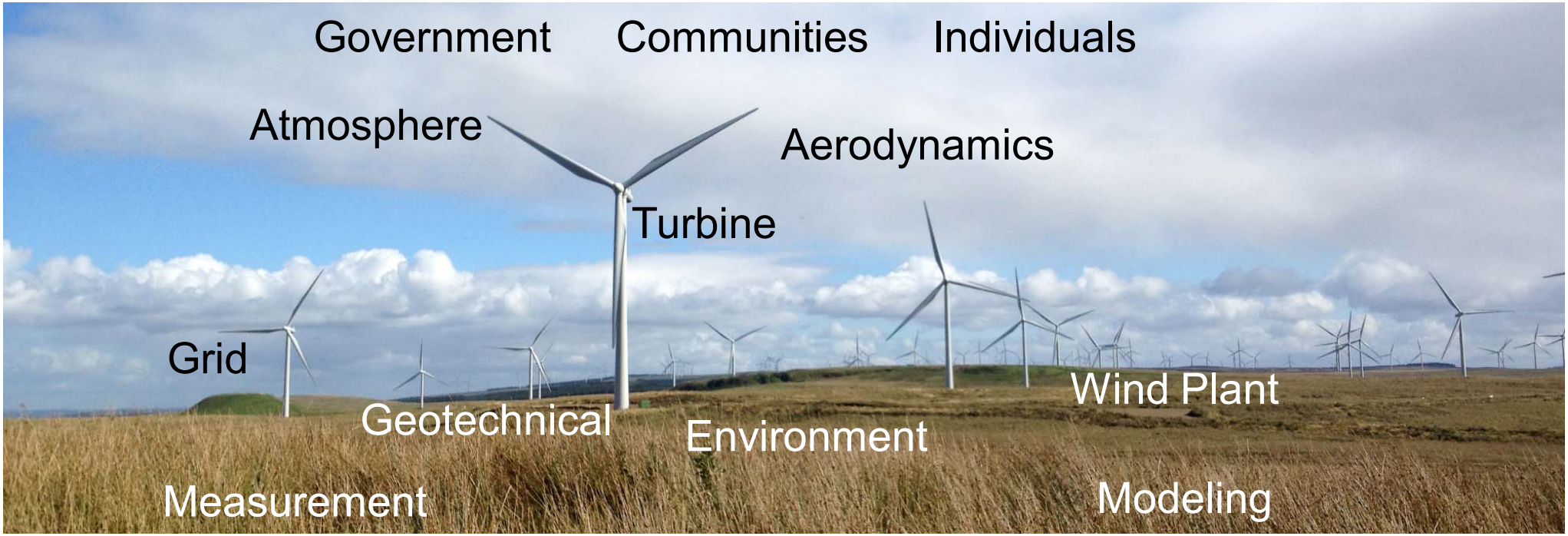
Mesoscale Microscale Rotor Boundary Layer



Source: A. Clifton

Bench tests Prototypes Commercial

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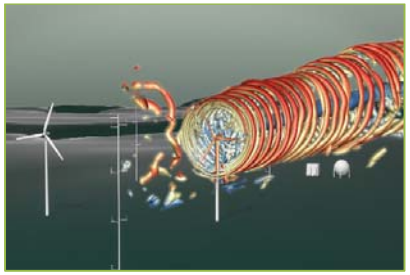

The WindForS Research Facility at Stötten

Stöttener Berg

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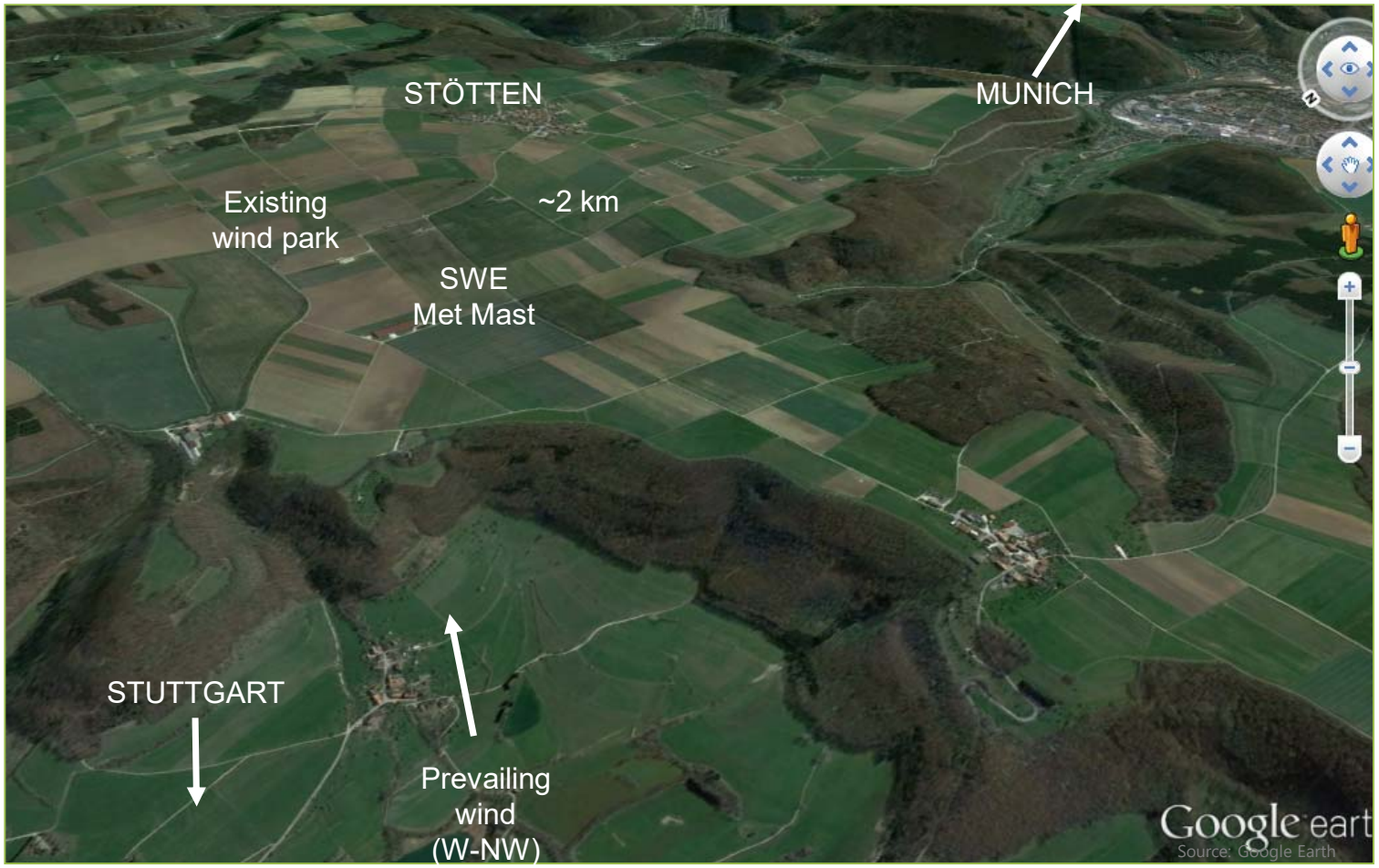
60 km east of Stuttgart in the Schwäbische Alb



Preliminary Flow Measurements

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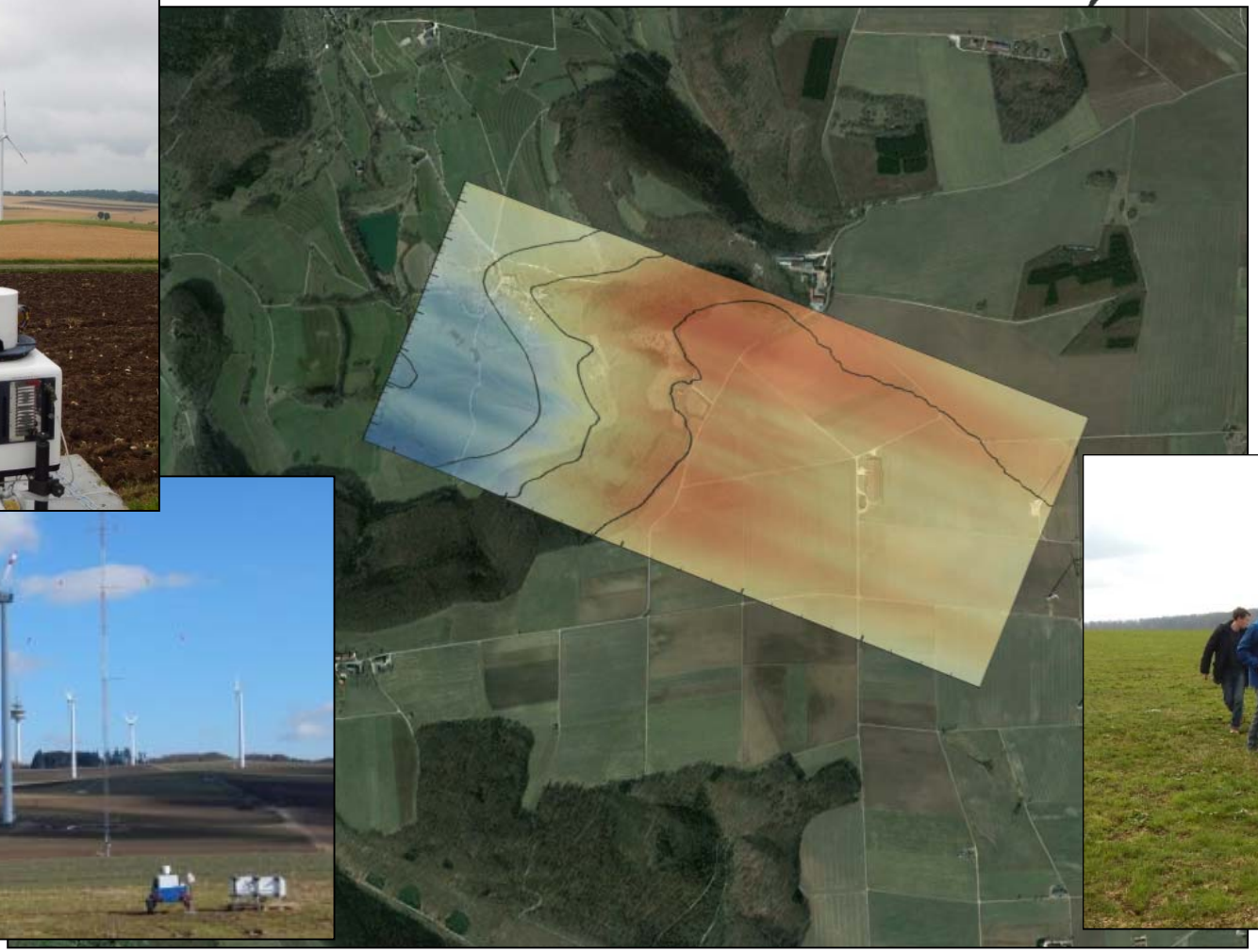

Sources: Google Earth, EKUT-UP, USTUTT-SWE, USTUTT-IAG

Complex Terrain Research Facility

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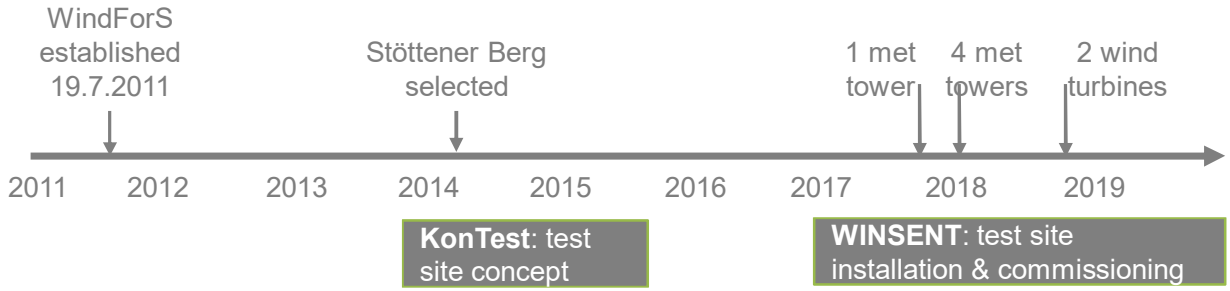

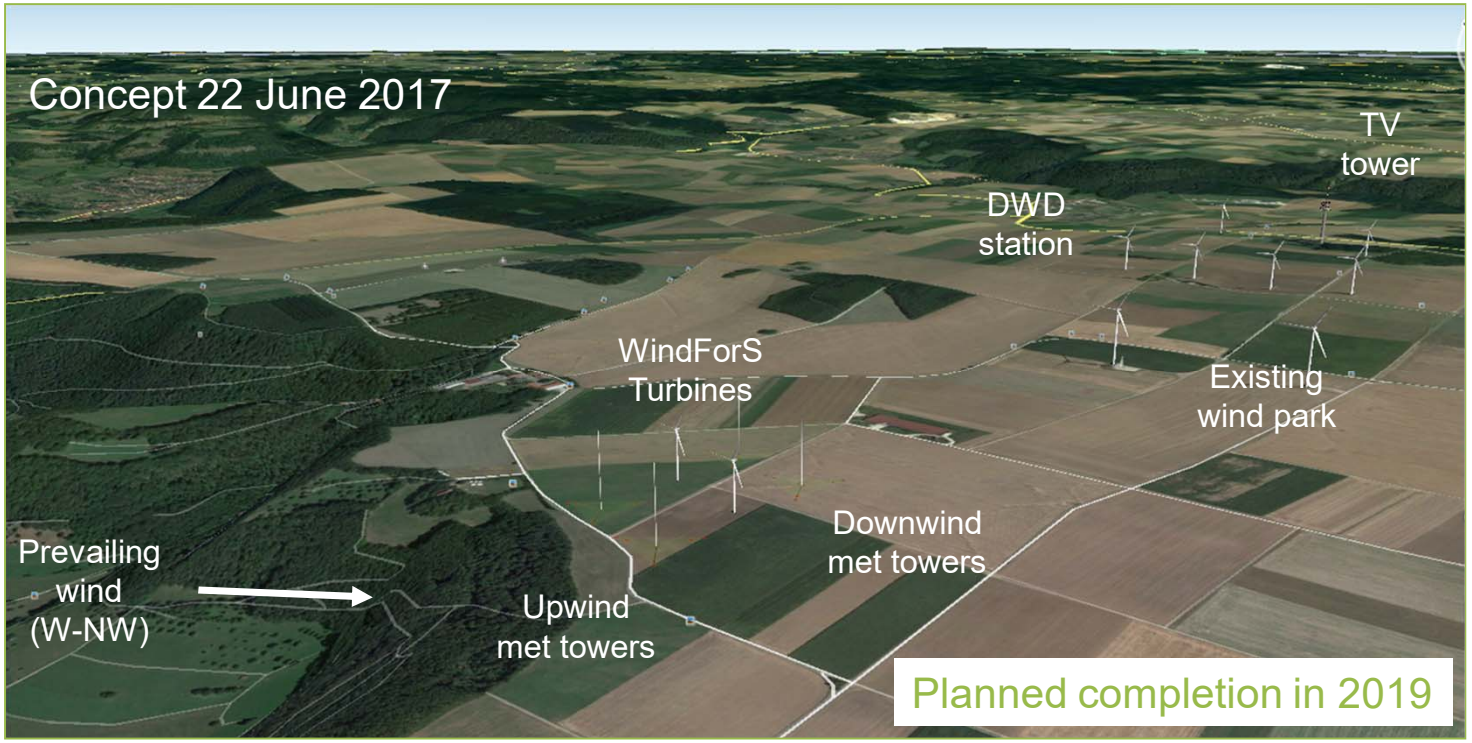

Source: ZSW

Met Tower Instrumentation

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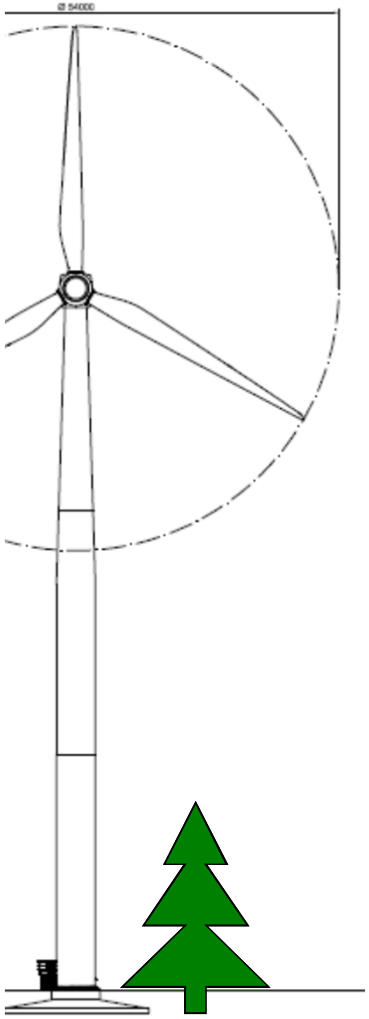

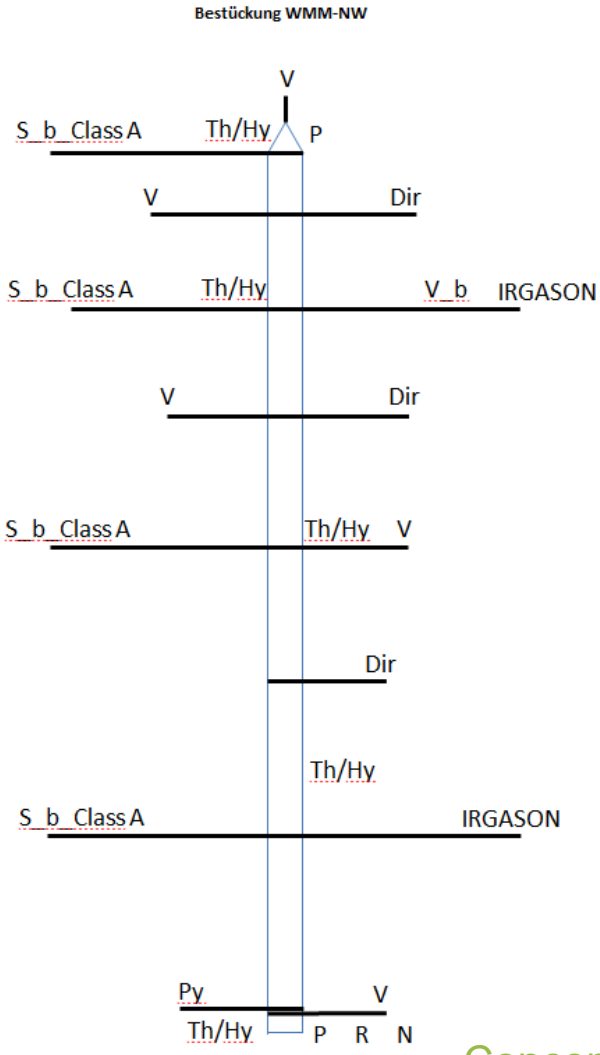

Abkürzung	Sensor
V_b	1st Class Cup-Anemometer beheizt
V	1st Class Cup-Anemometer
Th/hy	Thermo-Hygrogeber Compact
P	Barogeber
Dir	Windfahne
S_b_Class	
A	3D-Ultraschallanemometer - beheizt
S_b_Cage	3D-Ultraschallanemometer - beheizt
Py	Pyranometer
R	Regengeber Kippwaage
N	Niederschlagssensor
IRGASON	Gas Analyzer + 3D Ultrasonic

Source: ZSW

Concept 22 June 2017

Wind Simulation – Physical Models

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Three dimensional modelling of the turbulent flow considering mass, momentum and energy conservation

Important aspects modelling the flow in the atmospheric boundary layer are:

1.) Temperature gradient of the atmosphere
- Source terms in energy equation or Boussinesq formulation of momentum equation describing the temperature gradient in the Earth's atmosphere

2.) Coriolis forces
- Source term in momentum equation describes the deviation of the flow in the rotating system of the Earth

3.) Turbulence modelling by means of two equation turbulence models

4.) Canopy
- Geometrical description based on digital landscape model (CORINE)
- Source term in momentum equations respecting additional drag force
- Source terms for production and dissipation of turbulent quantities

Details: H. Knaus; A. Rautenberg; J. Bange: Model comparison of two different non-hydrostatic formulations for the Navier-Stokes equations simulating wind flow in complex terrain. Journal of Wind Engineering & Industrial Aerodynamics, Vol. 169 (2017), pp. 290-307

Wind Simulation - Model Chain

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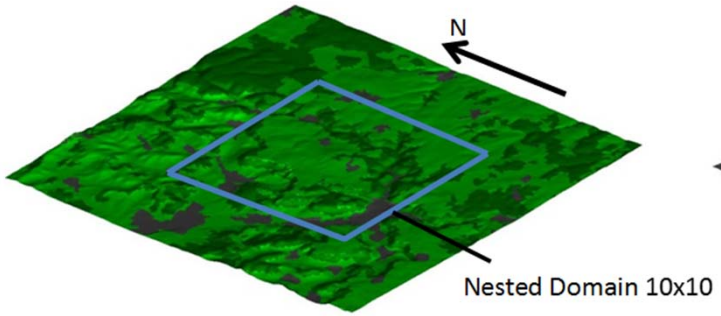
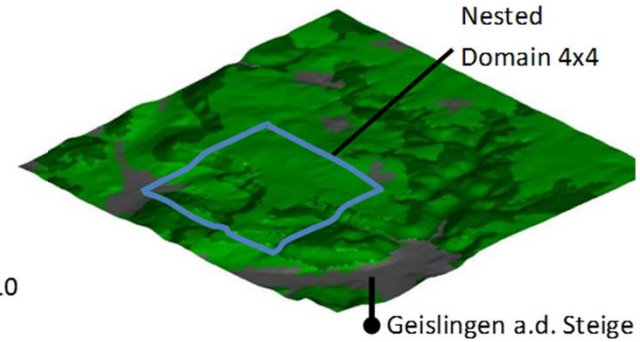
Case	Number of cells	Horizontal grid resolution at the ground	Vertical grid resolution at the ground	Maximum cell size
Parent Model	57.6 Mio.	30 m	3,0 m	100 m
Nested Domain 10x10	18.5 Mio.	24 m	1,5 m	48.0 m
Nested Domain 4x4	6.86 Mio.	10 m	1,0 m	40.0 m

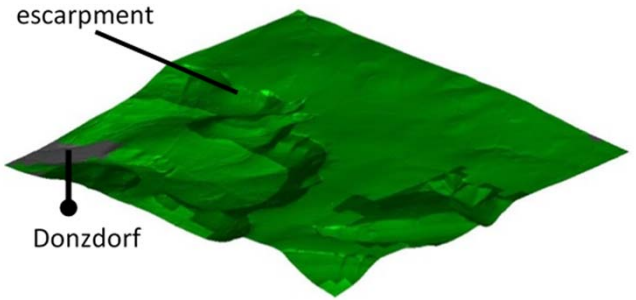
Mesh parameters for nested domains



Parent Model



Nested Domain 10x10



Nested Domain 4x4

Boundary conditions from weather forecast model (DWD or WRF) → Simulation for Parent Momain → Simulation of Nested Domain 10x10 → Simulation of Nested Domain 4x4 → Simulation result (velocities, tubulence, etc.)

increasing level of detail

Wind Simulation – Flow Distribution

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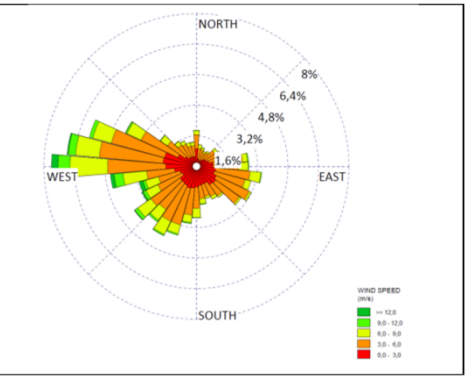
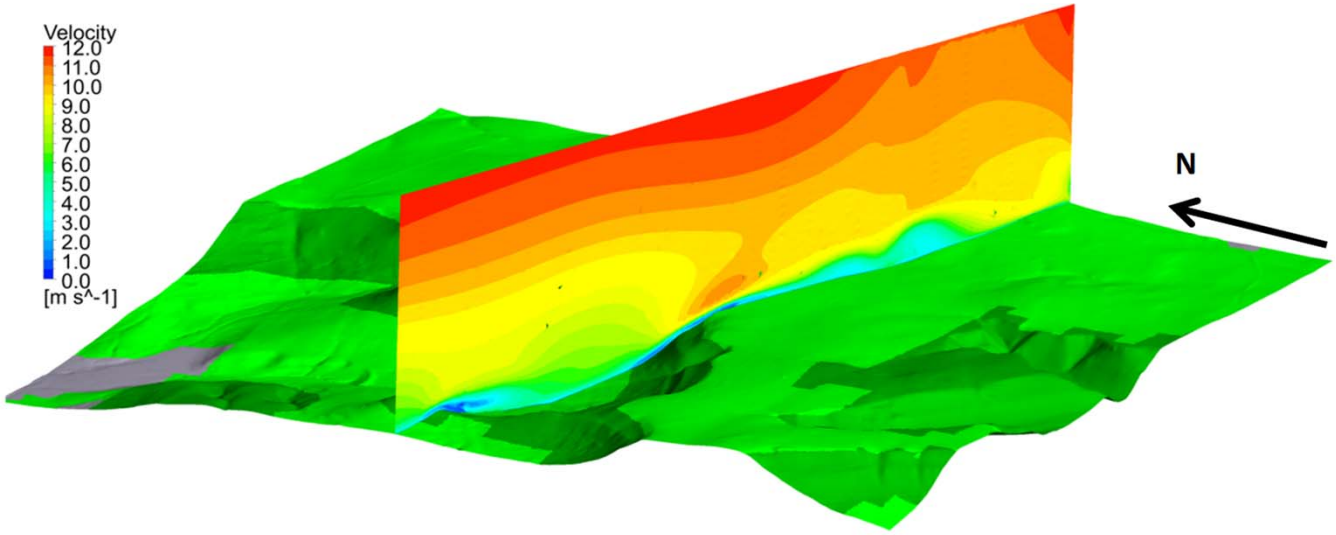
Date, time	Wind speed [m/s]	Wind direction [deg]
2015/03/27, 01:00 p.m.	7.1	290
2015/03/27, 02:00 p.m.	7.1	290
2015/03/27, 03:00 p.m.	7.3	290
2015/03/27, 04:00 p.m.	6.9	280



Wind speed and direction at DWD measuring station Stötten (734 m.a.s, 48.6654° latitude, 9.8655° longitude) as well as the wind rose in the timeframe 2014-2015



Vertical velocity distribution in direction of path measurement

Wind Simulation – Flow Distribution

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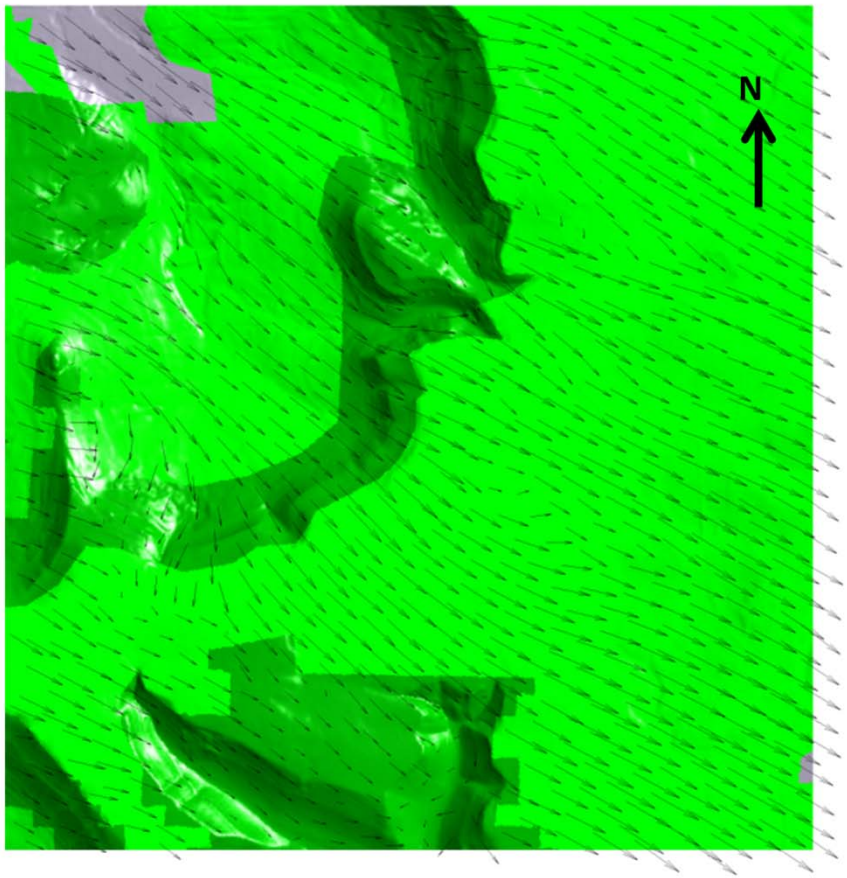

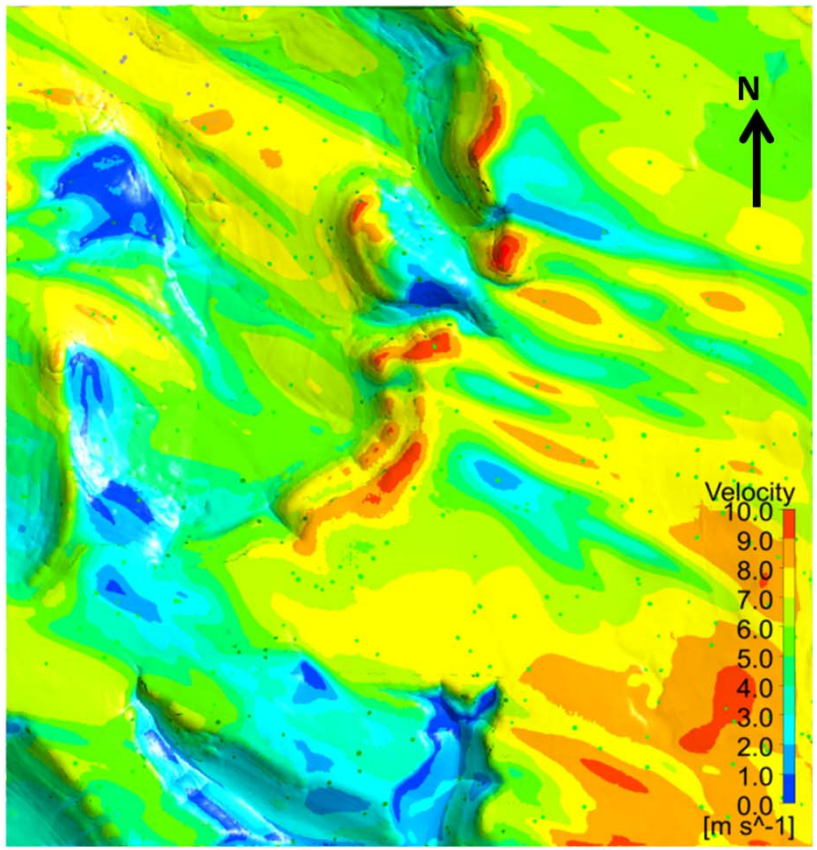

Velocity vectors and velocity contours 30 m above ground

Wind Simulation – Influence of Canopy

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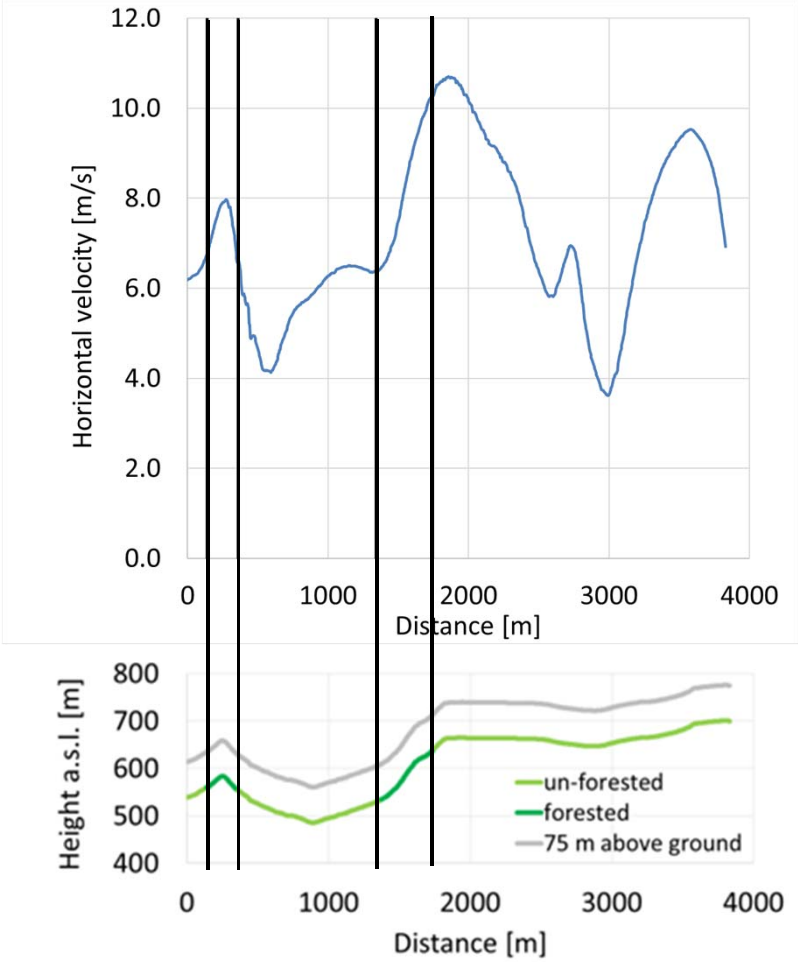

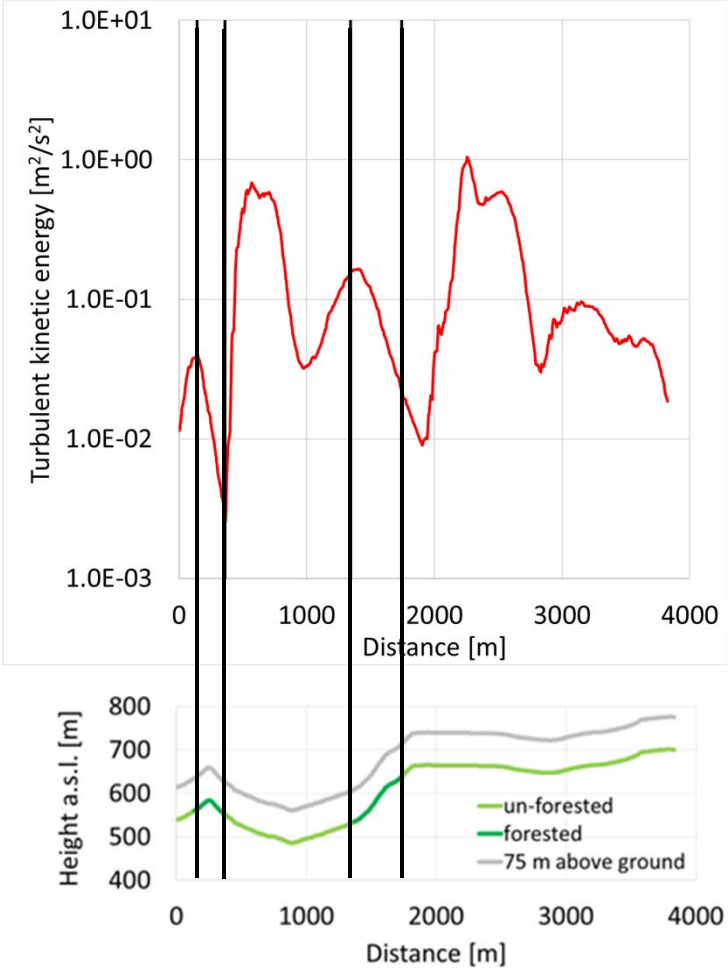

Wind Simulation – Computational Results vs. Mesurements

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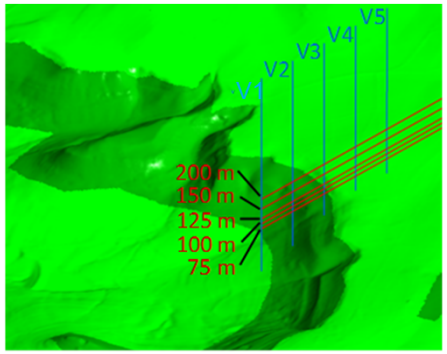
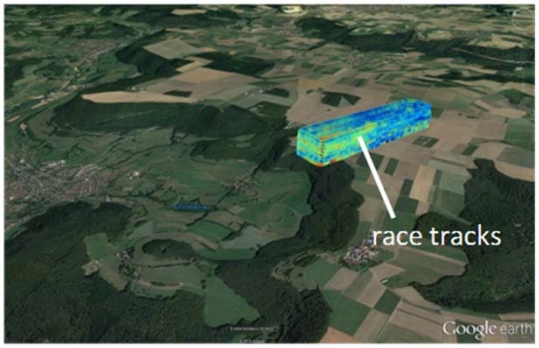
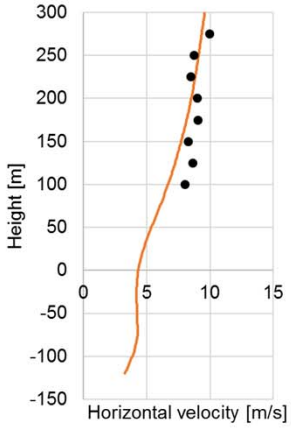


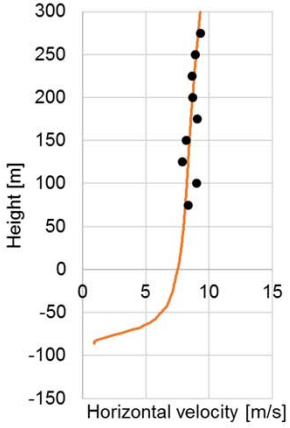
Locations vertical evaluation lines (blue)

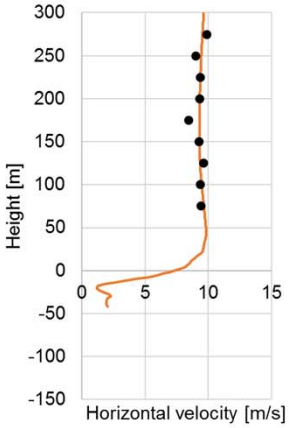
UAV measurement campaign at WindForS test site (source: University of Tuebingen)

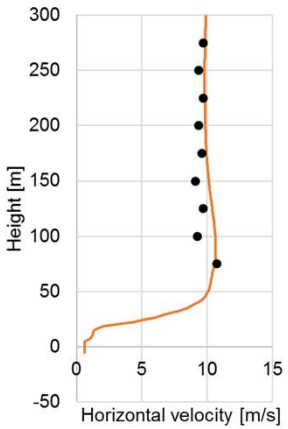


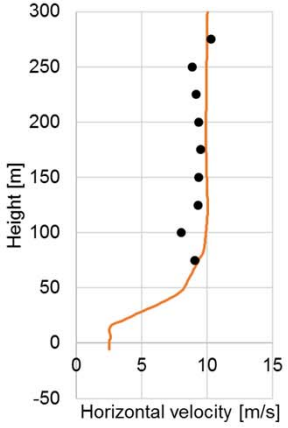
Measurement race tracks (© 2009 GeoBasis-DE/BKG, ©2016 Google)



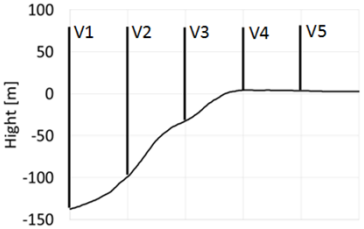








RMSD vertical:
0.6218 m/s



Comparison of measurements (black dots) and simulation results (orange line) along vertical evaluation lines V1-V5

Conclusions and Outlook

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Wind Simulation

- Generation of boundary conditions for detailed CFD simulations by means of weather forecast models is appropriate for complex terrain
- Strong velocity gradients perpendicular to the flow direction are found along the test site
- Good agreement with measurement data from UAV for the wind regime presented
- Validation of the simulation models with measurements in the vicinity of the Earth's surface are planned
- Work further improving the model chain are ongoing

Wind Research Facility

- wind energy in complex terrain is a many-sided challenge
- it includes aspects of acceptance, engineering optimization, and grid integration
- a community research facility (not a test site!) at Stötten is essential for progress

So you want to work with WindForS

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Academic Exchange

Ask me about opportunities for

- Summer students
- PhDs and postdocs
- Sabbaticals
- Visiting professionals

Collaborative Research

Huge potential for new work!

- Testing new technologies
- Model validation at all scales
- Energy storage and grid connection
- Techniques to increase acceptance

Source: Klaus Wolter

Acknowledgements

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Let's Talk!

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