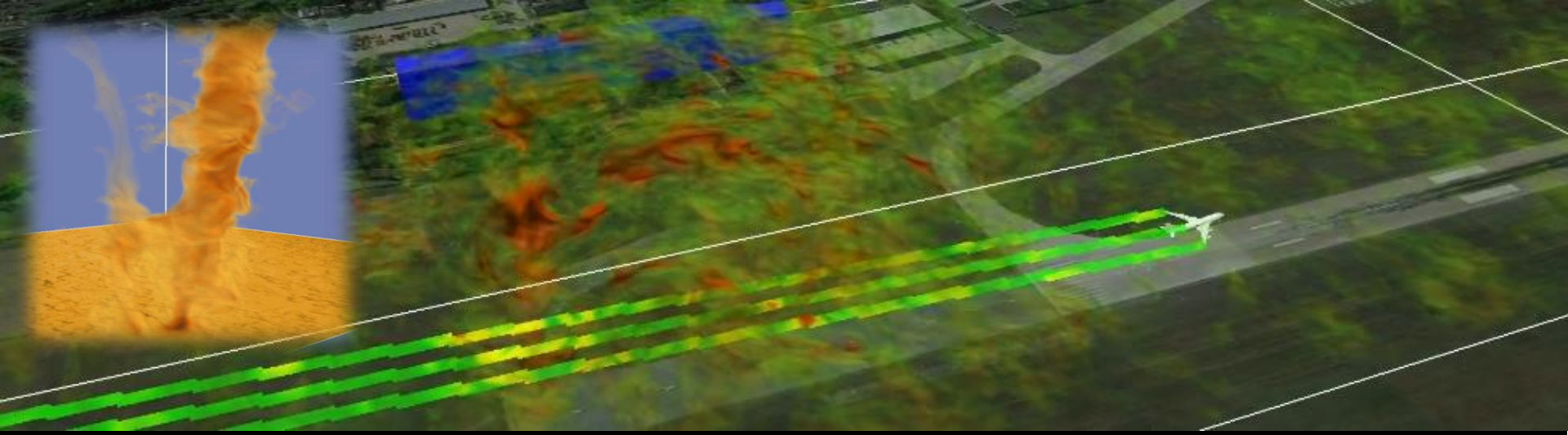
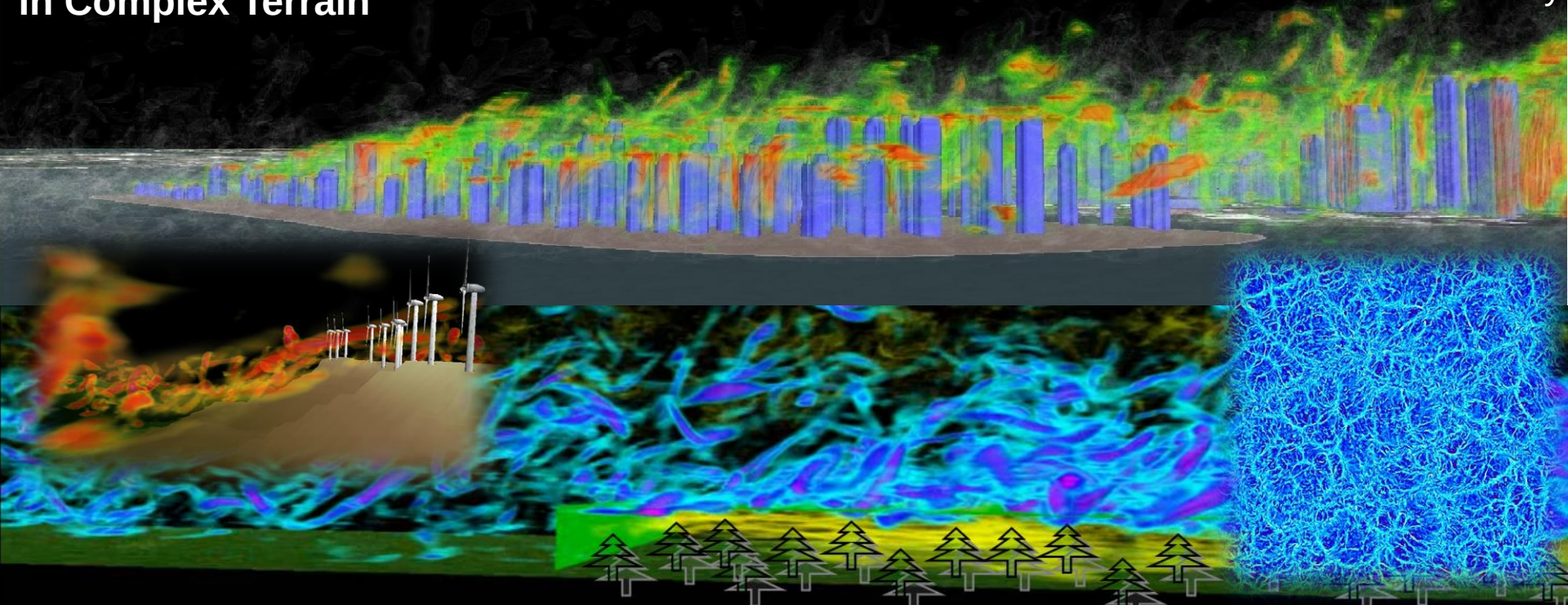


High Resolution Atmospheric Turbulence Simulations In Complex Terrain

Siegfried Raasch
Leibniz University Hannover
Germany



Simulation of Atmospheric Turbulence

- Institute of Meteorology and Climatology
- research group with about 15 Master-/PhD students and post-docs
- atmospheric boundary layer research since more than 30 years

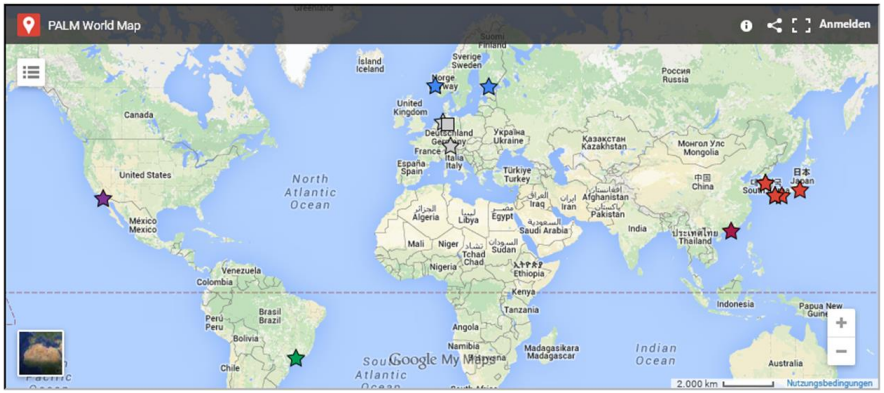
Working areas

- **Simulation of atmospheric boundary layer turbulence for basic and applied research questions**
- **Model development + optimization of numerical methods for high performance computing**
- **Visualization of complex flow phenomena**

- **PArallelized LES-Model PALM** ***(palm-model.org)***

  Maronga, B., et al. (2015): 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

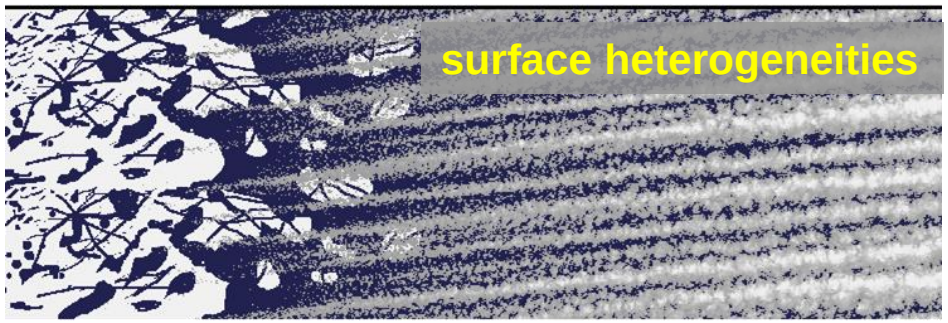
  – excellent scaling (tested with up to 40.000 cores)
  – large model setups with grid spacings down to 1m and up to 10^{12} gridpoints
  – growing worldwide user community (currently more than 300 users)

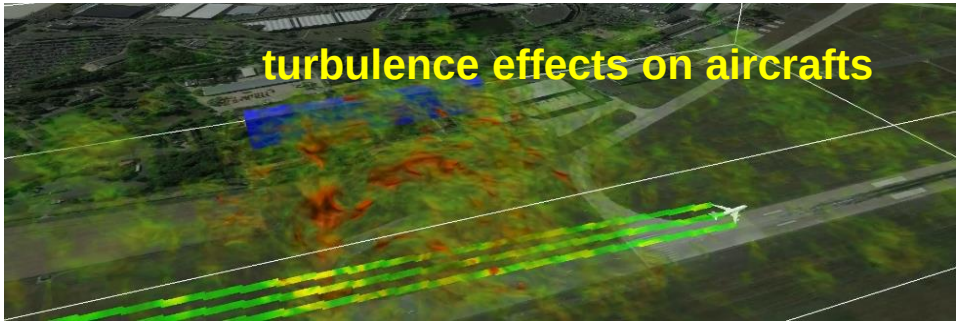


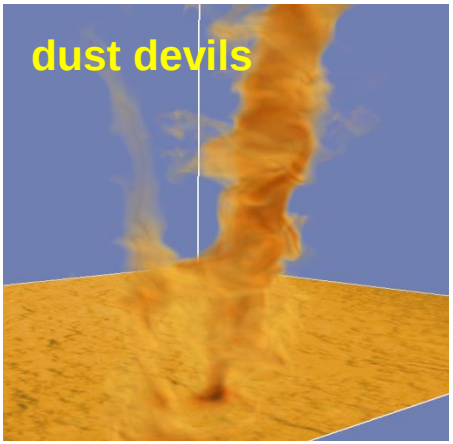
Groups which published peer-reviewed papers with PALM:

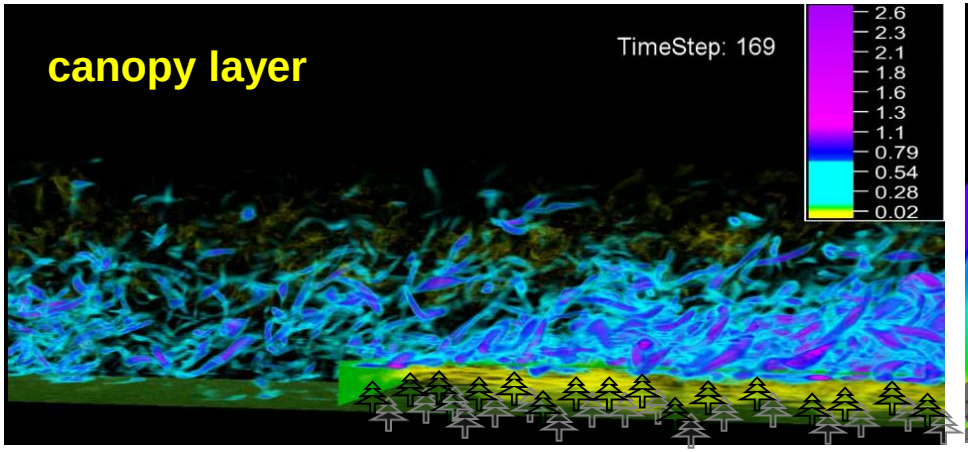
University of Bergen, Norway; Tokyo Institute of Technology; Kyushu Univ., Japan; Seoul National Univ., Yonsei Univ., Finnish Meteorological Institute; INPE, Brazil; University of California, San Diego; …

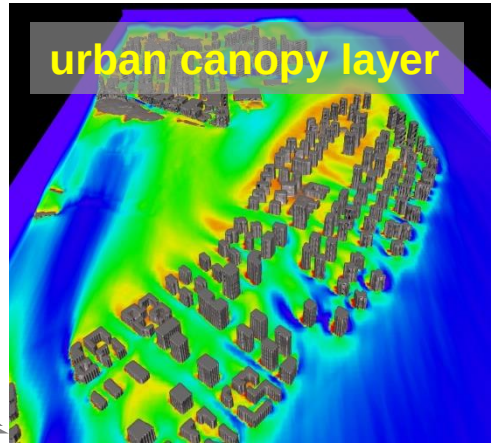
Some current research topics

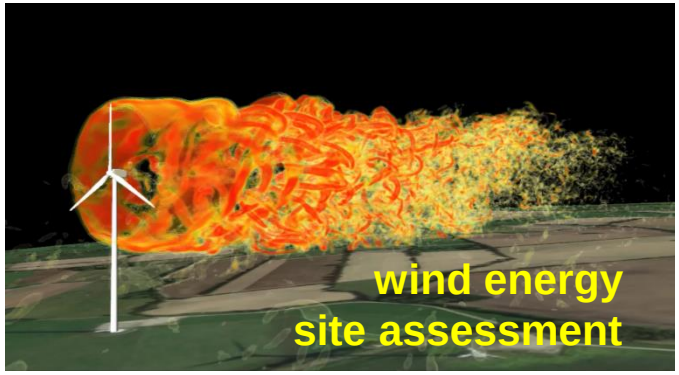


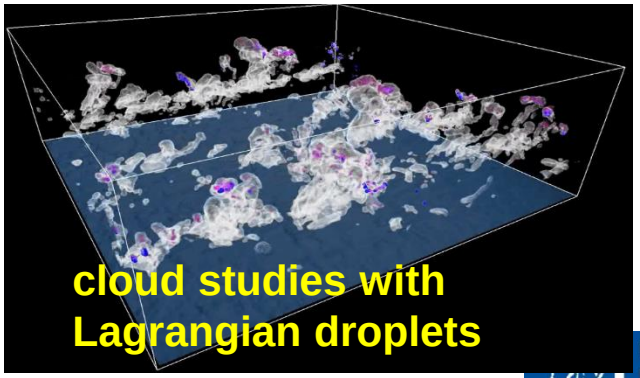




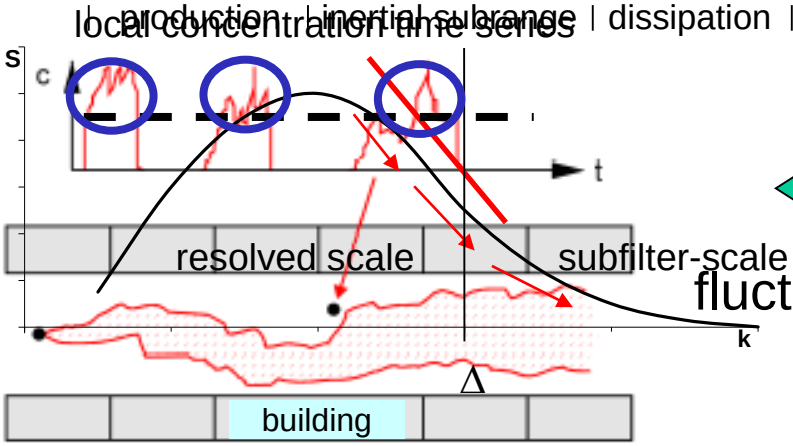




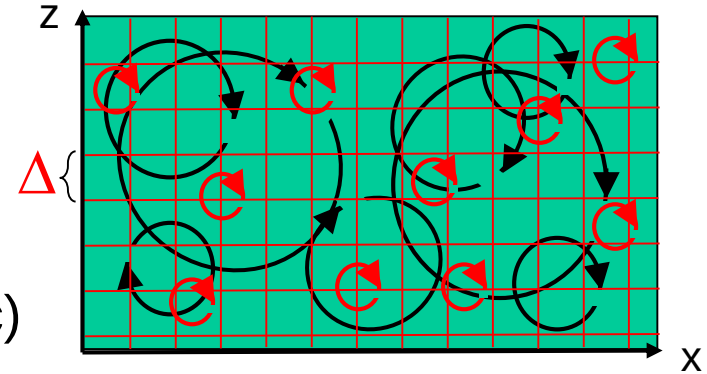




LES Principals



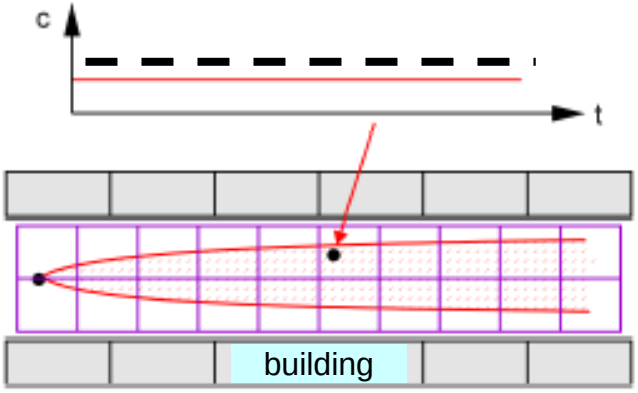
fluctuations (**u**, c)



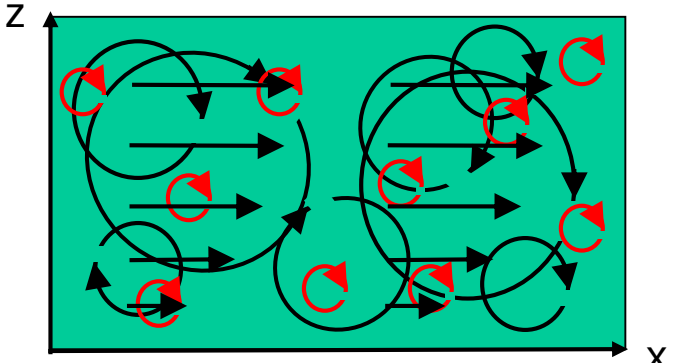
LES: volume average

critical concentration level

local concentration time series



smooth result



RANS: ensemble average

after Schatzmann and Leitl (2001)

PALM – Features / Numerics for real world applications

- finite differences
- cartesian staggered grid
- topography (cartesian, masking method)
- non-cyclic horizontal boundary conditions + turbulent inflow
- Runge-Kutta 3rd-order timestep scheme
- FFT- or multigrid-method for solving the Poisson-equation
- various higher order advection schemes available (default: Wicker-Skamarock)
- canopy model
- cloud physics (two moment scheme after Seifert and Beheng)
- embedded complete Lagrangian particle model (dispersion modelling, footprint calculation, cloud droplets, graphics, agent modelling)
- ocean-version with salinity (can be coupled with atmosphere)
- large-scale forcing and nudging
- online data analysis, all output in netCDF format

for further details see:

http://palm-model.org

Maronga et al., 2015:
Geosci. Model Dev., 8,
DOI: 10.5194/gmdd-8-2515-2015

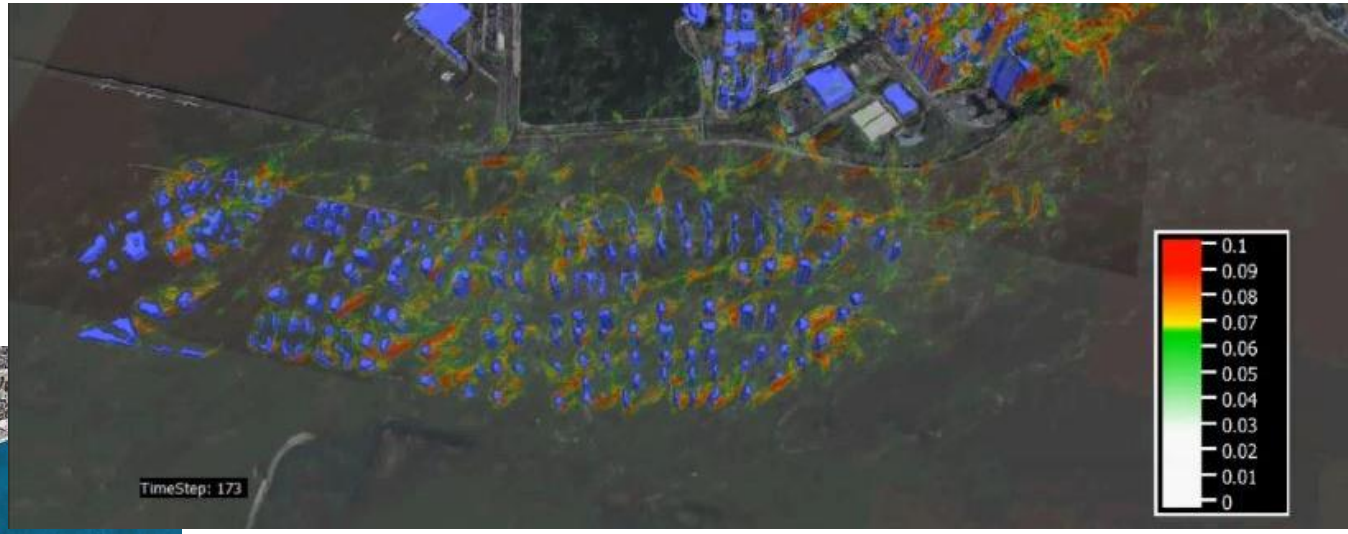
describes PALM 4.0 release

PALM applied applications (I)

Urban canopy flow of complete cities: Macau

PALM simulations

Δ = 2m
5000*3000*500 gridpoints



Macau

Effects of new reclamation areas on air quality at pedestrian level in existing parts of the city

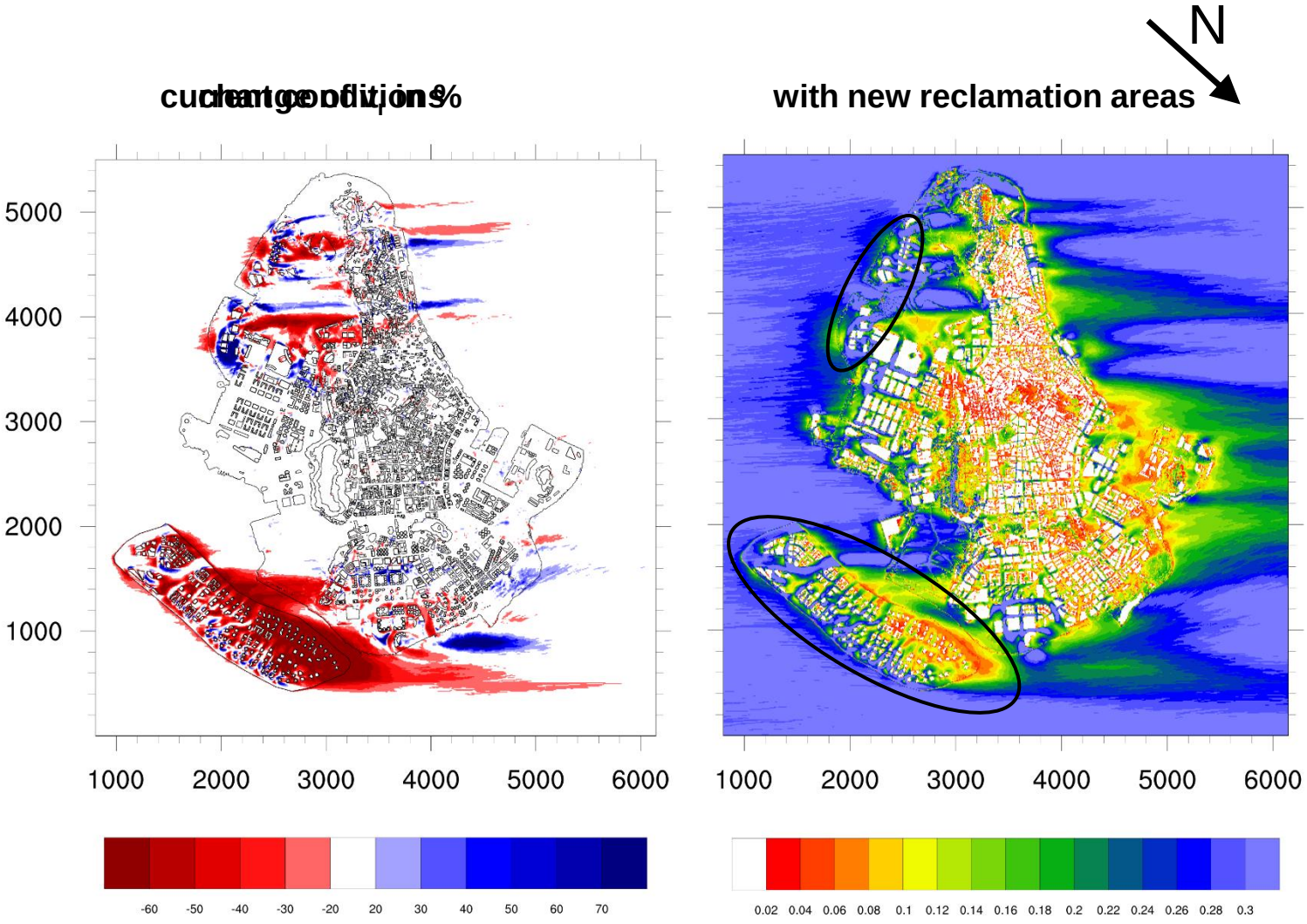
PALM applied research projects (I)

Urban canopy flow of complete cities: Macau

PALM simulations

Δ = 2m
5000*3000*500 gridpoints

- **neutral stratification is assumed, as usual in assessment studies**



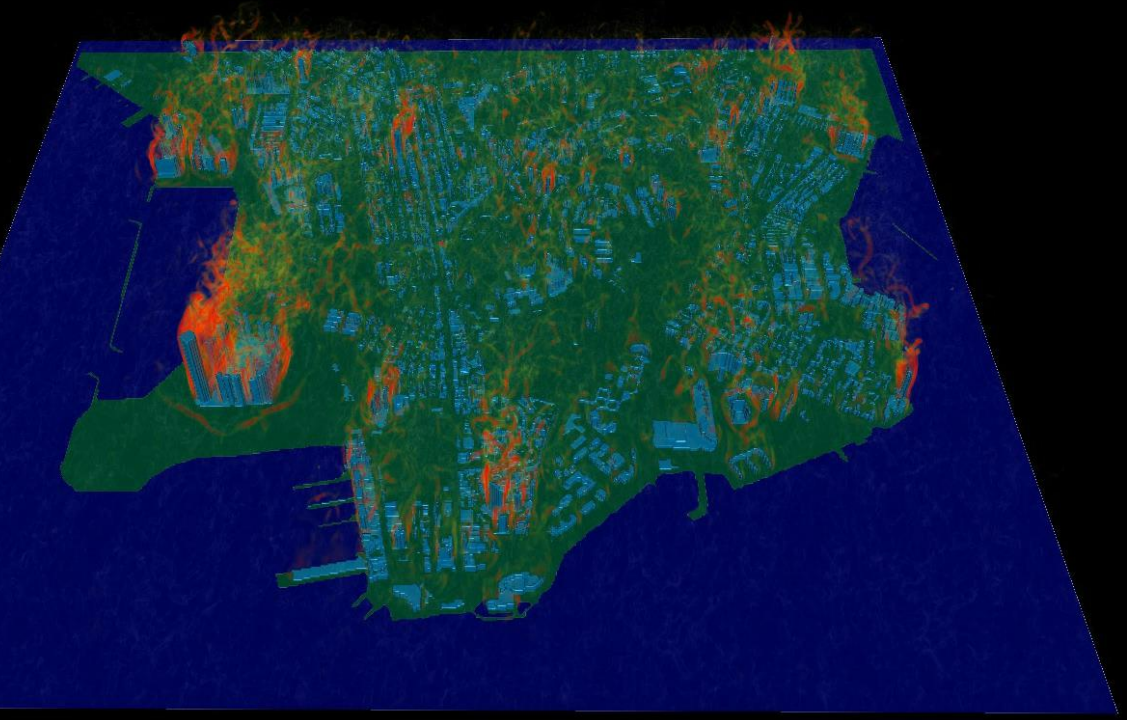
PALM applied research projects (II)

Urban canopy flow of complete cities: Kowloon (Hong Kong)

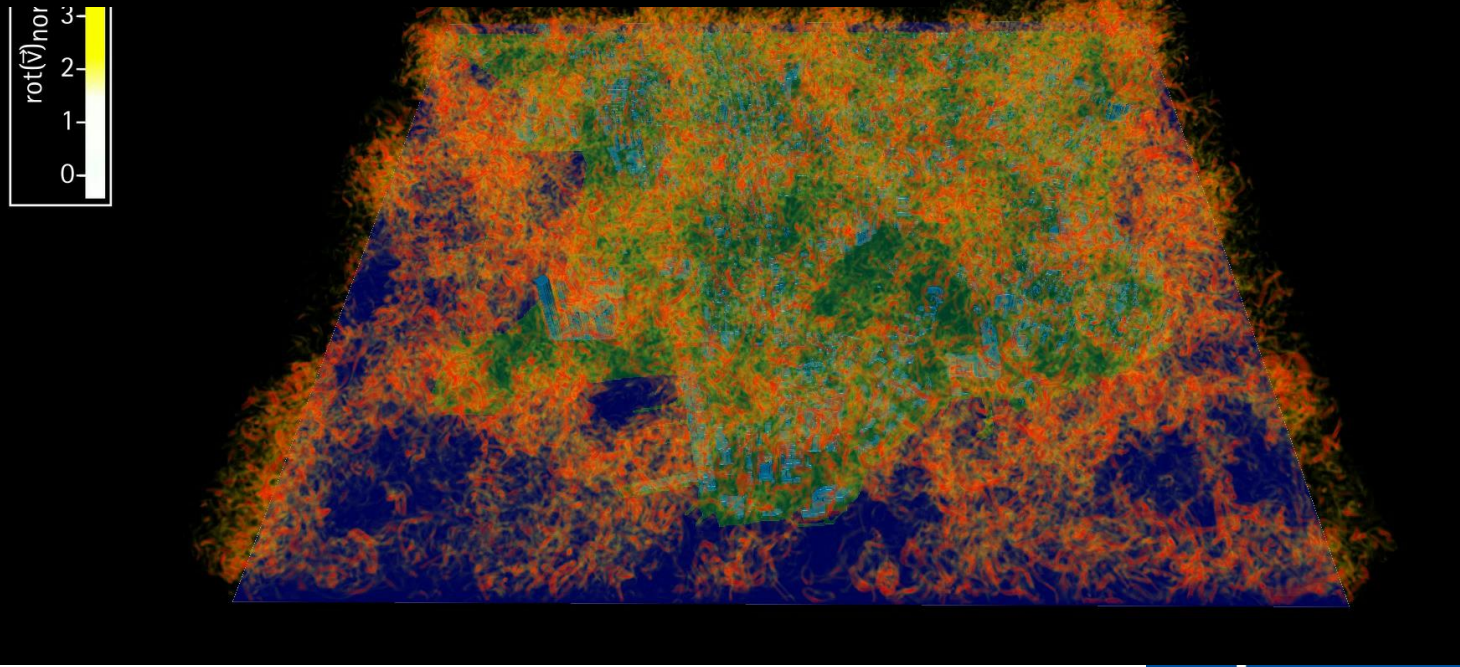
Kowloon:

Effect of stratification (atmospheric stability) on the ventilation

- ventilation studies are generally carried out for neutral stratification
- under daytime convective conditions, buoyancy may play a major role
- convective conditions frequently appear during hot and humid summer months in south-east asia



/isualization created with VAPOR (www.vapor



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- ventilation studies are generally carried out for neutral stratification
- under daytime convective conditions, buoyancy may play a major role
- convective conditions frequently appear during hot and humid summer months in south-east asia

- **during daytime conditions (unstable stratification) buildings have only weak effects on ventilation**

  Gronemeier et al., 2017: Atmosphere, 8.

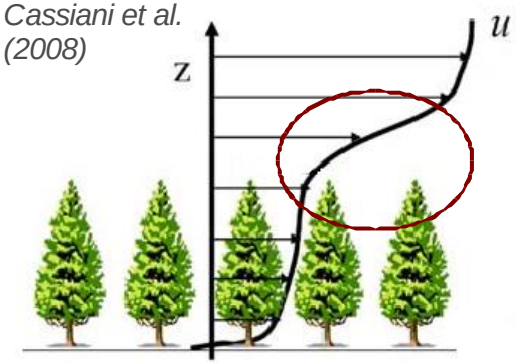
- **important new field of application for LES, since most of wind tunnels cannot handle stratified flows**

PALM applied research projects (III)

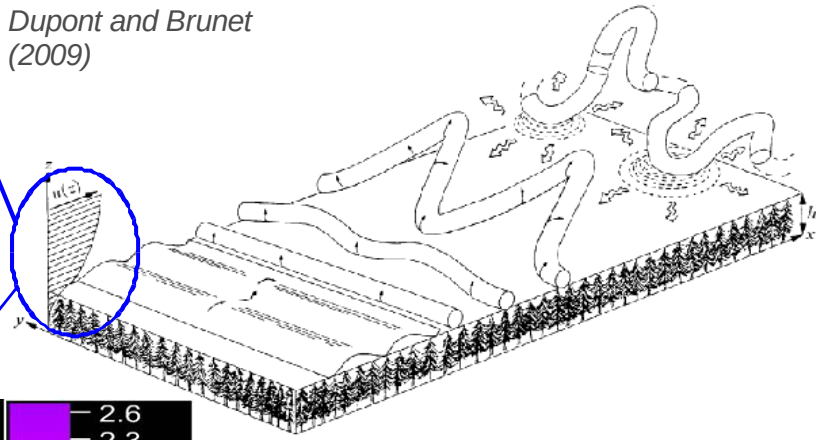
Interpretation of measurements near forest edges

- the canopy modified wind profile induces additional turbulence

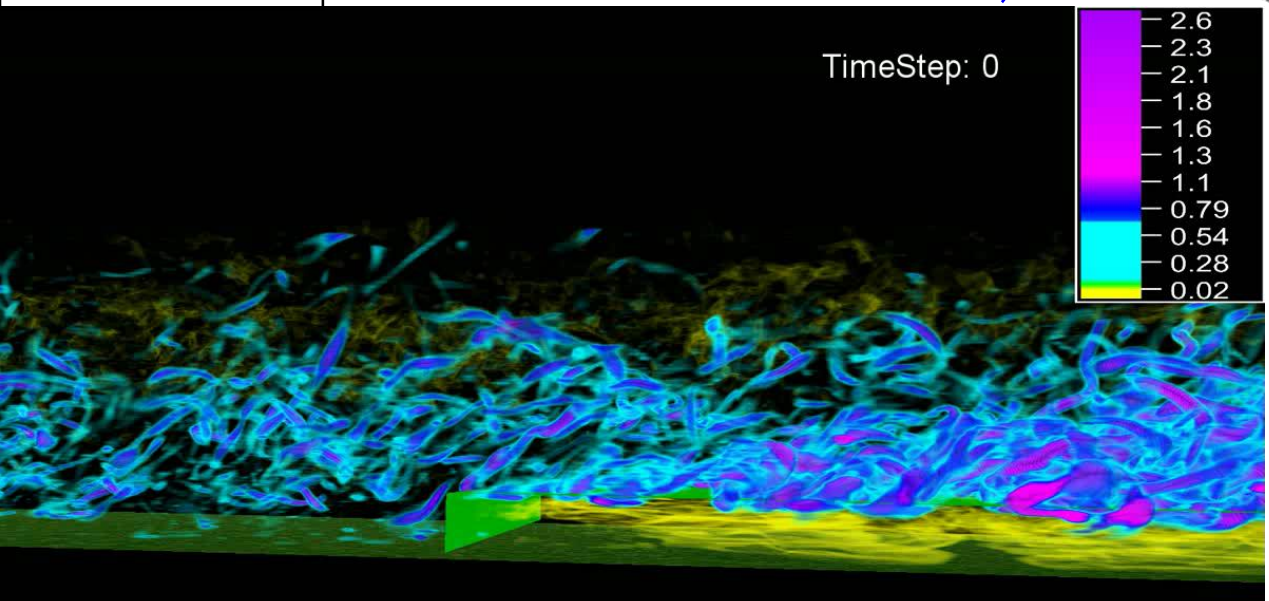
Cassiani et al. (2008)



Dupont and Brunet (2009)



vorticity [s^{-1}]



Question:

How does the forest edge effects turbulence measurements within the forest?

Kanani-Sühring and Raasch, 2015: Boundary-Layer Meteorol., 155.

PALM 5.0 and the [UC]² Project

Towards real environmental studies with a high resolution model

SPONSORED BY THE
Federal Ministry of Education and Research

MOSAIK

[UC]²: Urban **C**limate **U**nder **C**hange ~ 26 Mio € funding for 6 years

- **Main goal:** development of a new, modern, efficient, and user friendly city climate model, for (German) authorities, city planners, scientists,…
- **[UC]²** has three modules

a) model development:
   - based on PALM
   - coordinated by IMUK

b) validation measurements

c) user requirements (GUI)

- **should allow for simulations of complete major cities, with resolved buildings, include all processes of socio-economic importance**

DLR
Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD
Freie Universität Berlin
HUMBOLDT-UNIVERSITÄT ZU BERLIN
GEO-NET
Hochschule Offenburg
offenburg.university
KIT
Karlsruher Institut für Technologie
Leibniz Universität Hannover
Sieker
Die Regenwasserexperten

PALM 5.0 and the [UC]^2 Project

New processes considered in PALM 5.0

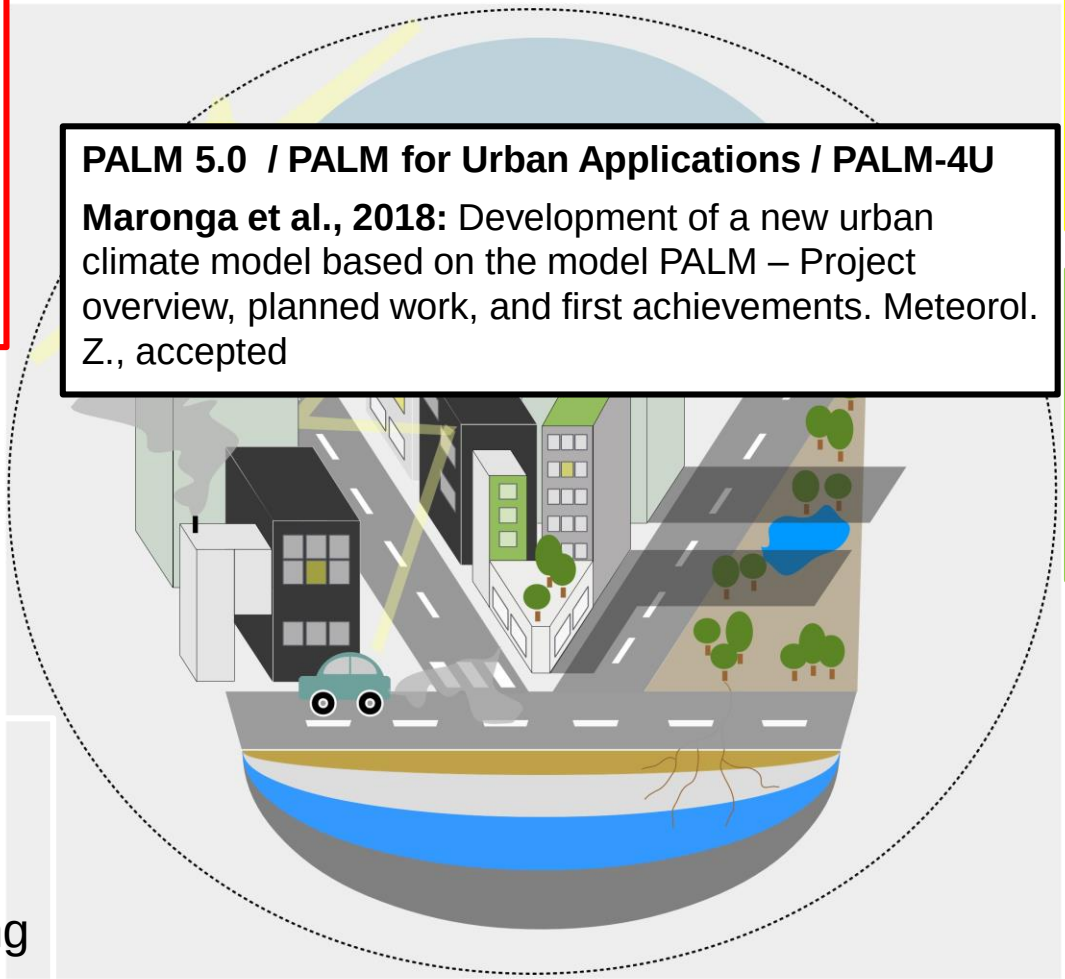
real surfaces & wall layers
- energy balance
- heat transfer
- surface material
- greening

chemistry
- emission
- transport
- reactions
- photolysis

nesting
- into large scale models
- LES / LES nesting as magnifier lens tool

PALM 5.0 / PALM for Urban Applications / PALM-4U

Maronga et al., 2018: Development of a new urban climate model based on the model PALM – Project overview, planned work, and first achievements. Meteorol. Z., accepted



radiation
- surface budget
- reflections
- shadows

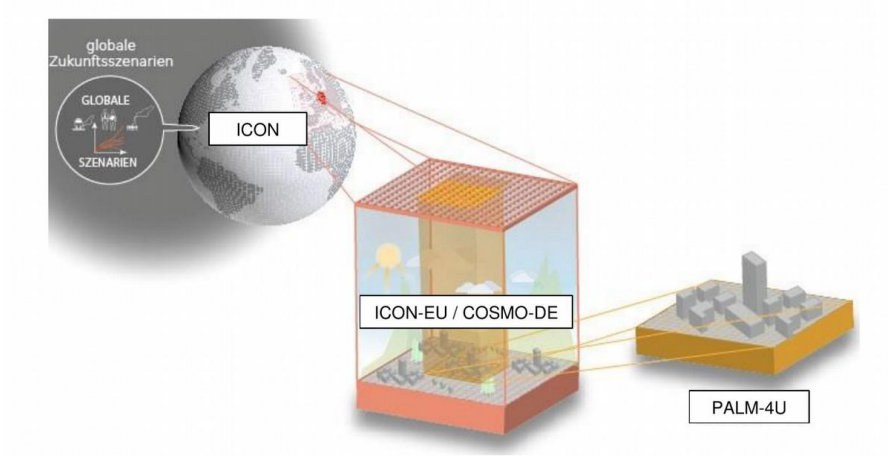
vegetation
- momentum sink
- energy balance
- roots
- soil water budget

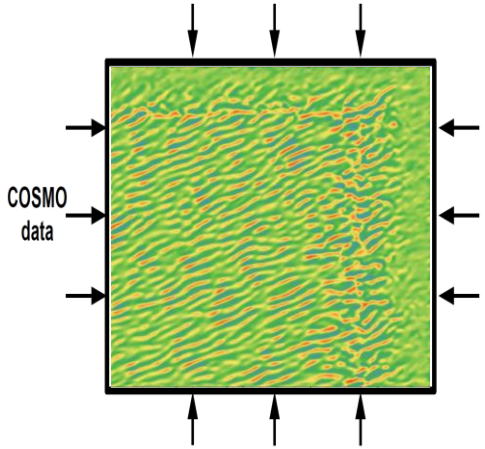
RANS mode
- based on k-ε model
- RANS / LES nesting with turbulent inflow

PALM-4U Selected Components

Nesting in larger-scale models

offline one-way-nesting into DWD-COSMO model





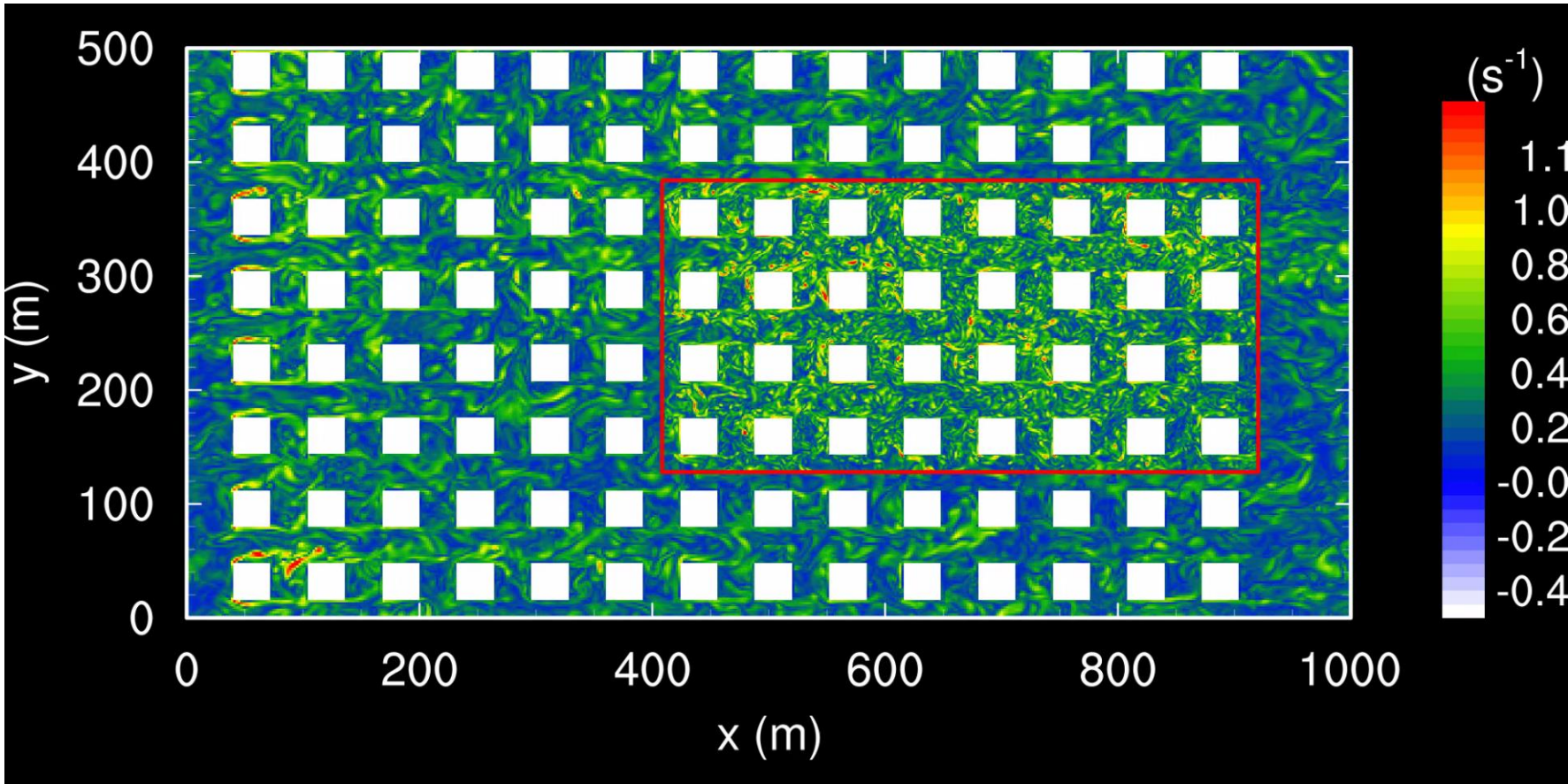
provides

- COSMO-derived initialization and forcing data to consider changing synoptic conditions during PALM-4U run
- turbulent inflow via synthetic turbulence generator is implemented

PALM-4U Selected Components

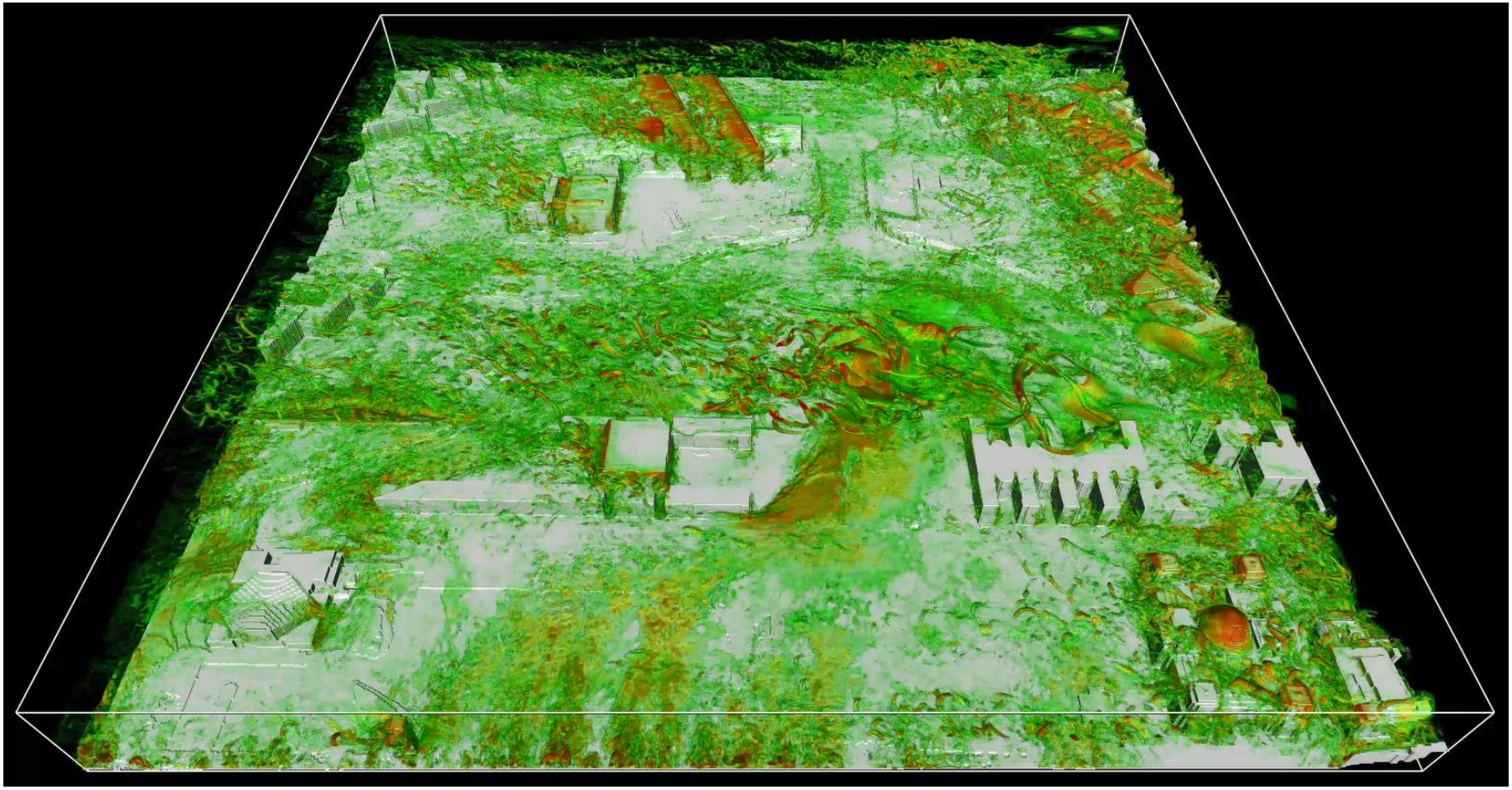
LES-LES nesting

- since our areas of interest are always fixed in space, we don‘t have a need for adaptive meshes
- a two-way nesting method is used instead
- animation shows the flow for a regular array of cubes (buildings)



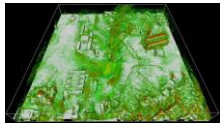
PALM-4U Application

Berlin – Government District



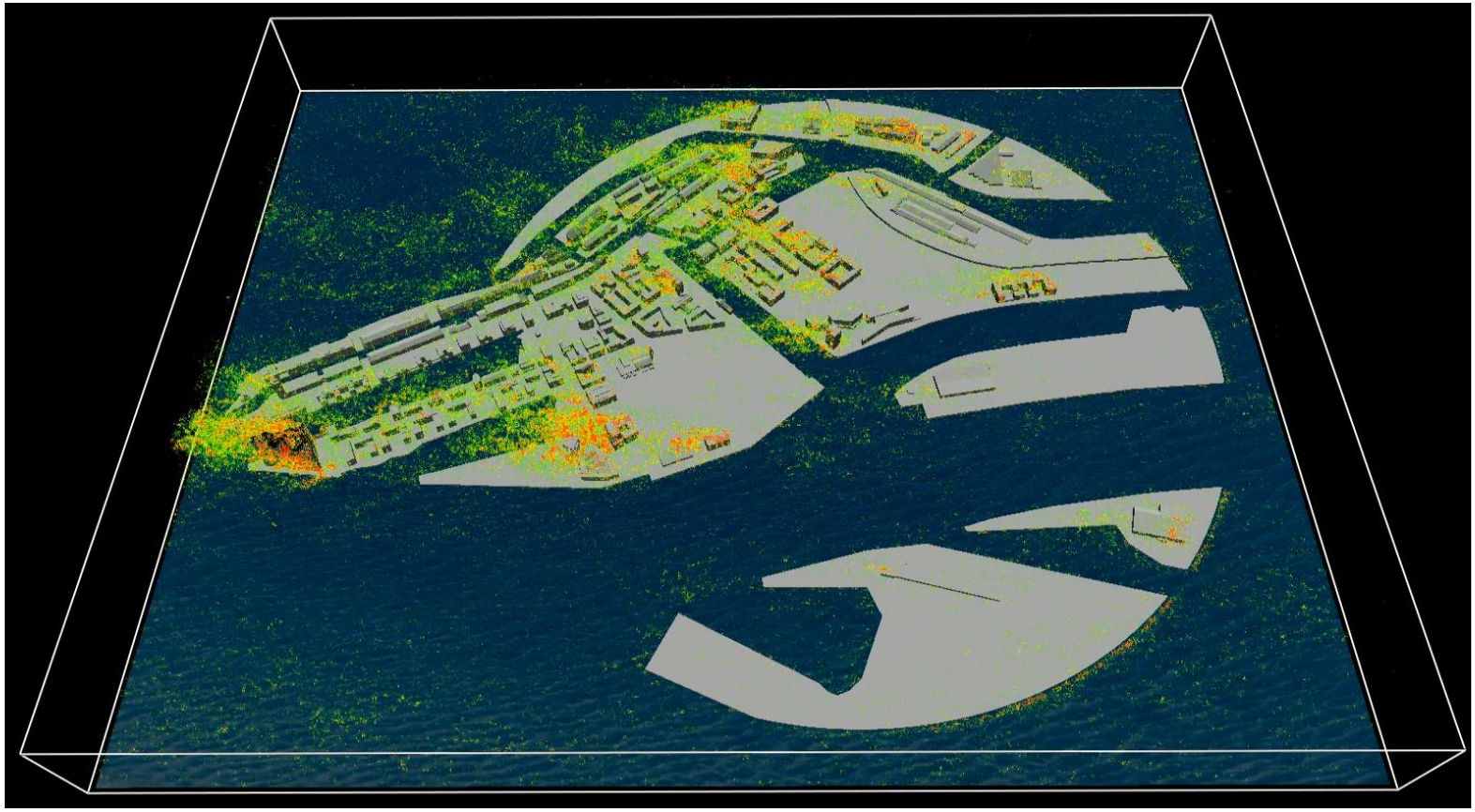
magnitude of rotation (s^{-1})
displayed time interval: 1:00 -1:30 UTC

output interval: 1s
750 GByte NetCDF raw data
rendering required 4h



PALM-4U Validation

with wind tunnel results from Univ. Hamburg



Hamburg Hafen-City

PALM-4U Validation

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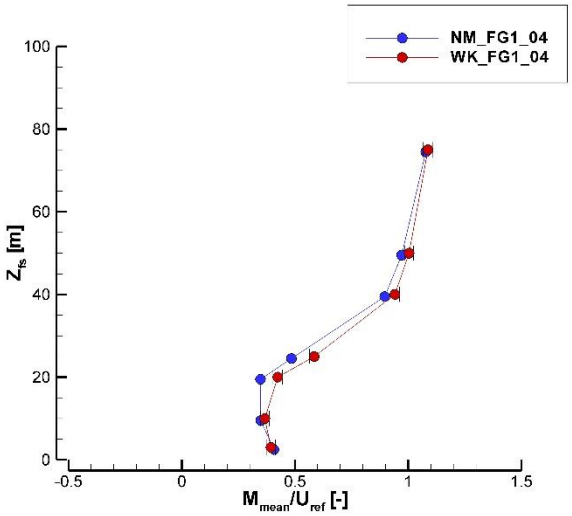
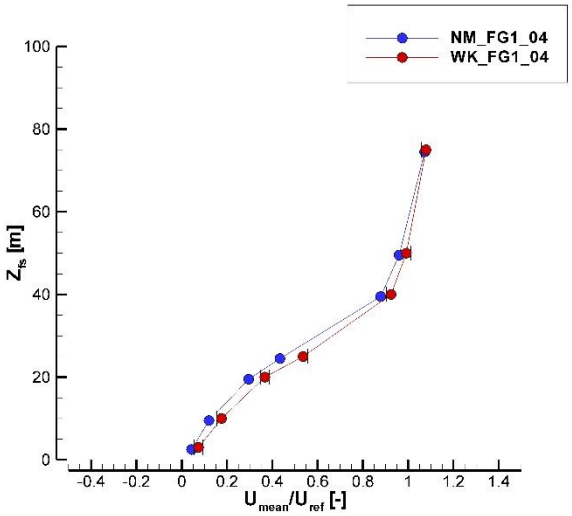
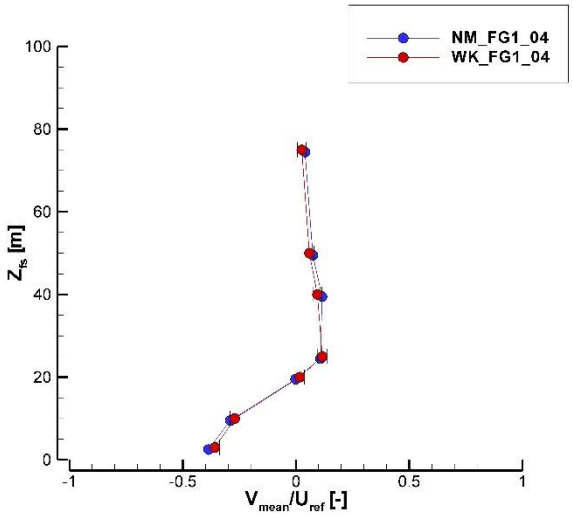
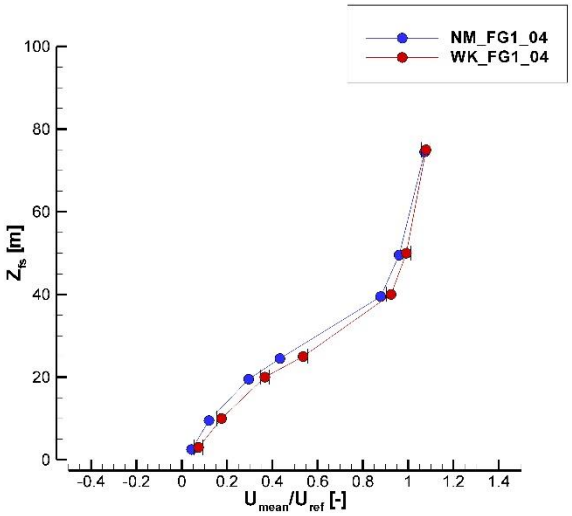
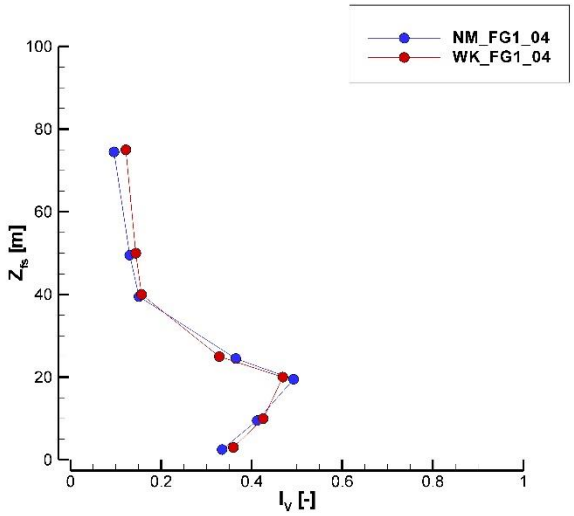
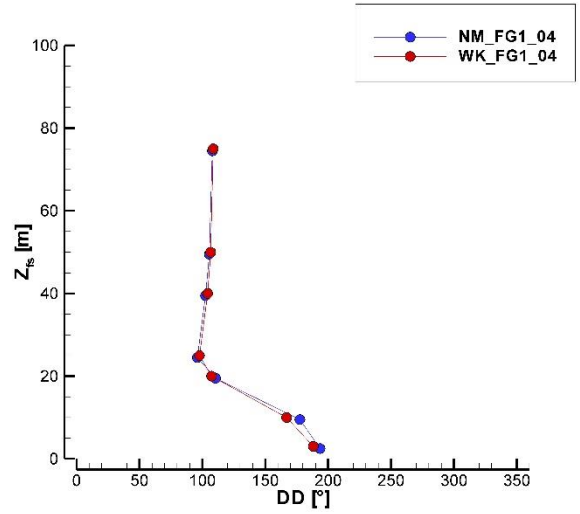






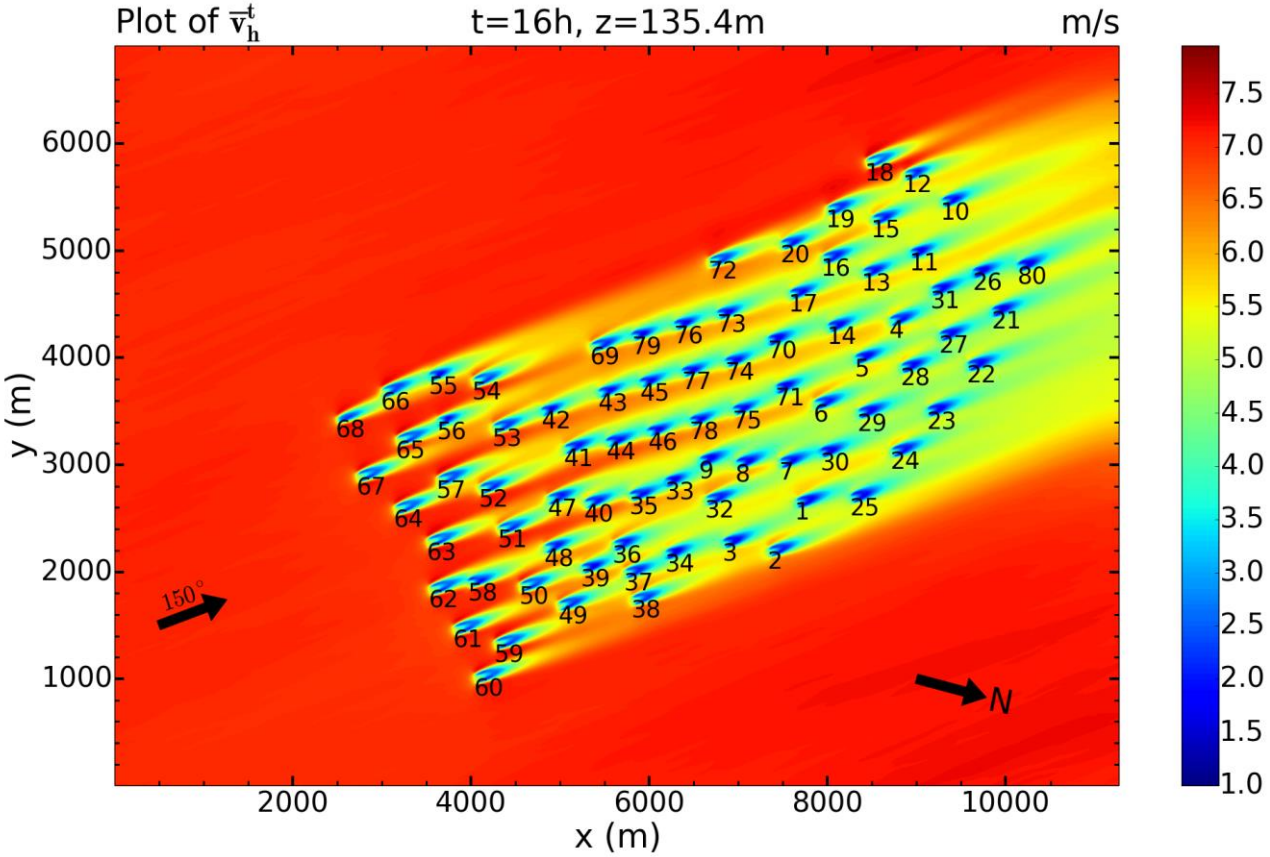






PALM – Wind Energy Applications

- Finished project: turbulence resolving simulation of windpark effect
- simulated with ADM-R method

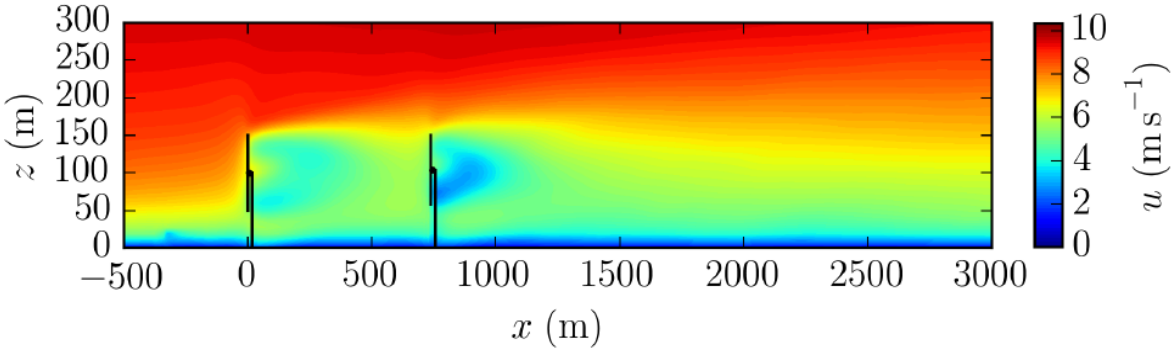


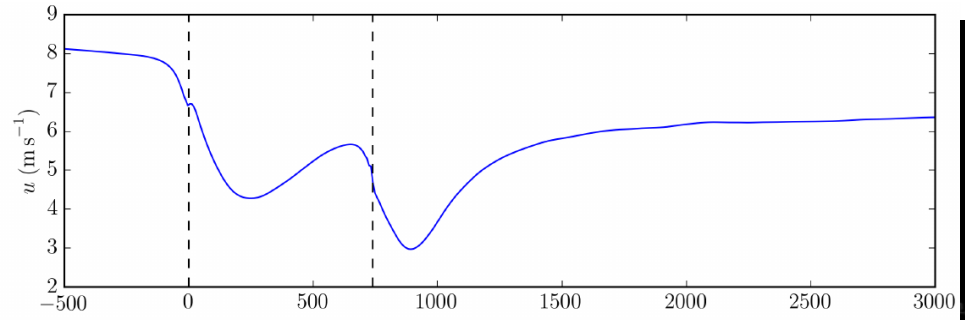
horizontal wind speed at hub height

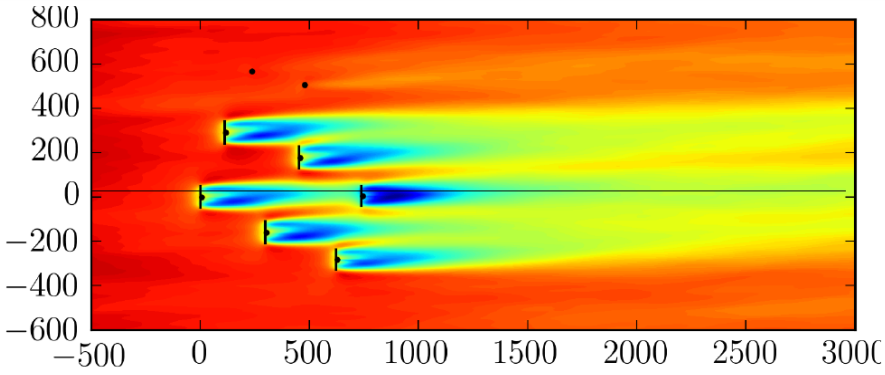
PALM – Wind Energy Applications

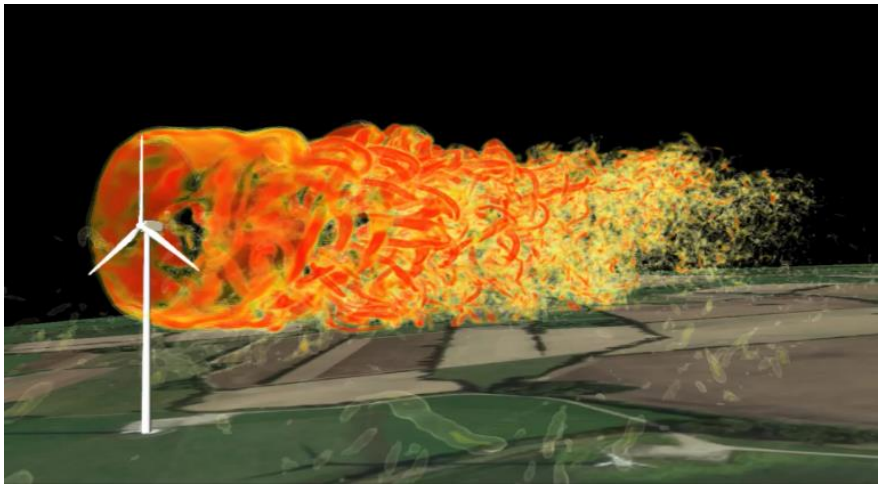
- BMWi-project WEA-Akzeptanz (with Senvion)

simulation of 3D-wind- and temperature fields for calculating noise propagation



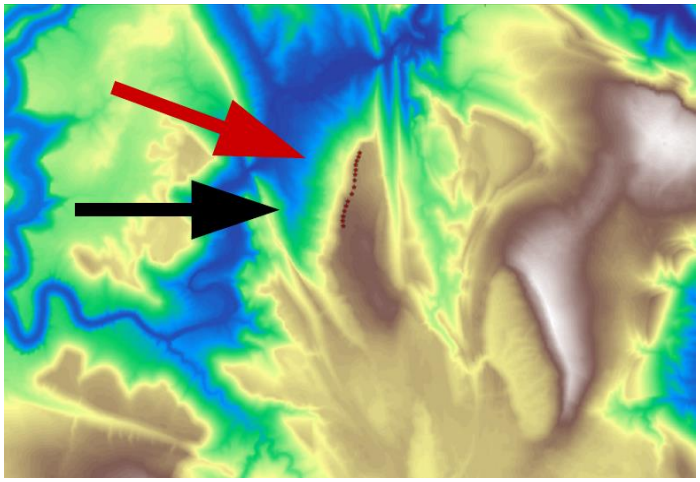


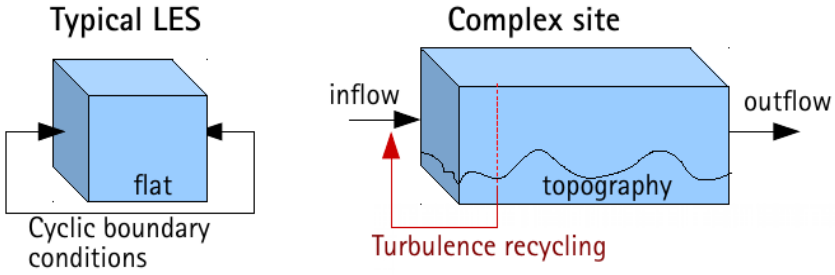


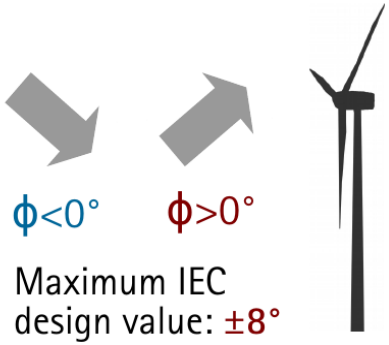


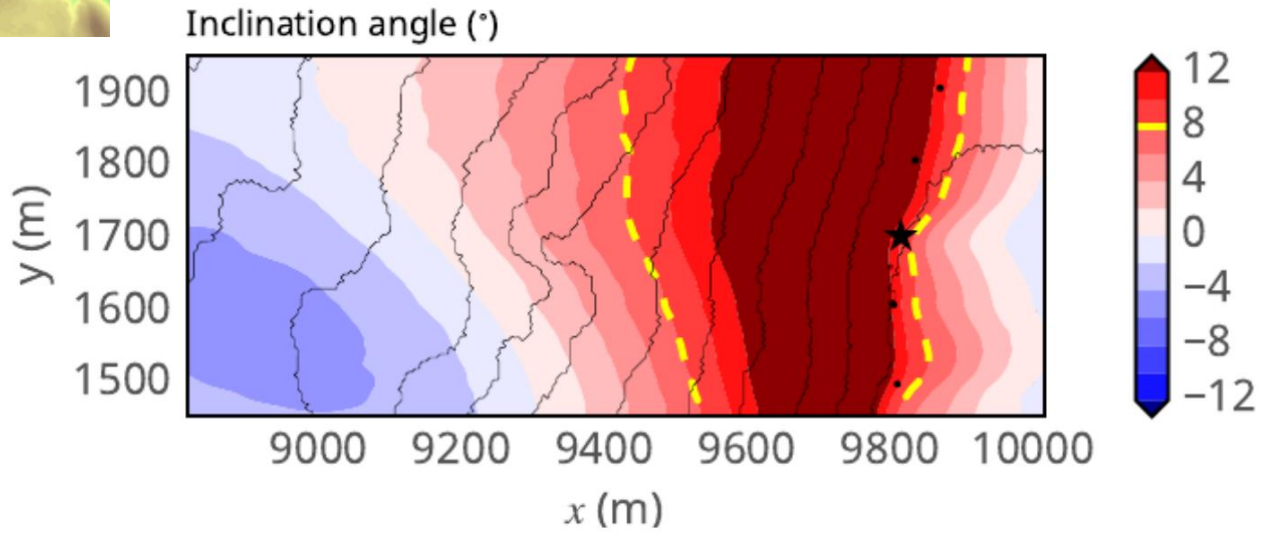
PALM – Wind Energy Applications

- BMWi-project AssiSt (with ENERCON): wind turbines in complex terrain









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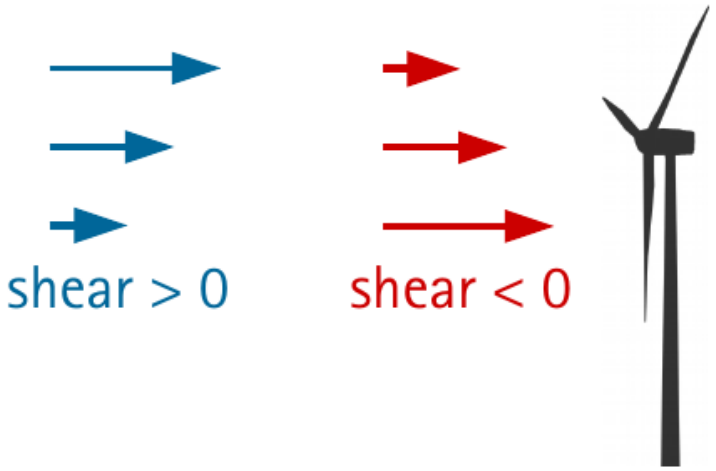
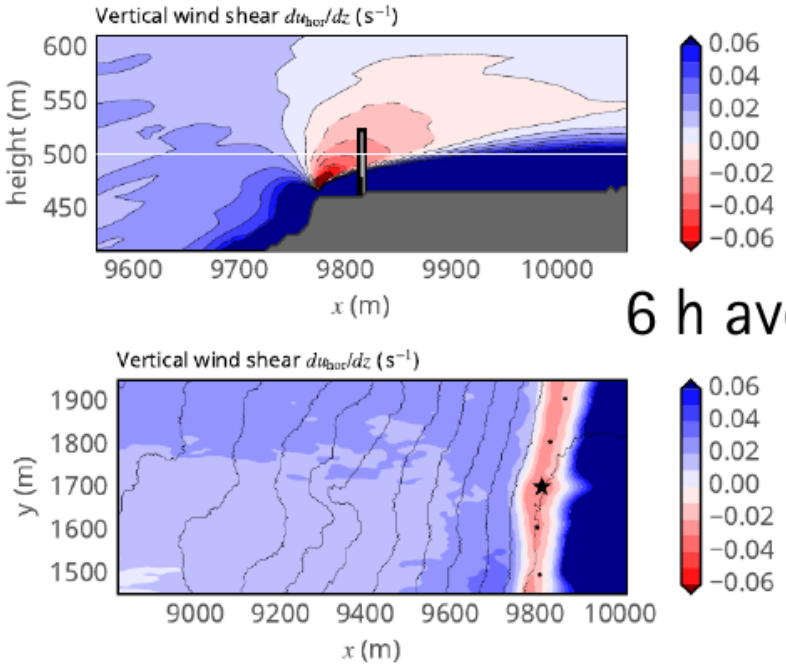
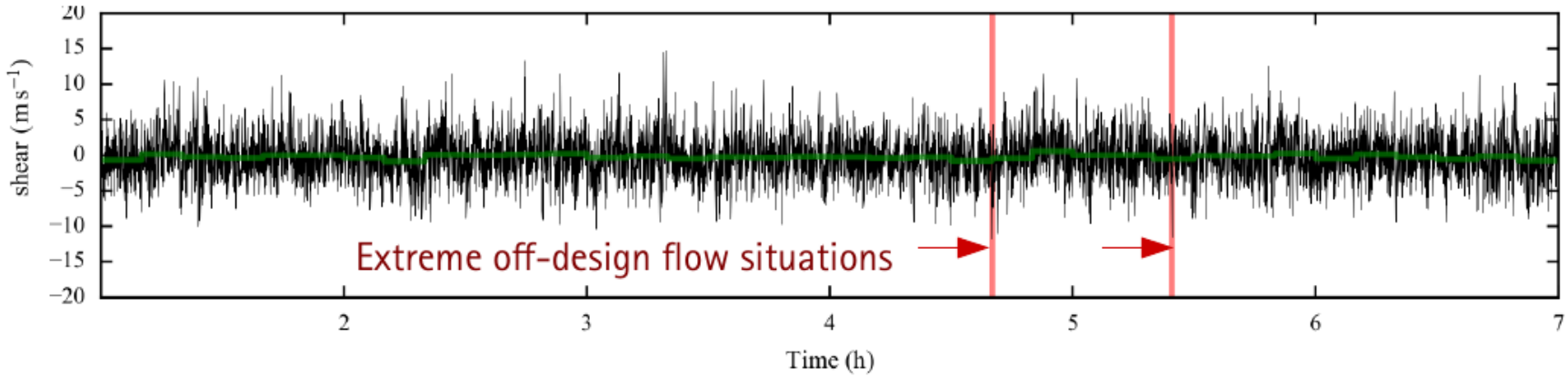




6 h average

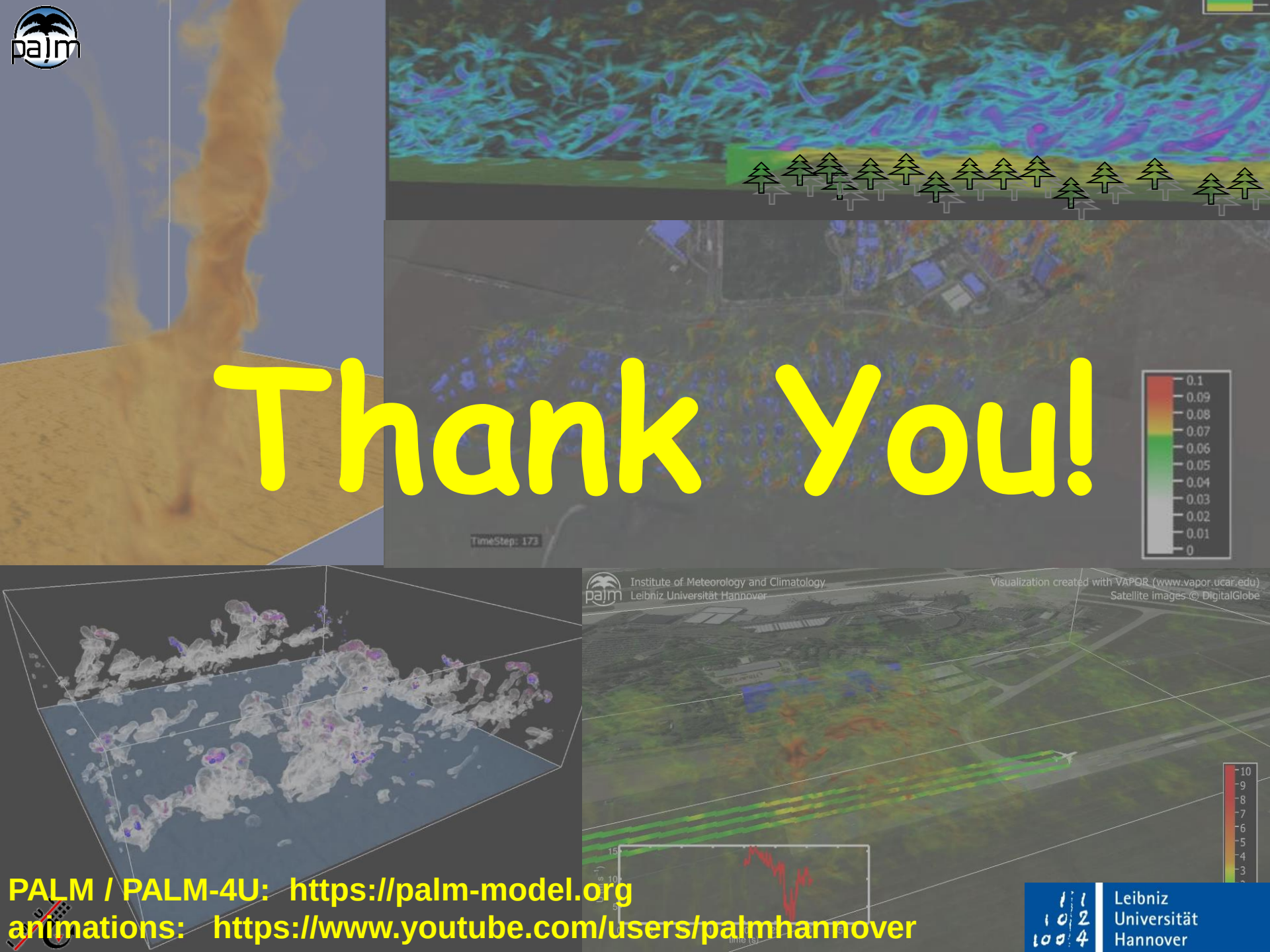


Challenges in Complex Terrain Flow Modeling

- **we can do:** high resolution simulation for a real site which is represented in the model as detailed as possible through
  - physical boundary conditions: high resolution topography, land cover / vegetation information, etc.
  - realistic meteorological conditions, i.e. different stability regimes, background flow, representation of the complete atmospheric boundary layer (otherwise turbulence may not be captured well)
  - consideration of complete daily cycles
- **we need:** thorough validation of simulation data for a complex site
  - requires high resolution observation of the 3D turbulence state at the site (point measurements not enough for a sufficient validation)
  - requires simulations nested into large scale model

Questions:

- Which is the benefit of such high resolution, turbulence resolving studies for site assessment, compared with cheaper RANS models?
- How precise must boundary conditions be known?
- What is the footprint of a site? Where is the turbulence originated from?
- How can the required computer resources be optimized?


Thank You!
TimeStep: 173
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