FINNISH METEOROLOGICAL INSTITUTE

Nested Multi-Scale System in the PALM Large-Eddy Simulation Model

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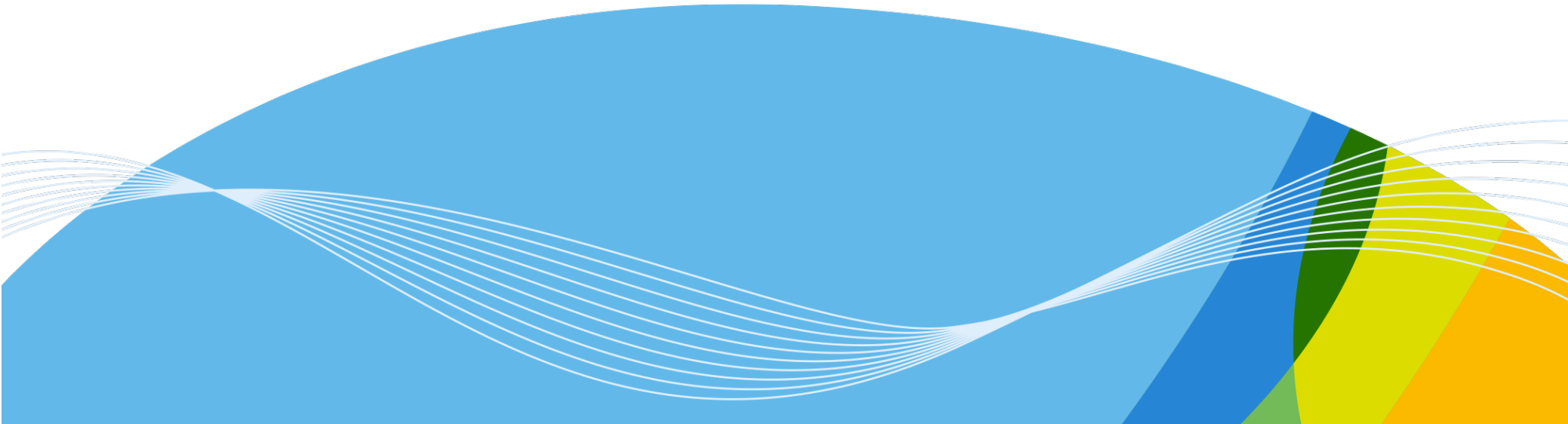


Motivation

- LES of wind flow in complex urban environment is a *multi-scale problem*
- The whole vertical extent of the Atmospheric Boundary Layer (ABL) must be solved simultaneously with the small-scale street-canyon turbulent events
- High enough resolution for a sufficiently large domain is usually too expensive → resolution must be concentrated to the area of principal interest

Motivation

- Unstructured-grid solvers would allow such refinement
- However, unstructured-grid solvers are inefficient and typically also less accurate compared to typical ABL LES solvers such as PALM that are based on structured orthogonal-grid arrangement
- For such solvers, model nesting is the only way to concentrate resolution to the principal area of interest
- We gain from both fast solver and spatially varying resolution!

PALM LES model

- PALM is a parallel LES model developed by the PALM-group led by Siegfried Raasch at Leibniz Universität Hannover, Germany
- Nowadays also Finnish Meteorological Institute (FMI) and University of Helsinki (UH) actively participate the development
- PALM is specifically designed for ABL problems
- Highly efficient and scalable MPI-parallelization tested up to 32 000 CPU-cores
- Open source code (under GNU general public licence) with complete documentation
- Freely available, see: https://palm.muk.uni-hannover.de/trac

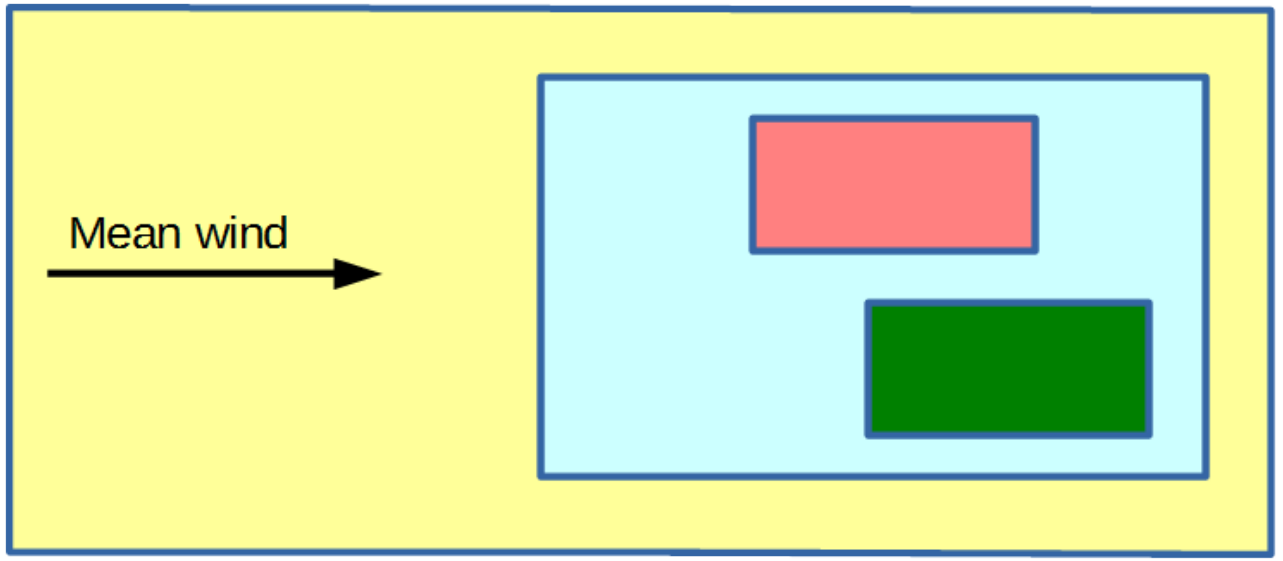
PALM LES model

- Incompressible Navier-Stokes equations in the Boussinesq form
- Anelastic equations being currently implemented
- Projection method with 3rd order Runge-Kutta time marching
- Pressure-step Poisson equation solved by a multigrid method (or by Fourier method in case of cyclic setup)
- Topography and buildings modelled by a simplified masking method
- Vegetation canopy model
- Coupled Lagrangian-stochastic particle model

Nesting method

- The system of nested domains consists of the *root domain* and *nest domains*
- There can be several nests but only one root
- Nests can have their own nests and so on (cascading domain arrangement)
- Nests can also be parallel to other nests
- Cascading and parallel nests can co-exist in the same run
- All the nests must always be completely inside their parent model domain

Nesting method



Root domain, the coarsest resolution

Nest domain, medium resolution

Nest domain, area of interest, the highest resolution

Nest domain, area of interest, the highest resolution

Nesting method

- The default mode of operation is *two-way coupling*
- A nest domain obtains its boundary-conditions from its parent domain through trilinear *interpolation*
- Next to a wall the trilinear interpolation is replaced by logarithmic interpolation (also in case of vertical wall)
- In two-way coupling the nest solution also influences its parent-domain solution through *anterpolation*
- Anterpolation consists of top-hat filtering, restriction to the coarser grid of the parent domain and replacement of the parent solution in the domain of overlap with some spatial over-relaxation applied near the nest boundaries

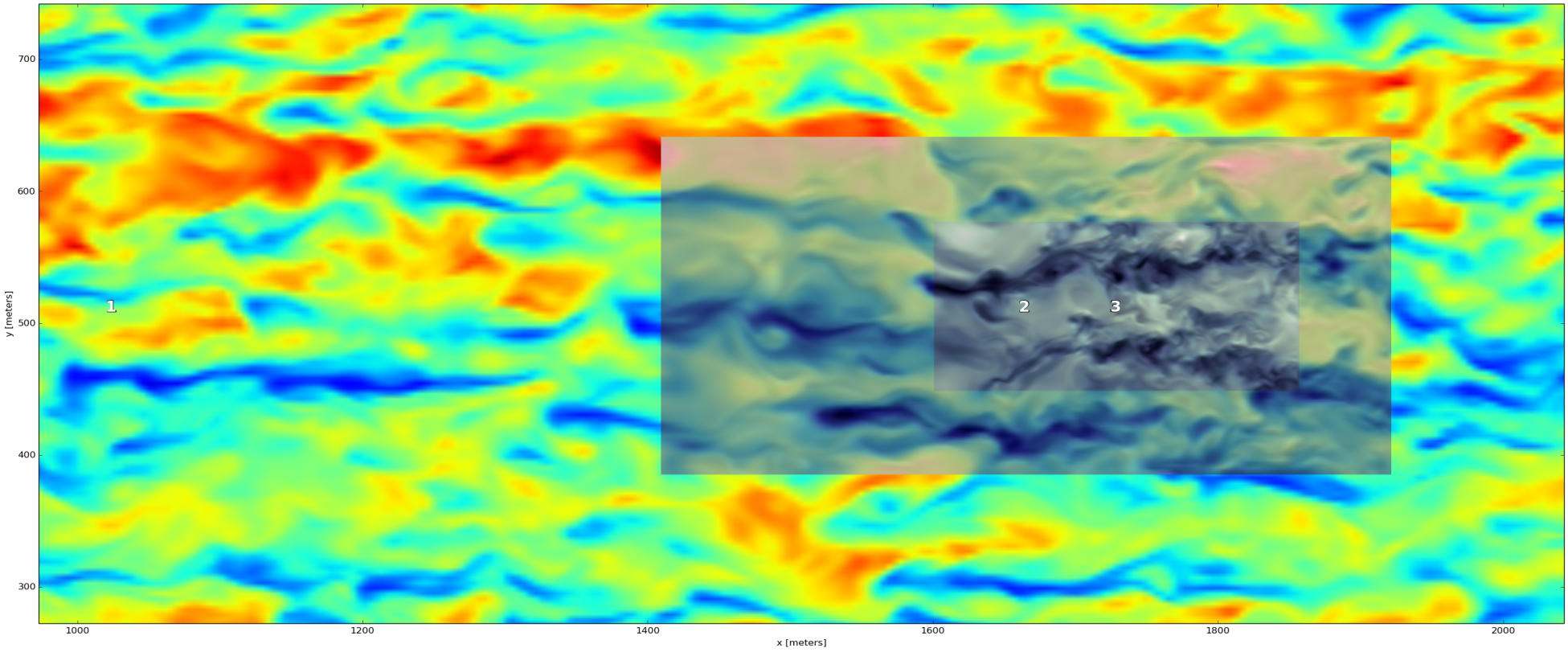
Nesting method

- This approach is known as *post insertion* (PI) method
- The coupling operations are made at each Runge-Kutta sub-step right *before* the pressure-projection step (this is actually our own variant of the PI method)

Implementation

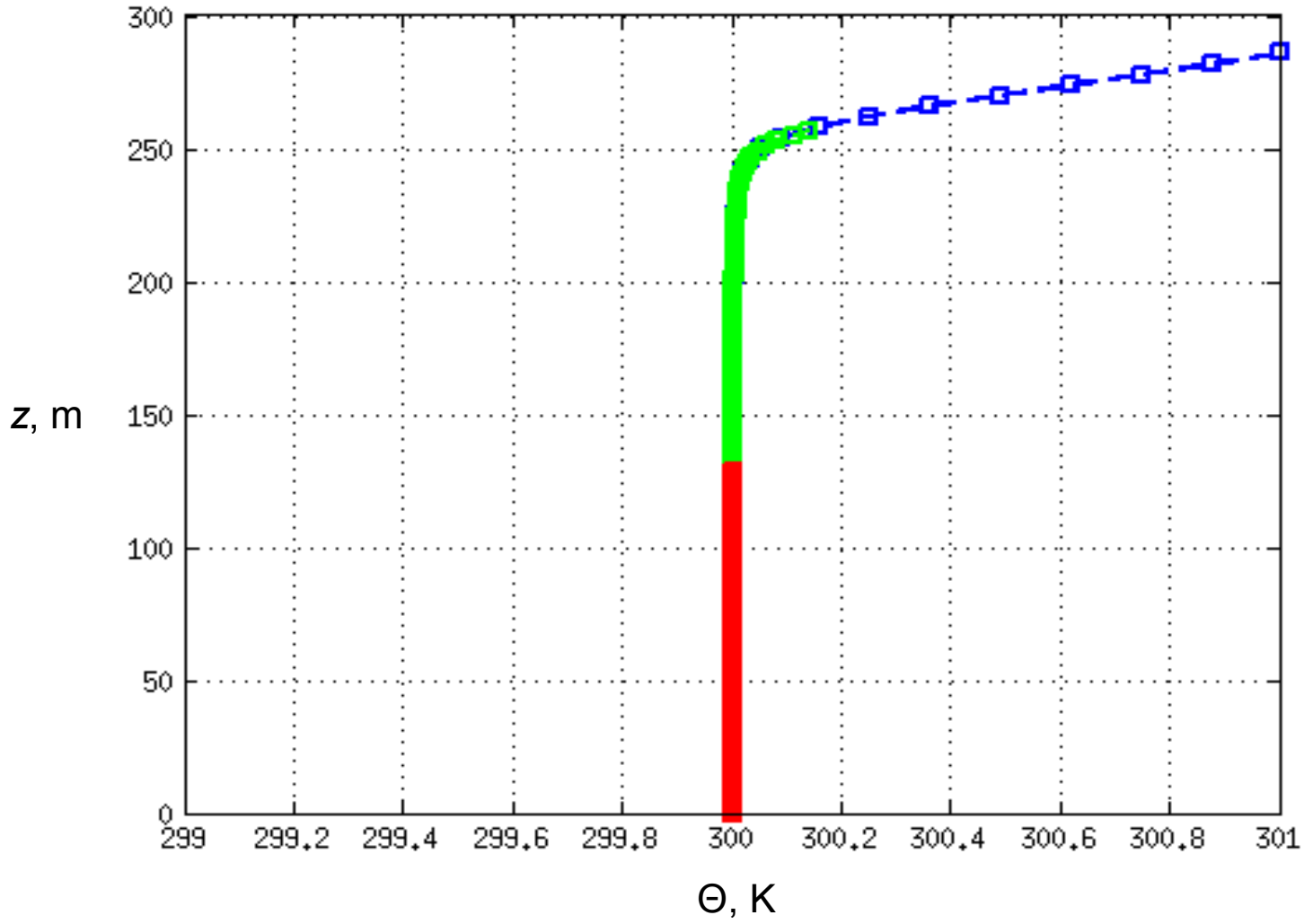
- The biggest challenge in the implementation was how to manage the complicated two-level parallelism: models run in parallel but they are also internally parallelized
- Palm Model Coupler (PMC) was developed to handle this complicated data transfer task
- PMC is a set of fortran modules and subroutines within PALM
- The PMC-routines are called from the pmc_interface-module which also includes all the interpolation and anterpolation algorithms
- Different MPI communicators are used for inter-domain and intra-domain communication
- PMC is implemented using the one-sided MPI-communication mode (Remote Memory Access, RMA)

Examples



Simple neutral boundary layer over flat terrain with inflow/outflow (left/right) BCs for the root domain. Three cascading domains. Instantaneous velocity *u*-component is shown at *z* =15 m. Different color schemes are used for the nests to make the boundaries visible.

Examples


300
250
200
150
100
50
0
z, m
299
299.2
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300.2
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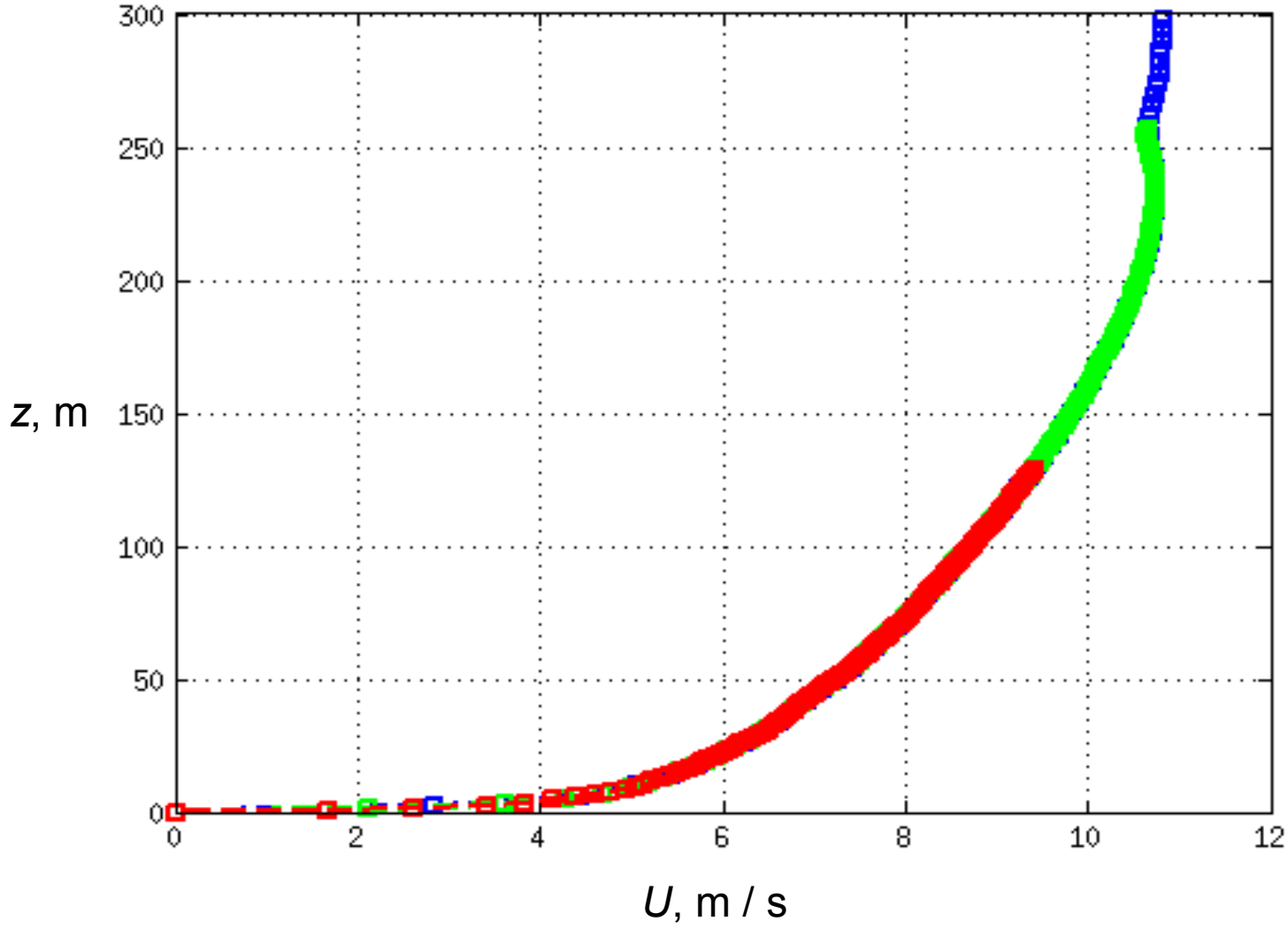
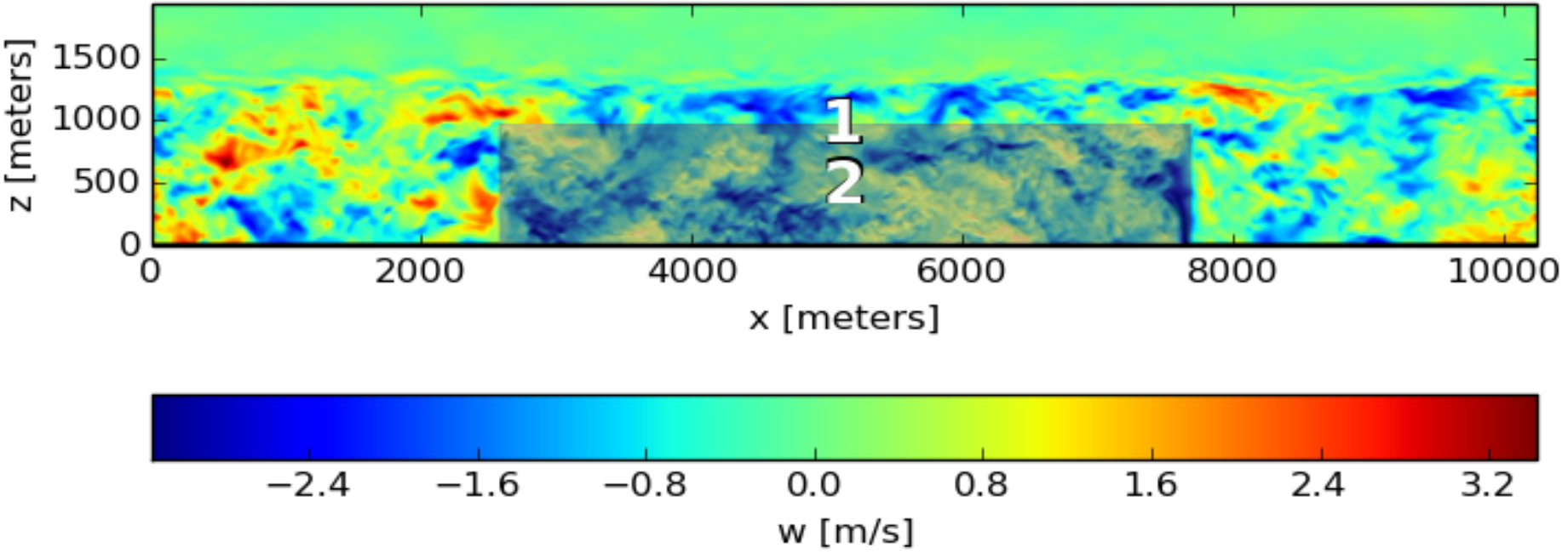
301
Θ, K

Examples

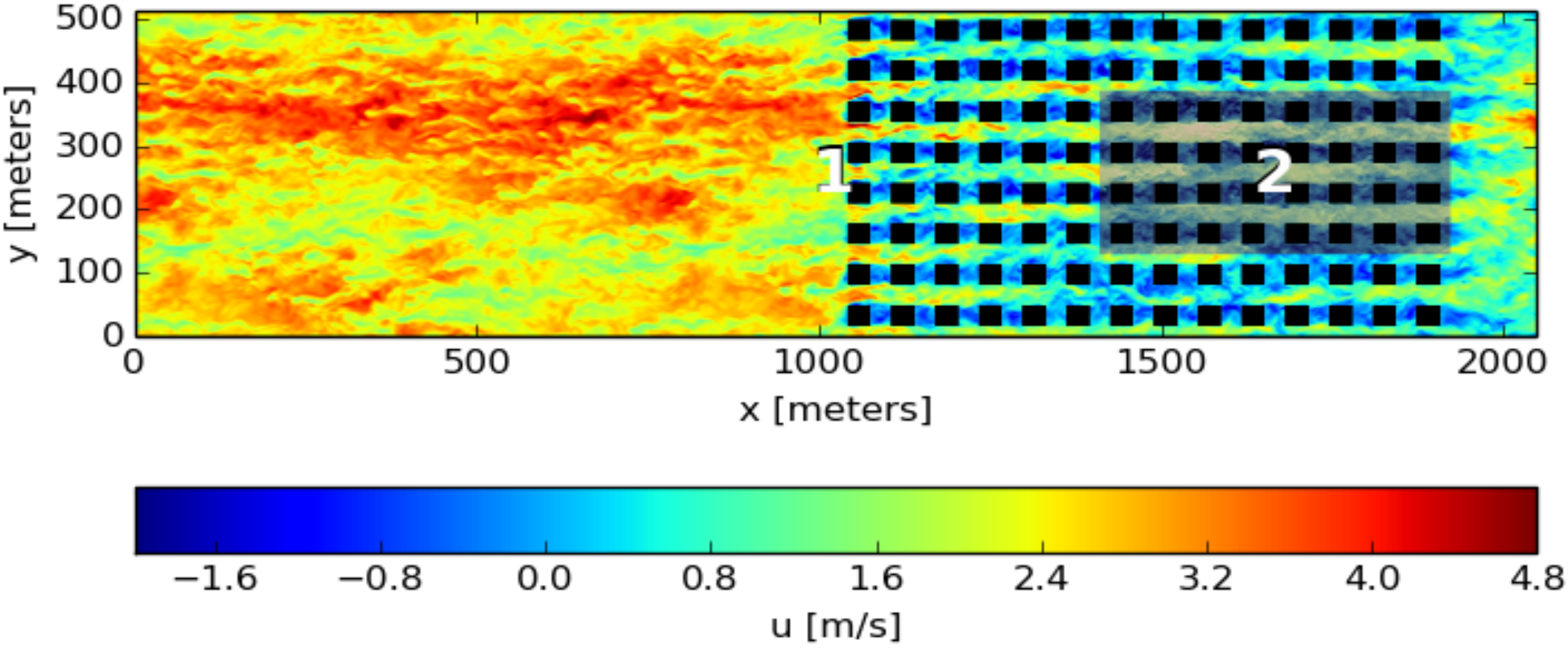


Examples



A convective boundary layer with zero mean wind. All cyclic BCs for the root domain.
A system of two domains. Instantaneous velocity *w*-component is shown on an *x*-*z*-plane.

Examples



A neutral boundary layer over an array of cuboids. Inflow/outflow BCs (left/right) for the root domain. A system of two domains. Instantaneous velocity *u*-component is shown on an *x*-*y*-plane.

Outlook

- The present nesting method works well according to all the tests made so far
- The extra time needed for data transfer, inter/anterpolations and time synchronization is typically from 10% to 17% if load balancing is taken care of – a price well worth paying
- A detailed validation will be carried out soon using the Complex Urban TEst setting (CUTE)
- We are already applying the nesting method to a practical urban-planning study involving real building geometries, terrain topography and trees

Motivation