PALM - Using Topography

PALM group

Institute of Meteorology and Climatology, Leibniz Universität Hannover

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Contents – Using Topography (I)

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    - Suitable driving methods, initial and boundary conditions
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- Data output

Purpose of Topography

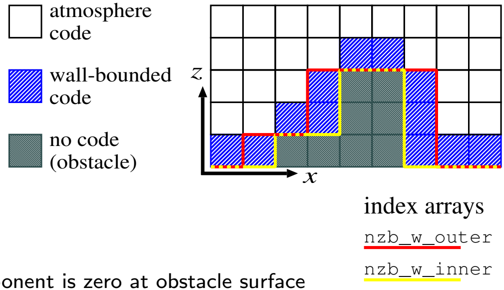
- Optional feature to simulate flow around/above obstacles
- Application fields
  - Urban meteorology, wind engineering
  - Mesoscale meteorology
  - Oceanography
  - ...

Definition

- Topography in PALM covers solid, impermeable, fixed flow obstacles with a volume of at least one grid box.
- Following qualifies as topography: ✓
  - Artificial obstacles (buildings)
  - Natural obstacles (hills, mountains)
- The following does NOT qualify as topography: ×
  - Permeable obstacles (vegetation) } Parameterization options in PALM: canopy model, local roughness length
  - Small obstacles (signposts)
  - Moving obstacles (vehicles, wind turbine rotors)

Realization - Physical Concept

- Flow cannot enter topography and is forced around/above it.
- Grid boxes are
  - 100% free fluid,
  - 100% fluid adjacent to an obstacle, or
  - 100% obstacle.



- No-slip boundary condition
  - Wall-normal velocity component is zero at obstacle surface
- Local surface layer for the first grid box adjacent to each obstacle surface 
  - Neutral Monin-Obukhov similarity

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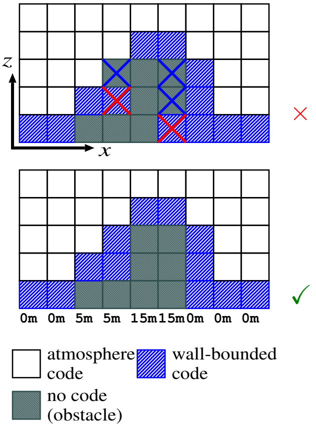
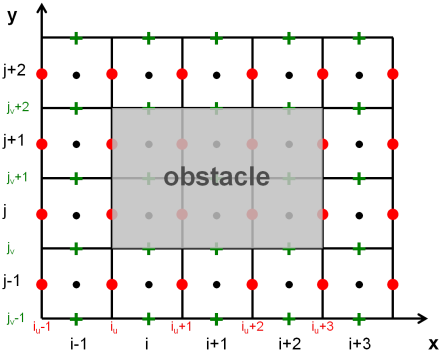
Realization - Numerical /Technical Implementation (I)

- Obstacles must be surface-mounted
- Overhanging structures ×, holes × etc. are not permitted.
  - This simplification allows extra performance optimization by reducing the 3D obstacle structure to a “2.5D“ structure.
  - “2.5D“ means that each surface grid cell is assigned only one building-height value (in m).
  - This conforms to the “2.5D“ format of Digital Elevation Models (DEM).



Realization - Numerical /Technical Implementation (II)

- The location of the wall-normal velocity component defines the location of the impermeable obstacle surface
- Obstacle surfaces that do not match the grid are approximated by grid boxes like a step-function



● scalars
● u (staggered)
+ v (staggered)

Realization - Numerical / Technical Implementation (III)

Rastering GIS data: "from GIS data to ASCII raster data"

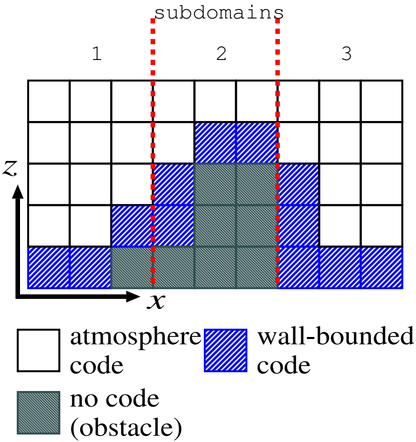
- In order to process topography from external data sources, the data must be made available to PALM as a rastered ASCII file:
  - see e.g. `trunk/EXAMPLES/topo_file/example_topo_file_topo`.
- The layout of this topography file must conform to the computational domain size and to the grid size `dx` and `dy`.
- The rastered height data of this topo file are given in m above ground and do not need to match the vertical grid, since they will be interpolated, if required.

- Software known to be able to perfom the rastering process of GIS data in vector and/or raster format to PALM raster format:
  - ArcGIS (commercial)
  - GRASS GIS (freeware)

Realization – Numerical / Technical Implementation (IV)

Potential issue: Load imbalance

- Since prognostic equations are not calculated inside buildings, **load imbalance** might occur, if topography is heterogeneously distributed among the subdomains.
  - This means "fast" CPU(s) must wait for "slow" CPU(s), leading to inefficient parallelization.



Summary: Strengths (+) and Limitations (–)

+ Horizontal and vertical surfaces can be exactly resolved (thanks to the finite difference Cartesian model architecture)
+ Optimization also for scalar computer architectures
+ Conforms with "2.5D" format of Digital Elevation Models (DEM)

– Obstacles must be surface-mounted
– Overhanging structures, holes etc. are not permitted due to the "2.5D" format
– Grid boxes can only be 100% fluid or 100% obstacle

  Obstacle surfaces that do not match the grid are approximated by grid boxes like a step-function, which can modify the real obstacle size or the orientation of the obstacle faces

Take a Short Break... Urban Flow Visualization

Hannover - Brühlstraße / Lange Laube

Set-up: neutral boundary layer

- Particle = passive tracer
- Colour ∼ particle height
- Tail length particle velocity

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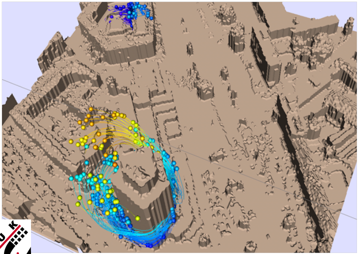

Set-up: neutral boundary layer

- Particle = passive tracer
- Colour $\sim$ particle height
- Tail length   particle velocity

- Flow past office tower:
  - initially laminar: not yet an LES
  - intermittent: different episodes
- Broad street canyon flow:
  - channeling
  - low-level upstream flow

Required Topography Control Parameters

topography =

- 'flat' — no topography (default)
- 'single_building' — generic single building
- 'single_street_canyon' — generic single quasi-2D street canyon
- 'read_from_file' — rastered ASCII file (e.g. trunk/EXAMPLES/topo_file)
- any other string — processed by user subroutine user_init_grid

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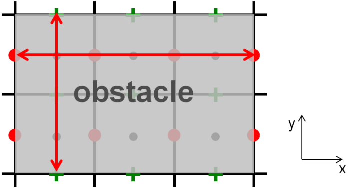
- any other string — processed by user subroutine user_init_grid

topography_grid_convention =

- 'cell_edge' — default for generic topography: ↔



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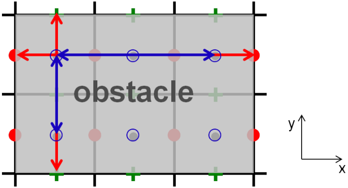
- any other string — processed by user subroutine user_init_grid

topography_grid_convention =

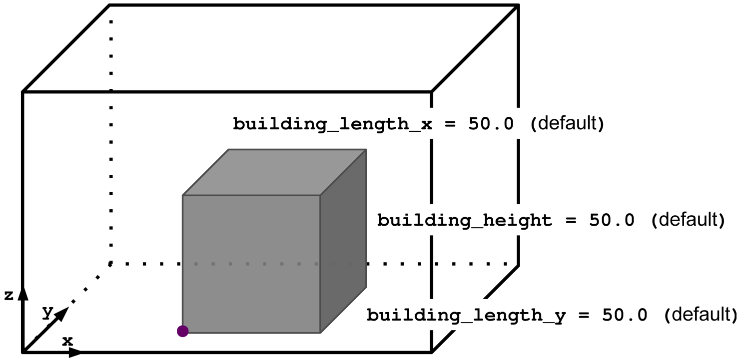
- 'cell_edge' — default for generic topography: ↔
- 'cell_center' — default for rastered topography: ◯ ↔



Optional Topography Control Parameters (I)

Generic topography

`topography = 'single_building'`

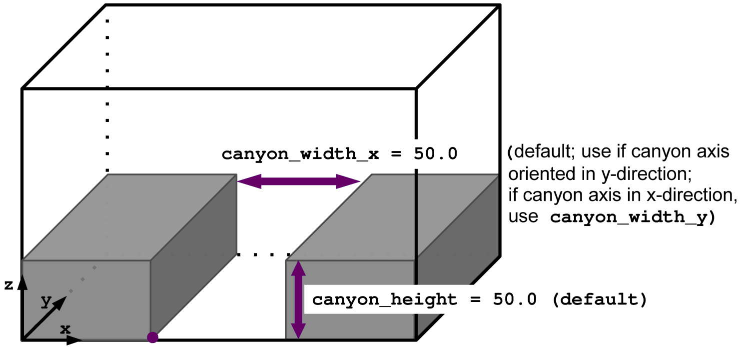


- **building_wall_left, building_wall_south**
  (in m, default is building centered in the model domain)

Optional Topography Control Parameters (II)

Generic topography

`topography = 'single_street_canyon'`

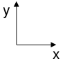


● **canyon_wall_left** (if canyon axis oriented in y-direction, otherwise use **canyon_wall_south**)

Optional Topography Control Parameters (III)

Rastered topography

- `topography` = 'read_from_file'
  - requires an external ASCII file, e.g. `example_topo`:




```
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

  - ASCII file `example_topo` must be available as INPUT file, like `example_p3d` (`JOBS/example/INPUT/`)
  - layout must conform to domain size and grid size `dx` and `dy`
  - height data in m above ground (INTEGER or REAL) do not need to match the vertical grid

Optional Topography Control Parameters (IV)

Rastered topography

- `topography` = 'read_from_file'
  - **mrun**-call:
    `mrun ...  -r 'd3# ...'`
  - `.mrun.config`:

```
#----------------------------------------------------------------------------
# List of input-files
#----------------------------------------------------------------------------
PARIN              in:job     d3#      $base_data/$fname/INPUT    _p3d
PARIN              in:job     d3f      $base_data/$fname/INPUT    _p3df
TOPOGRAPHY_DATA    in:locopt  d3#:d3f  $base_data/$fname/INPUT    _topo
```

General Control Parameters (I): Suitable Driving Methods

- **"Meteorological" set-up M: geostrophic wind / Coriolis force**
  - Set `omega` $\neq$ `0.0`
  - Construct a non-zero profile of geostrophic wind u_g and/or v_g using `ug_surface`, `ug_vertical_gradient` and `ug_vertical_gradient_level` and/or the respective parameter set for v_g
- **"Engineering" set-up E: direct external pressure gradient / no Coriolis force**
  - Set `omega = 0.0`
  - Set-up E1: direct external pressure gradient that does not change with time (the bulk velocity fluctuates with time)
    - Parameters: `dp_external`, `dp_smooth`, `dp_level_b`, `dpdxy`
  - Set-up E2: maintain a constant bulk velocity (the direct external pressure gradient fluctuates with time)
    - Parameters: `conserve_volume_flow`, `conserve_volume_flow_mode`, `u_bulk`, `v_bulk`
- **"Thermal" set-up T: directly prescribe sensible heatflux**
  - surface_heatflux at ground level only
  - wall_heatflux(0:4) at top/left/right/South/North obstacle face

General Control Parameters (II): Initialization

- **"Meteorological" set-up M**

  Initialize a non-zero profile of geostrophic wind u_g and/or v_g using
  - `initializing_actions` = **'set_constant_profiles' (e.g. for convective BL)**
    - Parameters: `ug_surface` $\neq$ `0.0` and/or `vg_surface` $\neq$ `0.0`
  - `initializing_actions` = **'set_1d-model_profiles' (e.g. for neutral BL)**
    - 1D model prerun parameters with suffix `_1d` (e.g. `end_time_1d`, `damp_level_1d`)

- **"Engineering" set-up E**

  Good initialization may require a priori knowlegde, e.g. from previous test runs. Here, `ug_...` and `vg_...` don't refer to geostrophic wind but to the initial wind profile.
  - `initializing_actions` = **'set_constant_profiles'**
    - Parameter set: `ug_surface`, `ug_vertical_gradient[_level]` and/or the respective set for v_g
  - `initializing_actions` = **'set_1d-model_profiles'**
  - `initializing_actions` = **'by_user' – processed by user_init_3d_model**

- **"Thermal" set-up T**

  Any of the above may apply

General Control Parameters (III): Boundary Conditions

- Lateral boundary conditions
  - Cyclic / non-cyclic: cf. lecture on "non-cyclic boundary conditions"
- Bottom boundary conditions
  - Cf. lecture on "numerics and boundary conditions"
- Top boundary conditions
  - **Channel**: `bc_uv_t` = **'dirichlet_0' (no-slip)**
  - **Open channel**: `bc_uv_t` = **'neumann' (slip)**
  - **"Constant flux" layer**: `bc_uv_t` = **'neumann' (slip)**
    with set-up E1 where `dp_level_b >> 0` and `dp_smooth = .T.`

General Control Parameters (IV): Pressure Solver

`psolver =`

- 'poisfft' (FFT scheme)
  - Good performance for urban PALM version
  - Cannot be used with non-cyclic boundary conditions
- 'multigrid' (Multigrid scheme)
  - Performance for very large number of grid points may be better than FFT
  - This is the only possible choice for non-cyclic boundary conditions

Data Analysis / Output – Some Considerations (I)

- How to get turbulence statistics?
  - Phase averaging if a direction of homogeneity exists
  - Temporal averaging
  - Ensemble averaging
- Definition of turbulent fluctuations

  Spatial fluctuations: deviation from representative instantaneous spatial average
  - PALM: many statistics calculated on-the-fly as time series, 1D vertical profiles
  - Not suitable for topography unless a direction of homogeneity exists

  Temporal fluctuations: deviation from representative local temporal average
  - Suitable for all applications including topography
  - Requires much hard disk space and post-processing CPU time
  - PALM: not natively supported, but following procedure works:
    - Collect time-series during the simulation (2D/3D data output or user-defined time series)
    - Check for (quasi-)steady turbulent state and sufficient averaging time
    - Calculate statistics by post-processing making use of the Reynolds decomposition:

$$\overline{w'\theta'} = \overline{w\theta} - \overline{w}\,\overline{\theta}$$

Your Responsibility and Contribution

PALM's topography features have been frequently applied within the last years, but there may be still some parameter combinations which have not been used so far, and which may not work properly.

Therefore, we ask you for your responsibility and contribution:

- Please always check your PALM setup carefully. PALM is not a black box.
- For example, design a simple case and test your expectation.
- Please report potential bugs using our trouble ticket system.

Some recent examples of topography/building applications with PALM

Street canyon flows

Letzel, M.O., M. Krane and S. Raasch 2008: High resolution urban large-eddy simulation studies from street canyon to neighbourhood scale, Atmos. Env., **42**, 8770-8784, doi:10.1016/j.atmosenv.2008.08.001.

Turbulence generated by topography

Esau, I. and I. Repina, 2012: Wind climate in Kongsfjorden, Svalbard, and attribution of leading wind driving mechanisms through turbulence-resolving simulations. Advances in Meteorology, **Volume 2012**, Article ID 568454, 16 pages, doi:10.1155/2012/568454.

Airflow within or over building arrays

Abd Razak A., A. Hagishima, N. Ikegaya and J. Tanimoto, 2013: Analysis of airflow over building arrays for assessment of urban wind environment. Building and Environment, **59**, 56-65, doi:10.1016/j.buildenv.2012.08.007.

Kanda, M., A. Inagaki, T. Miyamoto, M. Gryschka and S. Raasch 2013: A New Aerodynamic Parameterization for Real Urban Surfaces, Boundary-Layer Meteorol., **148**, 357-377, doi:10.1007/s10546-013-9818-x.

Thermal effects of building walls

Park, S.B., J.J. Baik, S. Raasch and M.O. Letzel 2012: A large-eddy simulation study of thermal effects on turbulent flow and dispersion in and above a street canyon., J. Appl. Meteor. Climatol., **51**, 829-841, doi:10.1175/JAMC-D-11-0180.1.

PALM coupled to a building energy model

Yaghoobian, N., J. Kleissl and K. T. Paw U, 2014: An Improved Three-Dimensional Simulation of the Diurnally Varying Street-Canyon Flow, Boundary-Layer Meteorol., doi:http://dx.doi.org/10.1007/s10546-014-9940-4.

Topography - Scenario examples

Set-up Scenario: Single Street Canyon (I)

Single quasi-2D street canyon in neutral open channel flow with constant bulk velocity

- `trunk/EXAMPLES/canyon/`
  - Parameter file `example_canyon_p3d`
  - Run-control file `example_canyon_rc`
  - Some documentation `example_canyon.odt`

```
&inipar nx = 39, ny = 39, nz = 40,
        dx = 2.0, dy = 2.0, dz = 2.0,

        omega = 0.0,                            ! no Coriolis force
        conserve_volume_flow = .T.,             ! maintain constant bulk velocity

        initializing_actions = 'set_constant_profiles',
        ug_surface = 1.0, vg_surface = 0.0,     ! implies bulk velocity of 1 m/s
        roughness_length = 0.1,                 ! applies to all surfaces locally

        bc_pt_b = 'neumann',
        bc_uv_t = 'neumann',                    ! open channel boundary condition

        topography = 'single_street_canyon',    ! regular street canyon
        canyon_height  = 40.0,                  ! - axis oriented in y-direction
        canyon_width_x = 40.0,                  ! - centered in x-direction

        surface_heatflux = 0.0,                 ! strictly neutral simulation
        wall_heatflux = 0.0, 0.0, 0.0, 0.0, 0.0,  /
```

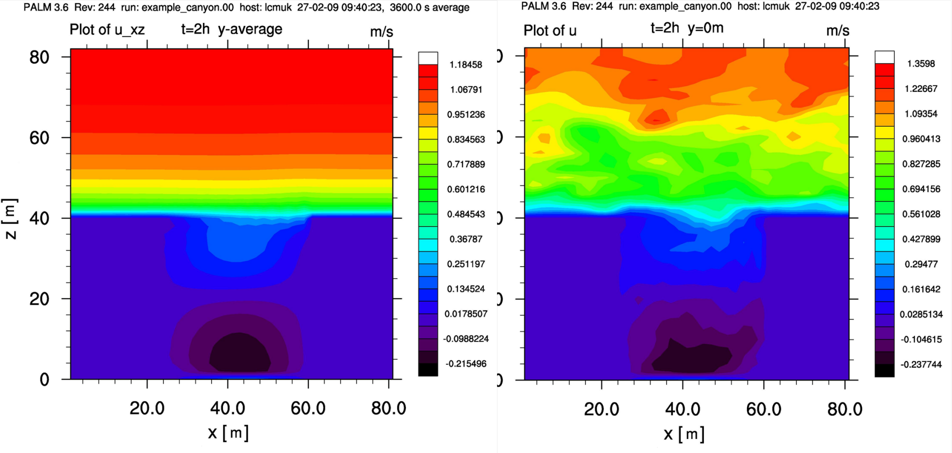
Set-up Scenario: Single Street Canyon (II)

The phase average makes use of homogeneity in y-direction:

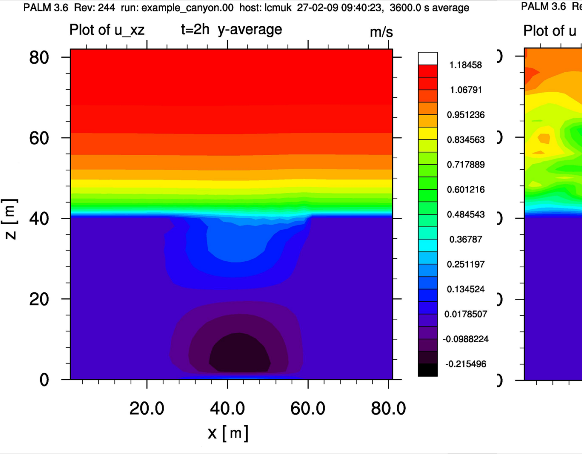
`section_xz = -1`, `data_output = 'u_xz_av', 'v_xz_av', 'w_xz_av'`

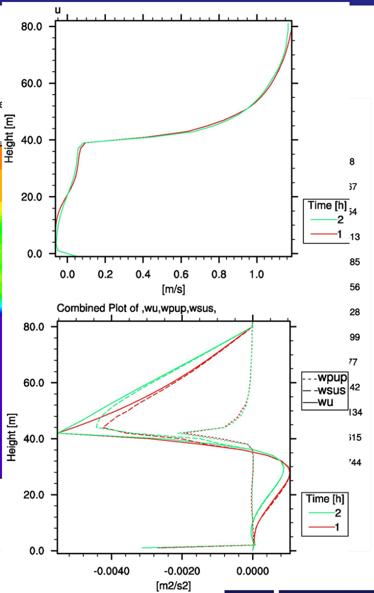
```
&d3par  end_time                    =   7200.0,
        termination_time_needed     =    900.0,
        create_disturbances = .T.,

        dt_run_control              =      6.0,
        dt_dots                     =      6.0,

        skip_time_dopr              =      0.0,
        dt_dopr                     =   3600.0,
        averaging_interval_pr       =   3600.0,
        dt_averaging_input_pr       =      6.0,

        skip_time_data_output       =      0.0,
        dt_data_output              =   3600.0,

        averaging_interval          =   3600.0,
        dt_averaging_input          =      6.0,

        section_xz = -1,

        data_output_pr = '#u',  'w"u"', 'w*u*', 'wu', 'u*2',
                         '#v',  'w"v"', 'w*v*', 'wv', 'v*2',
                         'w', 'w*2', 'e', 'e*', '#km', '#l',

        data_output = 'u',       'v',       'w',
                      'u_xz_av', 'v_xz_av', 'w_xz_av',
```

Data output/ Scenarios

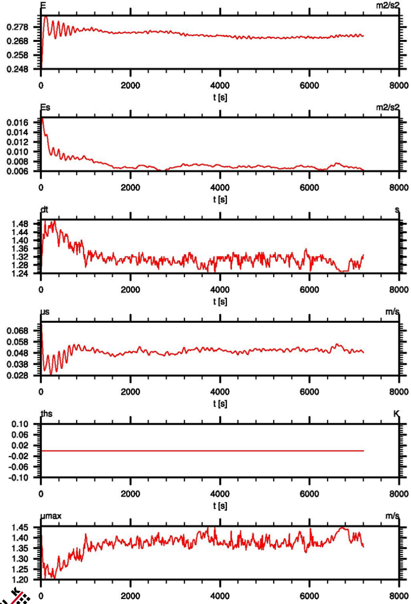


Data output/ Scenarios





Data output/ Scenarios

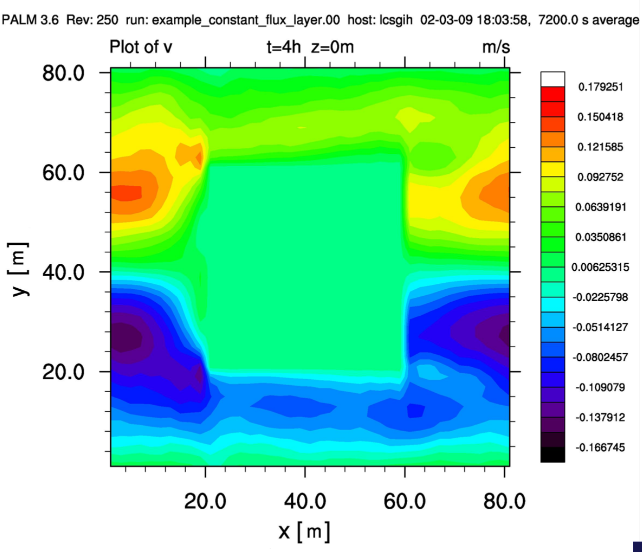


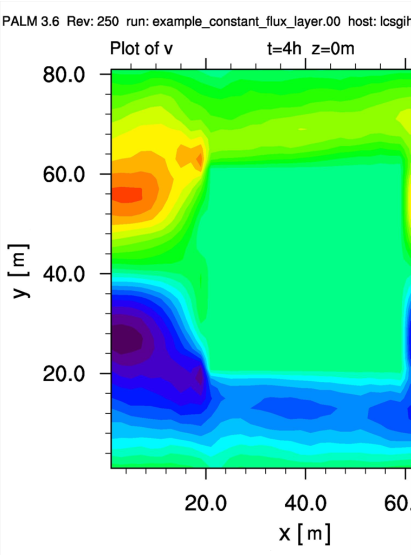
Set-up Scenario: Constant Flux Layer

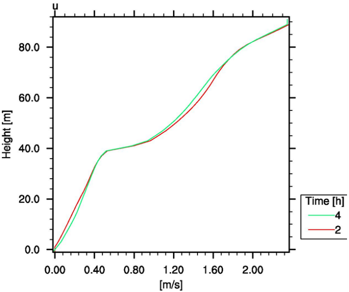
Single surface-mounted cube in neutral open channel flow with a constant flux layer

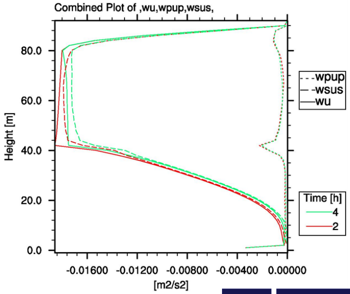
- trunk/EXAMPLES/constant_flux_layer/
  - Parameter file — example_constant_flux_layer_p3d
  - Run-control file — example_constant_flux_layer_rc
  - Some documentation — example_constant_flux_layer.odt

```
&inipar nx = 39, ny = 39, nz = 45,
        dx = 2.0, dy = 2.0, dz = 2.0,

        omega = 0.0,                       ! no Coriolis force
        dp_external = .T.,                 ! external pressure gradient
        dp_level_b = 80.0,                 ! ...acting above 80 m height
        dp_smooth = .T.,                   ! ...vertically smoothed
        dpdxy = -0.003, 0.0,               ! ...in x-direction, determined empirically

        initializing_actions = 'set_constant_profiles',
        ug_surface = 0.0, vg_surface = 0.0,
        ug_vertical_gradient       = 2.5,  ! linear vertical ug gradient
        ug_vertical_gradient_level = 0.0,  ! starting from the ground
        roughness_length = 0.1,            ! applies to all surfaces locally

        bc_pt_b = 'neumann',
        bc_uv_t = 'neumann',               ! open channel boundary condition

        topography = 'single_building',
        building_height   = 40.0,
        building_length_x = 40.0,
        building_length_y = 40.0,
```

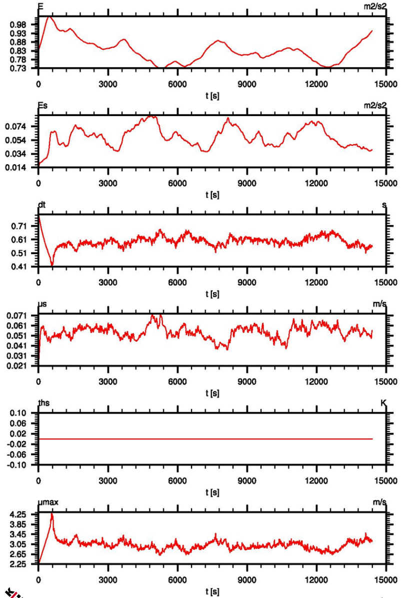

PALM 3.6 Rev: 250 run: example_constant_flux_layer.00 host: lcsgih 02-03-09 18:03:58, 7200.0 s average
Plot of v
t=4h z=0m
m/s
80.0
60.0
40.0
20.0
y [m]
20.0
40.0
60.0
80.0
x [m]
0.179251
0.150418
0.121585
0.092752
0.0639191
0.0350861
0.00625315
-0.0225798
-0.0514127
-0.0802457
-0.109079
-0.137912
-0.166745

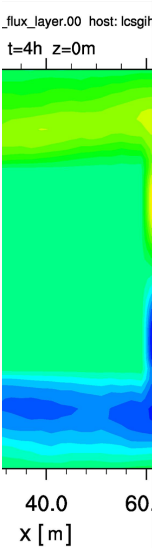

PALM 3.6 Rev: 250 run: example_constant_flux_layer.00 host: lcsgih
Plot of v
t=4h z=0m
y [m]
x [m]
80.0
60.0
40.0
20.0
20.0
40.0

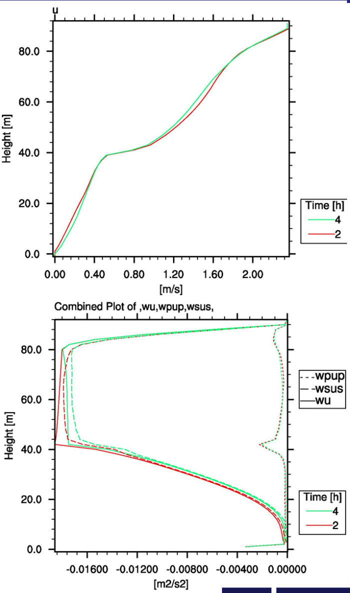

u
Height [m]
[m/s]
0.00
0.40
0.80
1.20
1.60
2.00
Time [h]
4
2


Combined Plot of ,wu,wpup,wsus,
Height [m]
[m2/s2]
-0.01600
-0.01200
-0.00800
-0.00400
0.00000
wpup
wsus
wu
Time [h]
4
2

Data output/ Scenarios







Rules of Good Practise

- If you run PALM with topography, make sure that it is really LES...
  - "Large eddies" are "small" between obstacles
    - use fine grid length to resolve turbulence there
  - Ratio of resolved to SGS fluxes
- Check for (quasi-)steady turbulent state and sufficient averaging time.
  - Fluctuations of time series of E, E*, maximum velocity components etc.
- Make sure that your PALM result is independent of numerical parameters such as domain size and grid size.
  - Sensitivity studies
- If you intend to do a comparison with some kind of reference data, it is essential to configure the set-up of PALM in the same way as the reference experiment.
  - For example, if you compare PALM with wind tunnel results, you have to follow the wind tunnel set-up for setting up PALM.