PAUL SCHERRER INSTITUT

Wir schaffen Wissen – heute für morgen

Paul Scherrer Institut

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Dispersion of Passive Scalars in the Aare Valley

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  - Motivation
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  - Empty Domain
  - Obstacle within Domain
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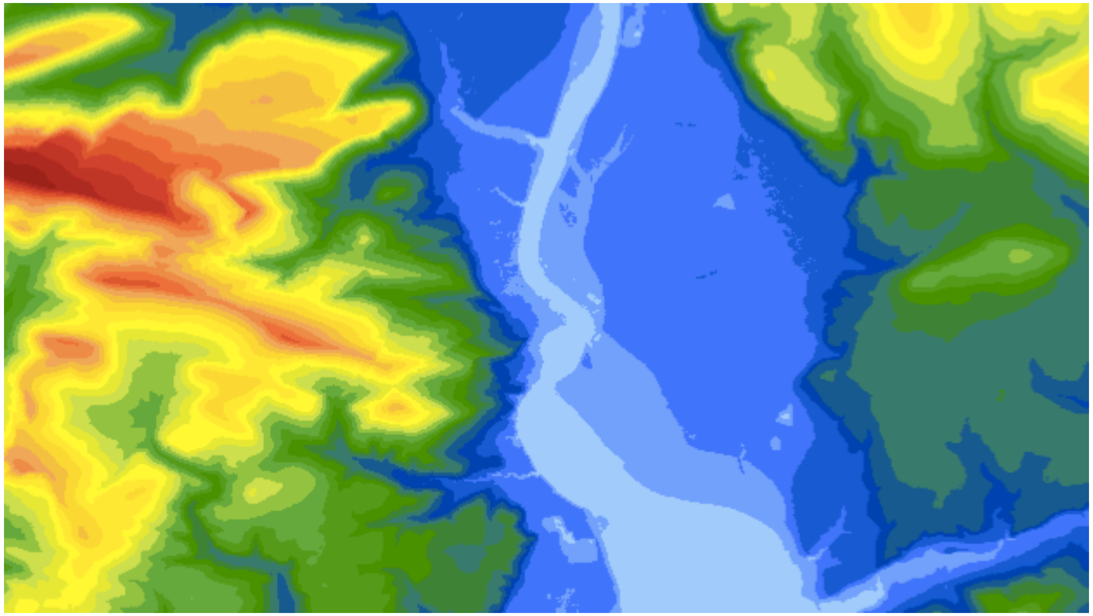
Aare Valley

Δx = 8.7 km

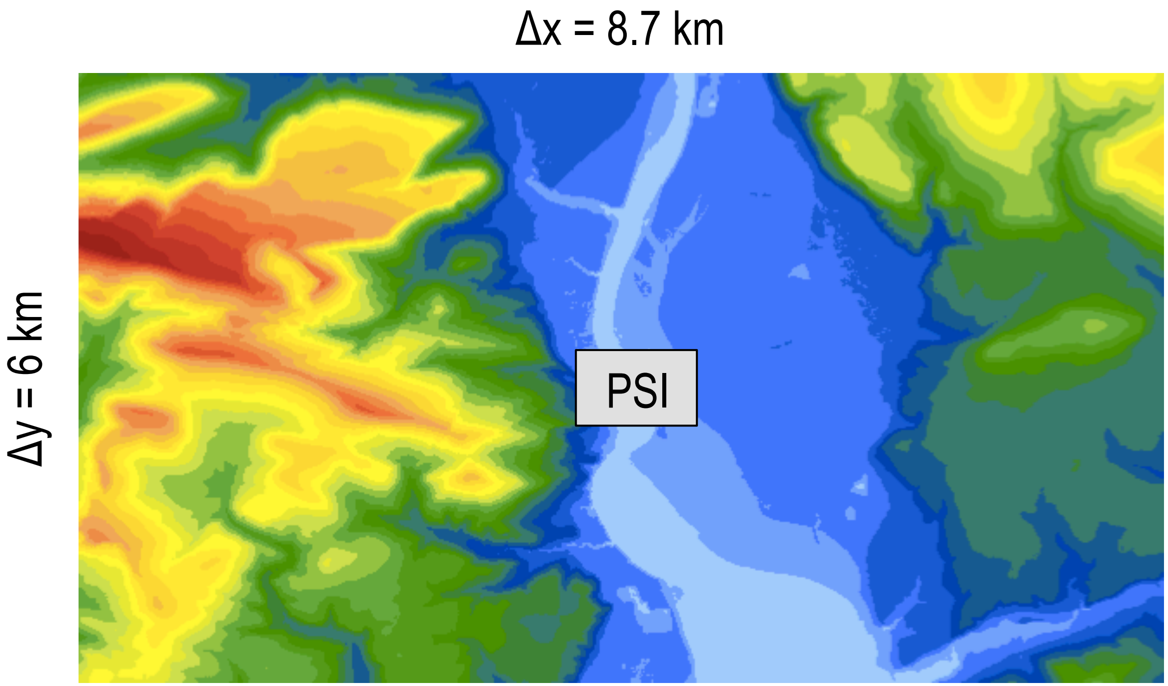
Δy = 6 km



Area around the Paul Scherrer Institute (PSI)

- Aare Valley: Region in Switzerland formed by the river Aare
- Aare: Longest river in Switzerland

Aare Valley



Area around the Paul Scherrer Institute (PSI)

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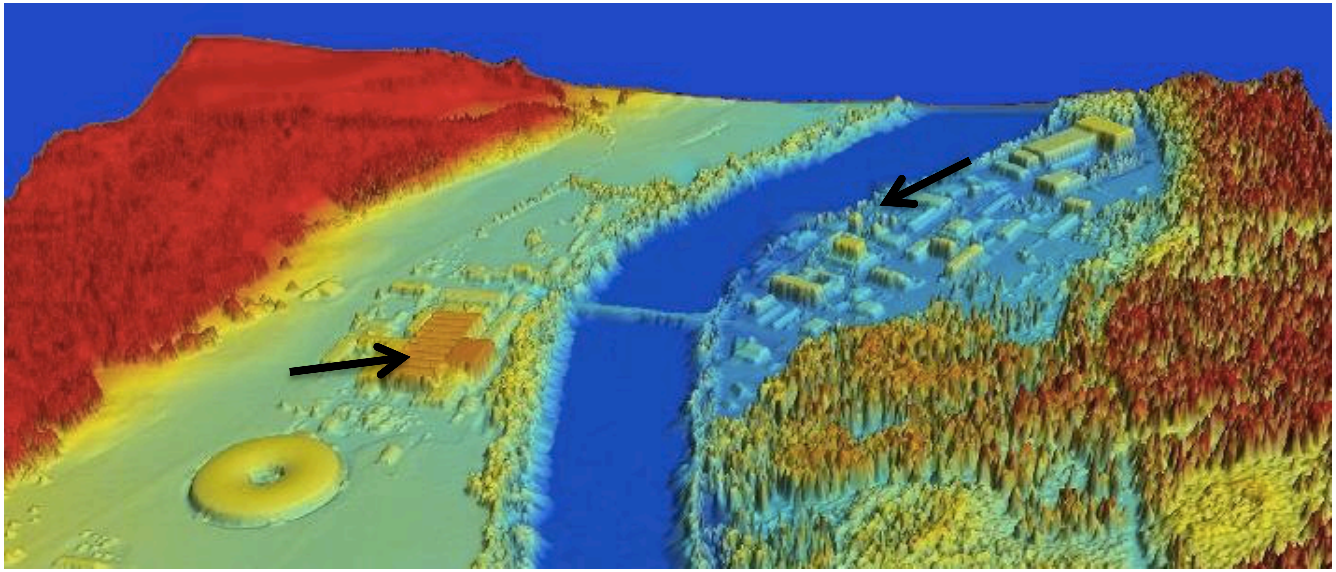
Motivation

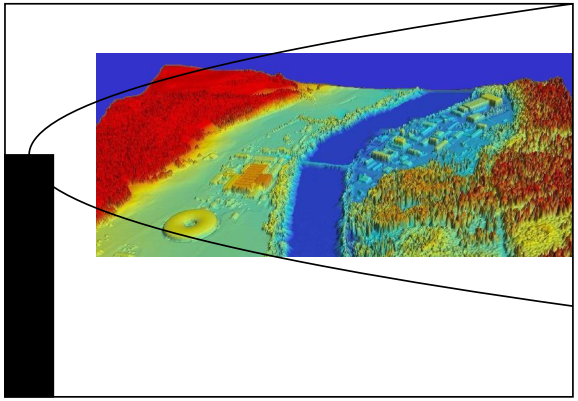


Paul Scherrer Institute (PSI)

- Radionuclides emitted from two main sources
- PSI predicts dispersion of radionuclides

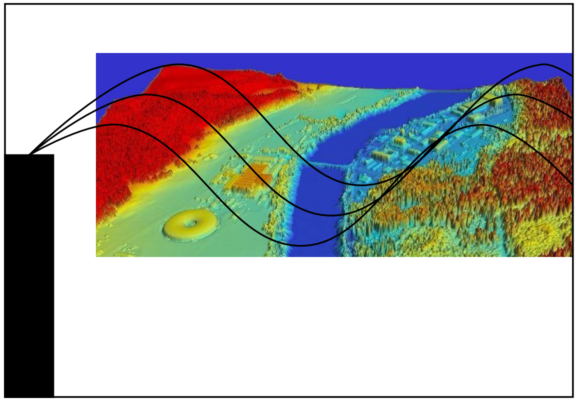
  → Estimate dose rate at PSI area and surroundings

Current Dispersion Model ESS41



- ESS41: Gaussian model
- Not appropriate for taking into account
  - Varying atmospheric background states
  - Dispersion of plume in complex topography
- Good results under near-neutral stratification

New Model



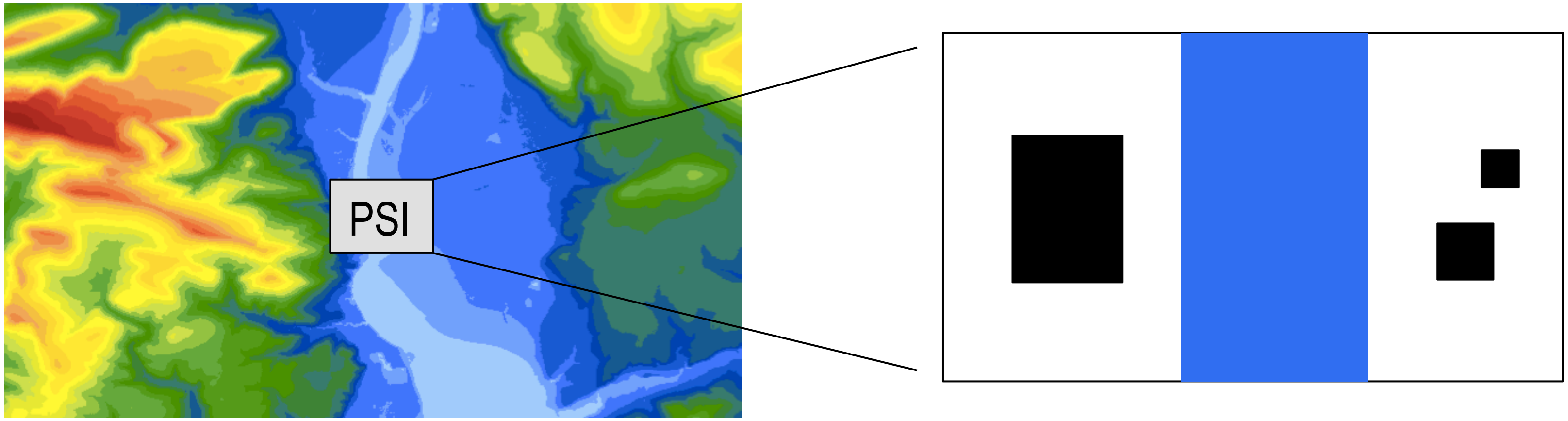
- Shall replace Gaussian model ESS41 in future
- Requirements:

  High resolution

  Topography as input data

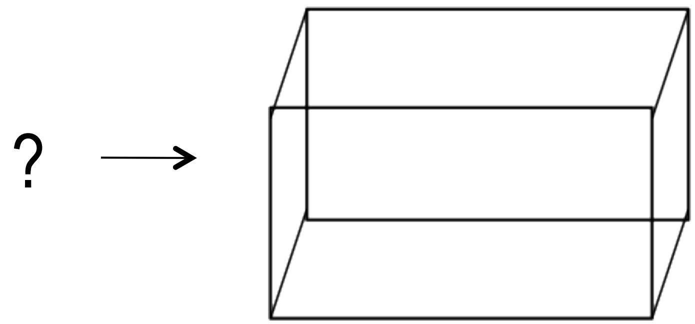
  Direct simulation of turbulent flow
- Boundary conditions from COSMO-2

Objectives



- Take idealised PSI geometry with idealised Aare, some buildings and idealised hills
- Sensitivity studies for different atmospheric stratifications (emphasis)
- Simulations with real topography as input

Objectives

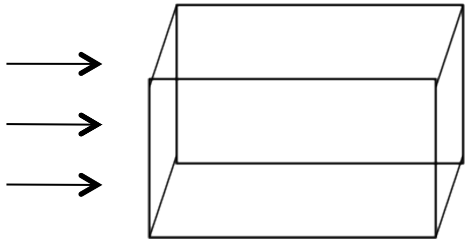


- Find appropriate inflow conditions
- Common approaches: Cyclic boundaries and laminar inflow
  - Cyclic boundaries: not suitable for complex orography
  - Laminar inflow: difficulties ensuring correct surface conditions / computationally expensive if no roughness elements used
- 5 different inflow profiles tested for empty domain
- 2 different inflow profiles tested for domain with single building

Inflow Conditions

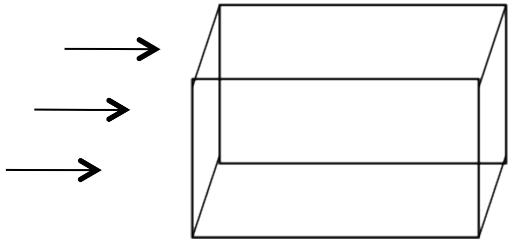
- Constant inflow

$U_0(z) = 2.5$ m/s



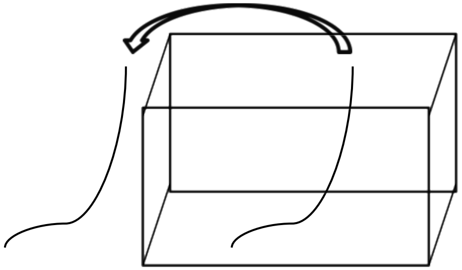
- Specified shear

$U_0(z) = 2.5 + 0.025\ z$

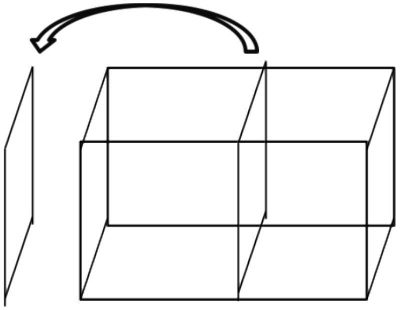


- 1) Initialisation with developed profile from spin-up simulation

$u(nx/2,ny/2,z,t_{30})$, $v(nx/2,ny/2,z,t_{30})$



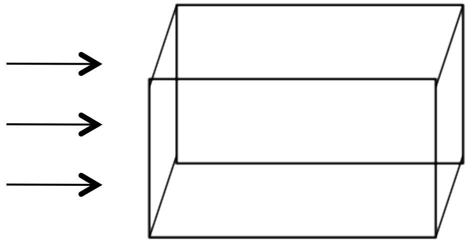
- Same as above, but with whole plane $u(nx/2,y,z,t_{30})$, $v(nx/2,y,z,t_{30})$



Inflow Profiles

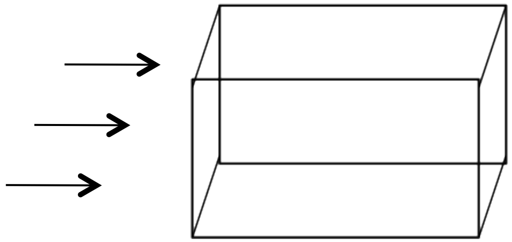
- Constant inflow

$U_0(z) = 2.5$ m/s

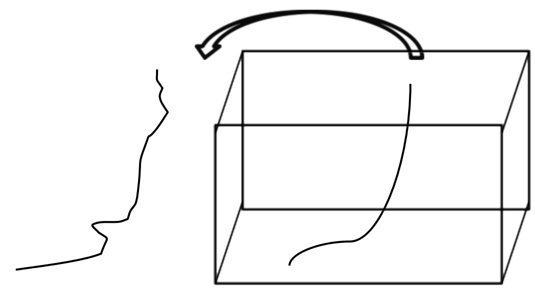


- Specified shear

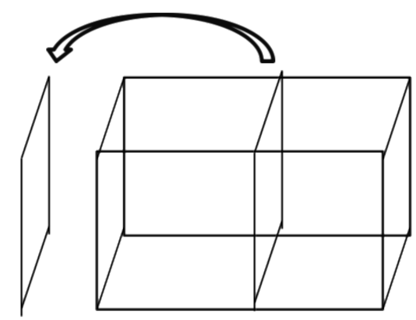
$U_0(z) = 2.5 + 0.025\, z$



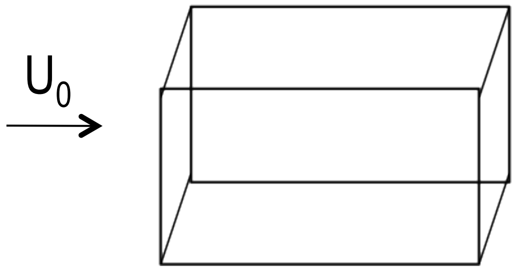
- 2) Initialisation with developed profile overlayed by random numbers [-0.2,0.2]



- Same as above, but with whole plane $u(nx/2,y,z,t_{30})$, $v(nx/2,y,z,t_{30})$



Numerical Simulations for Empty Domain

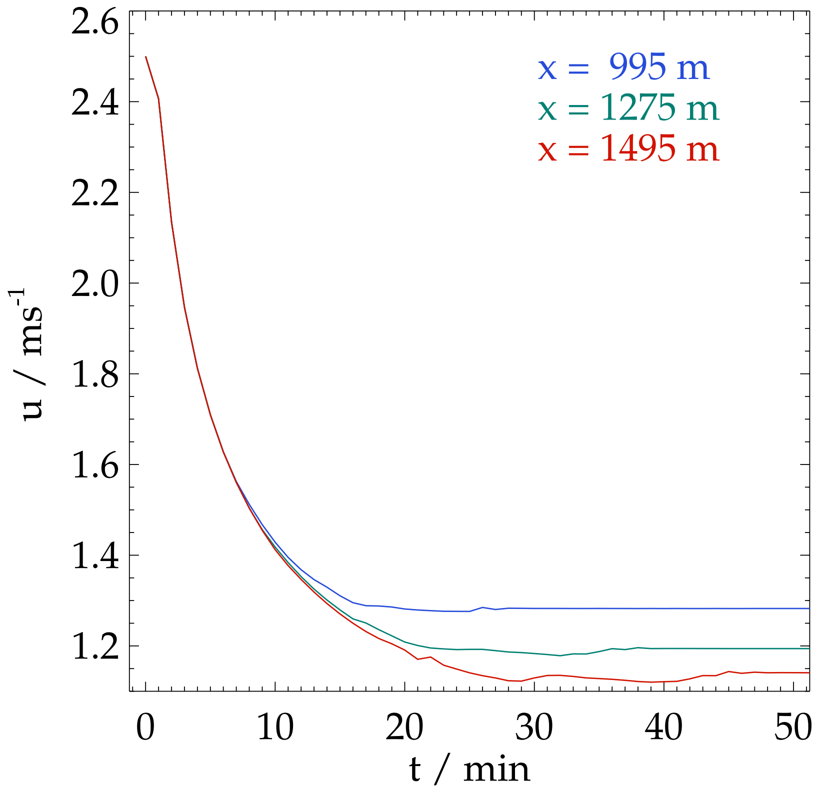


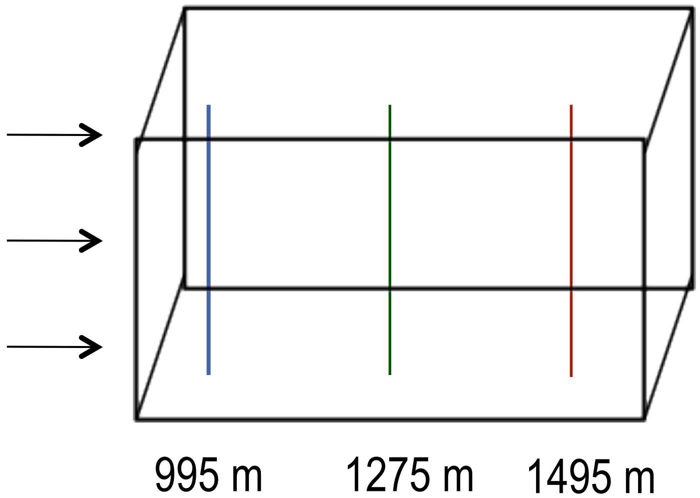
- Open boundary conditions in x,y,z coordinates
- $\Delta x = \Delta y = 5$ m, $\Delta z = 0.5$ m, nx = 512, ny = 16, nz = 101
- Aerodynamic roughness length $z_0 = 0.25$ m at lower surface (isflx=1)
- Initial conditions:

  $u(x,y,z,t_0) = U_0$, $v(x,y,z,t_0) = w(x,y,z,t_0) = 0$.
- 5 different inflow profiles U_0

Stationarity

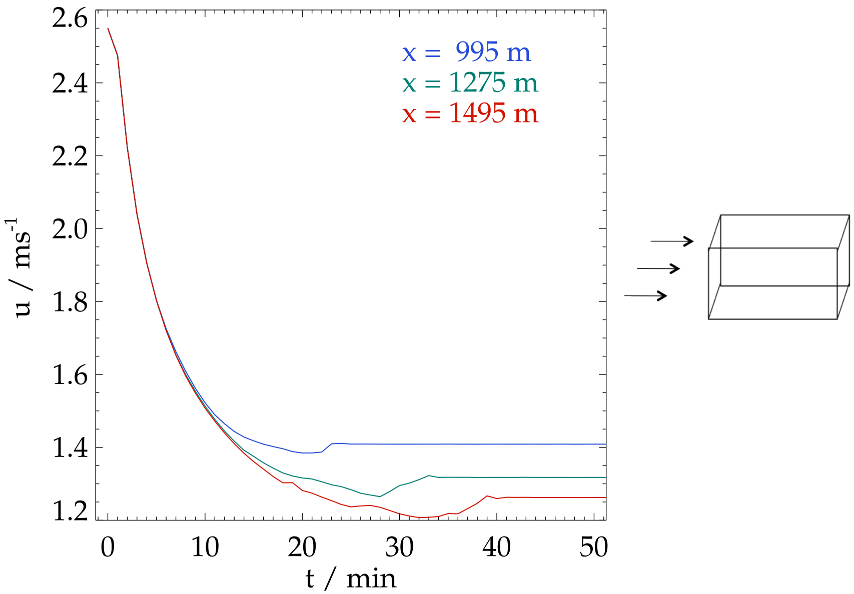
$U_0(z)$ = const

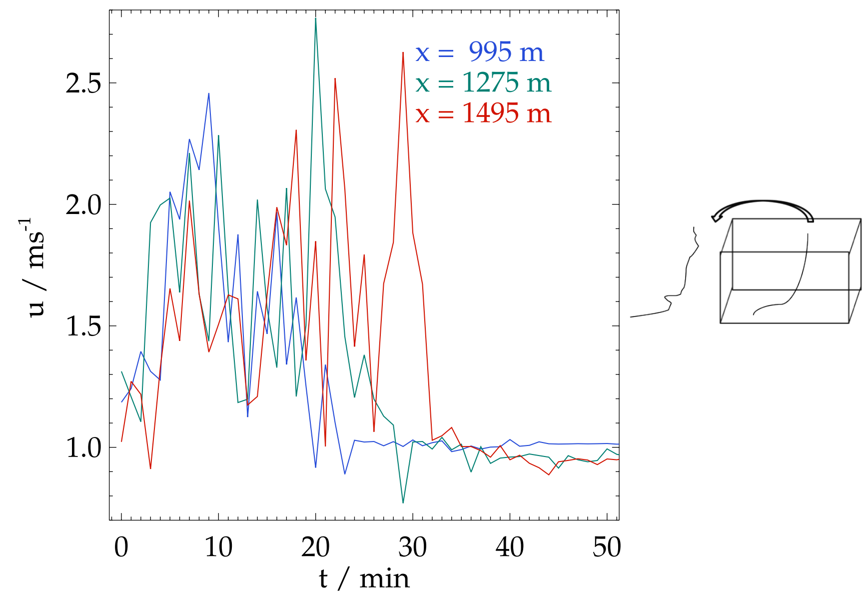


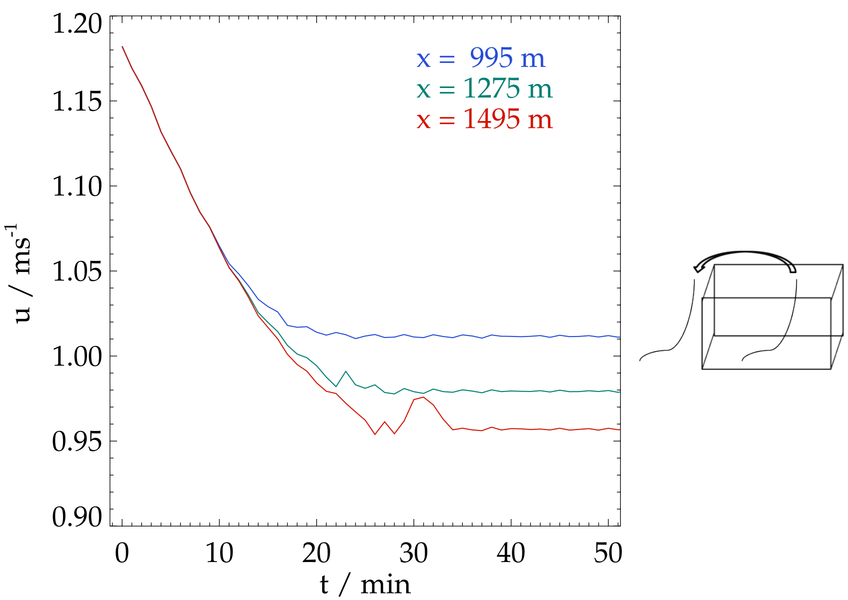


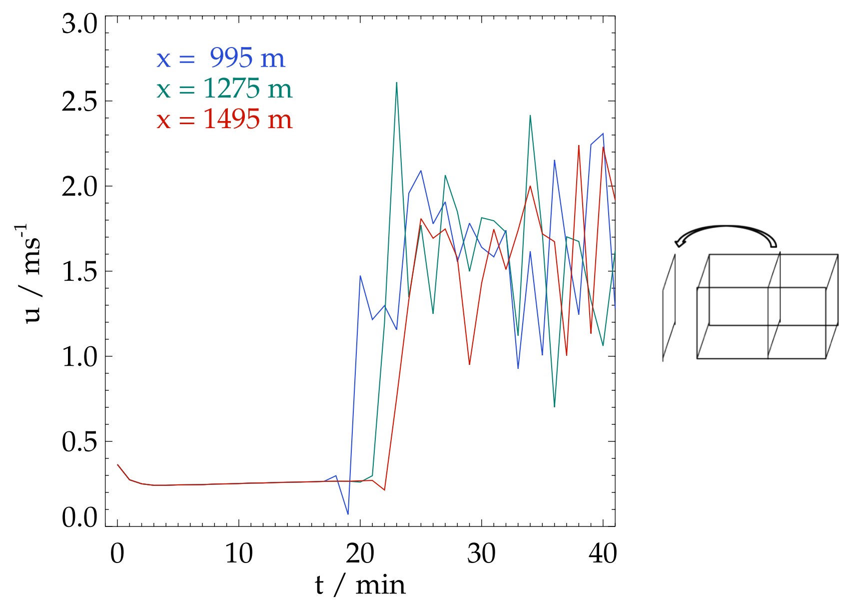
- Profiles taken at z = 2 m and y = 40 m (middle of domain)
- Blue: 995 m, Green 1275 m, Red: 1495 m

Stationarity

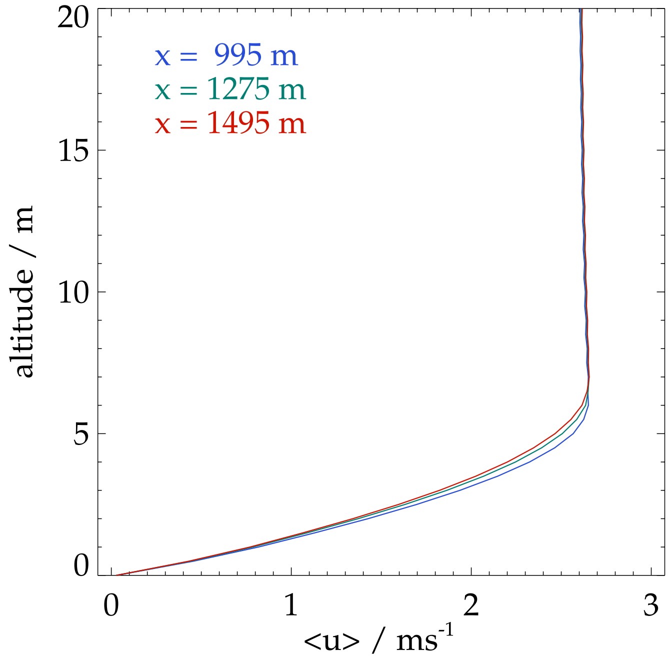




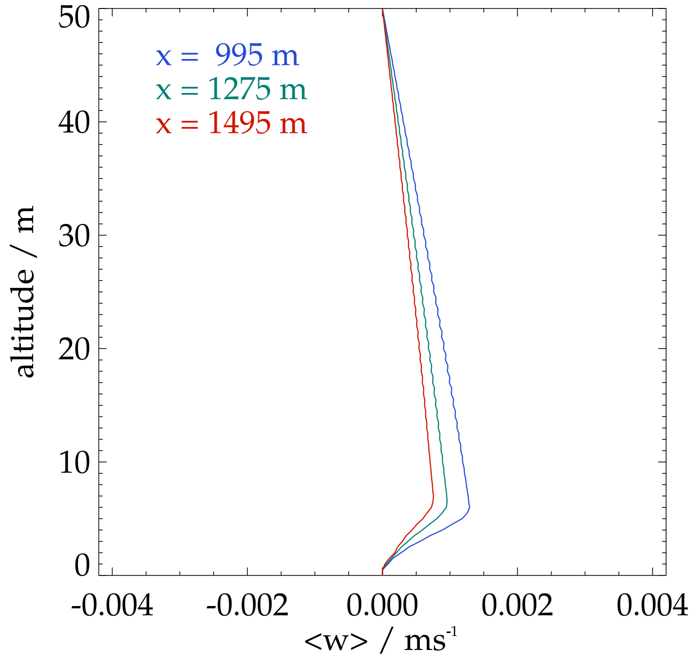


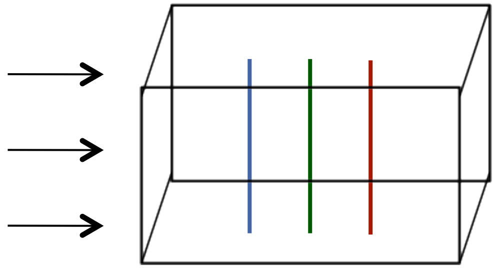


Mean Horizontal and Vertical Velocity



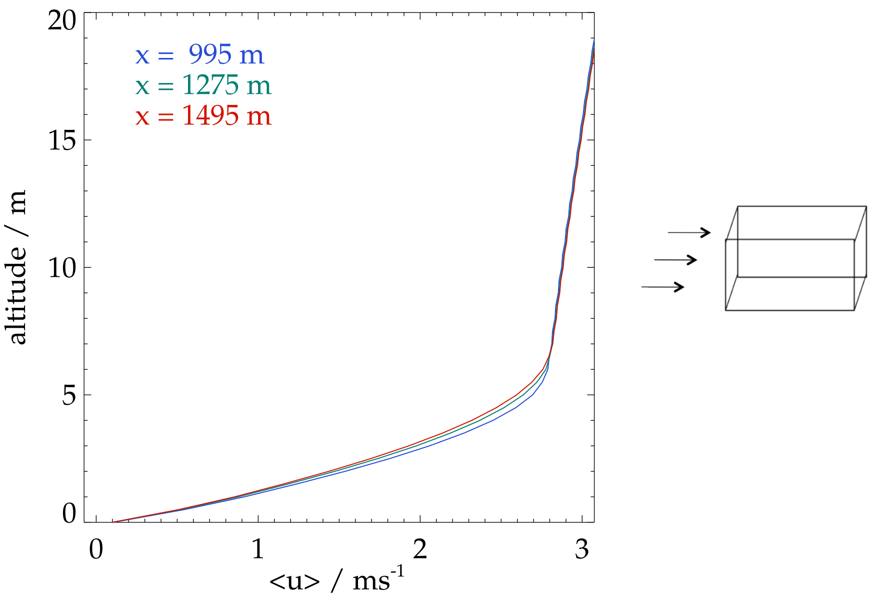
$U_0(z)$ = const

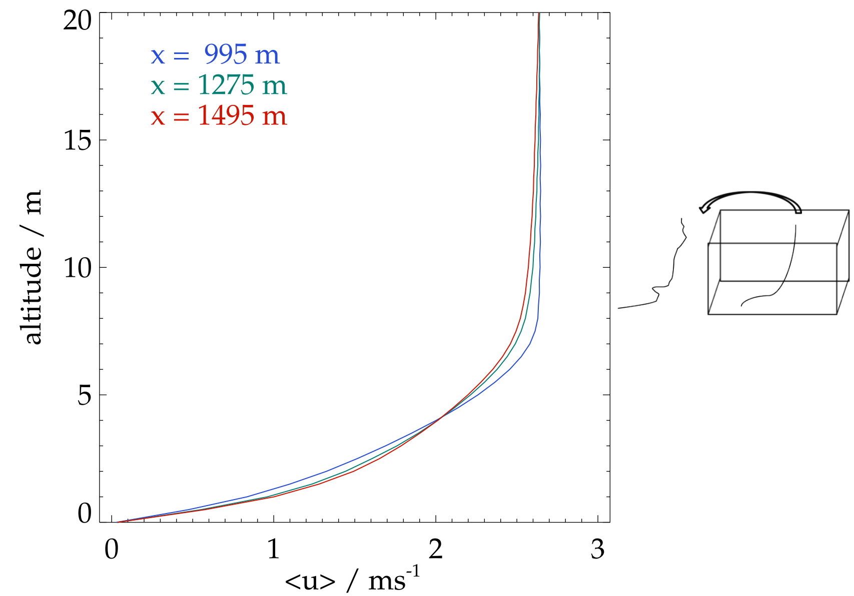


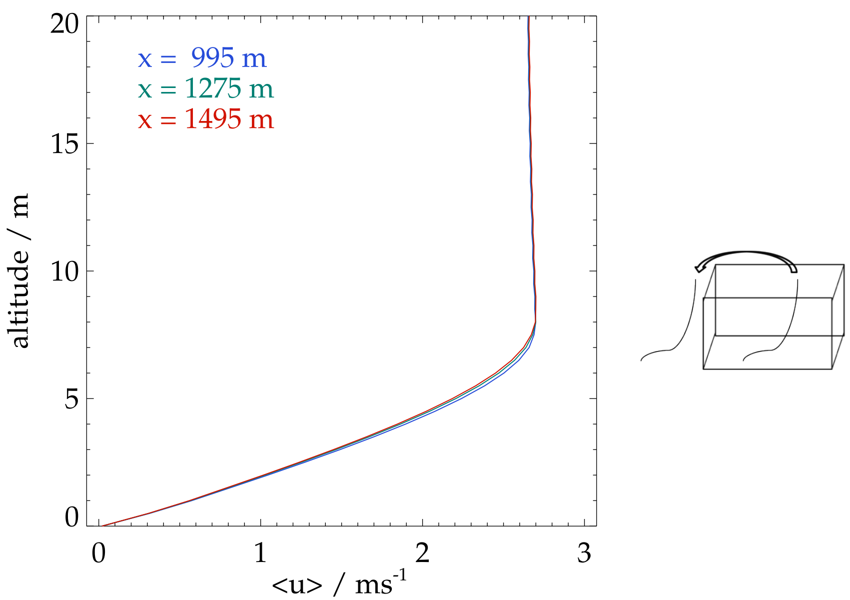


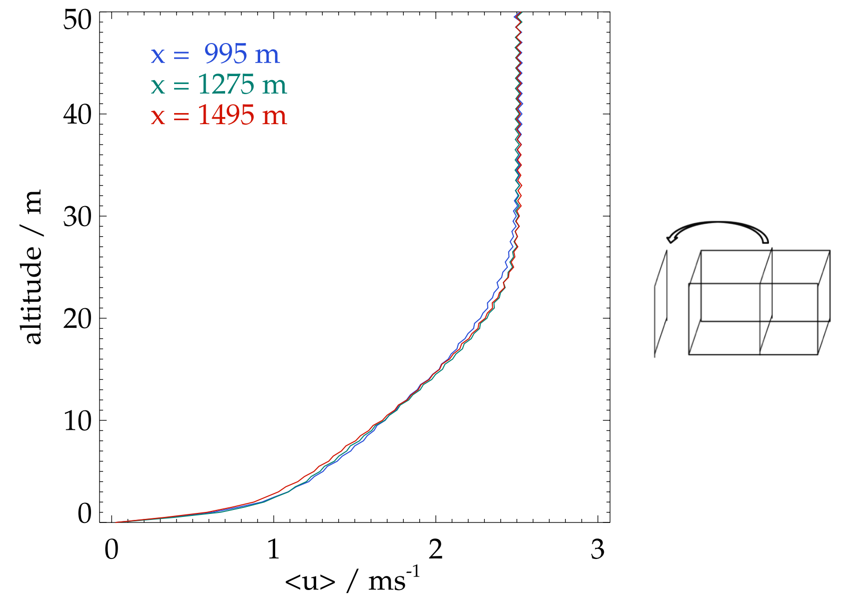
- Profiles taken at y = 40 m (middle of domain) after 40 minutes
- Blue: 995 m, Green 1275 m, Red: 1495 m

Mean Horizontal Velocity

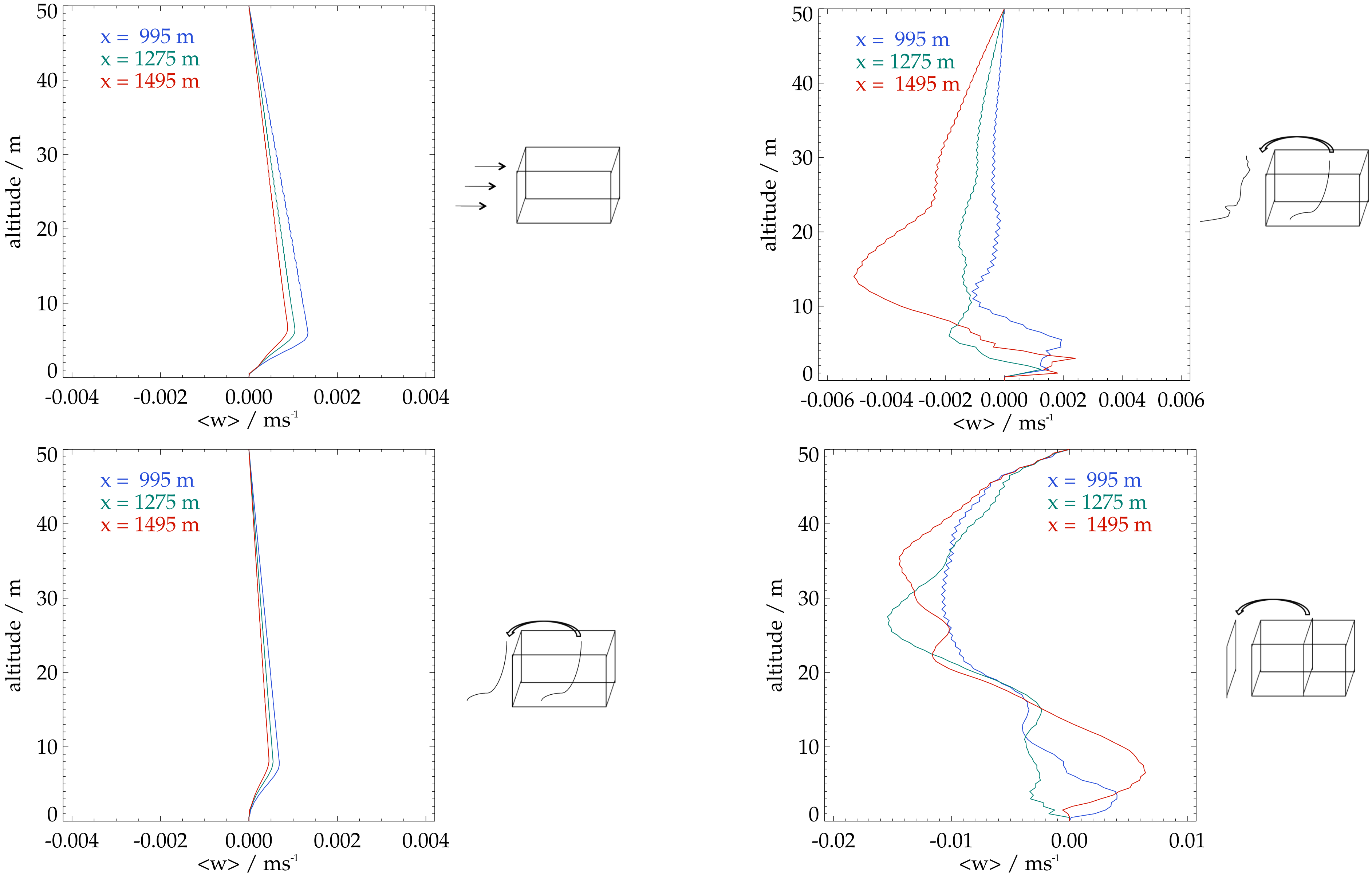








Mean Vertical Velocity



Conclusions

- Steady state reached between 20 and 40 minutes in all simulations
- Stationarity sooner/later reached at inflow/outflow region
- Differences between form of velocity profiles
- Further simulations with two profiles

- Place block in the middle of domain

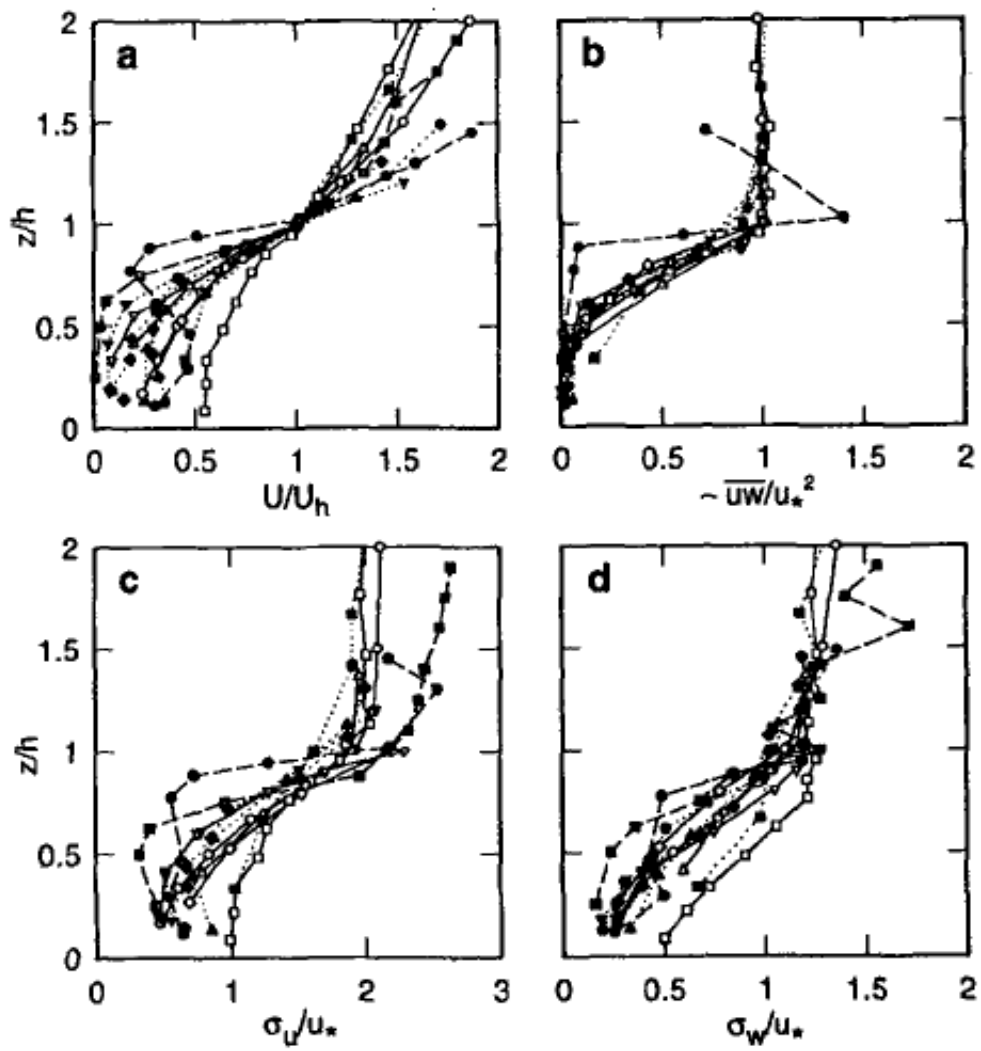
  → Investigate canopy turbulence

Canopy Turbulence

- Urban canopy: Assemblage of buildings, trees etc. forming towns and cities
- Concept analogous to that of vegetation canopy except that

  Built part open to the sky

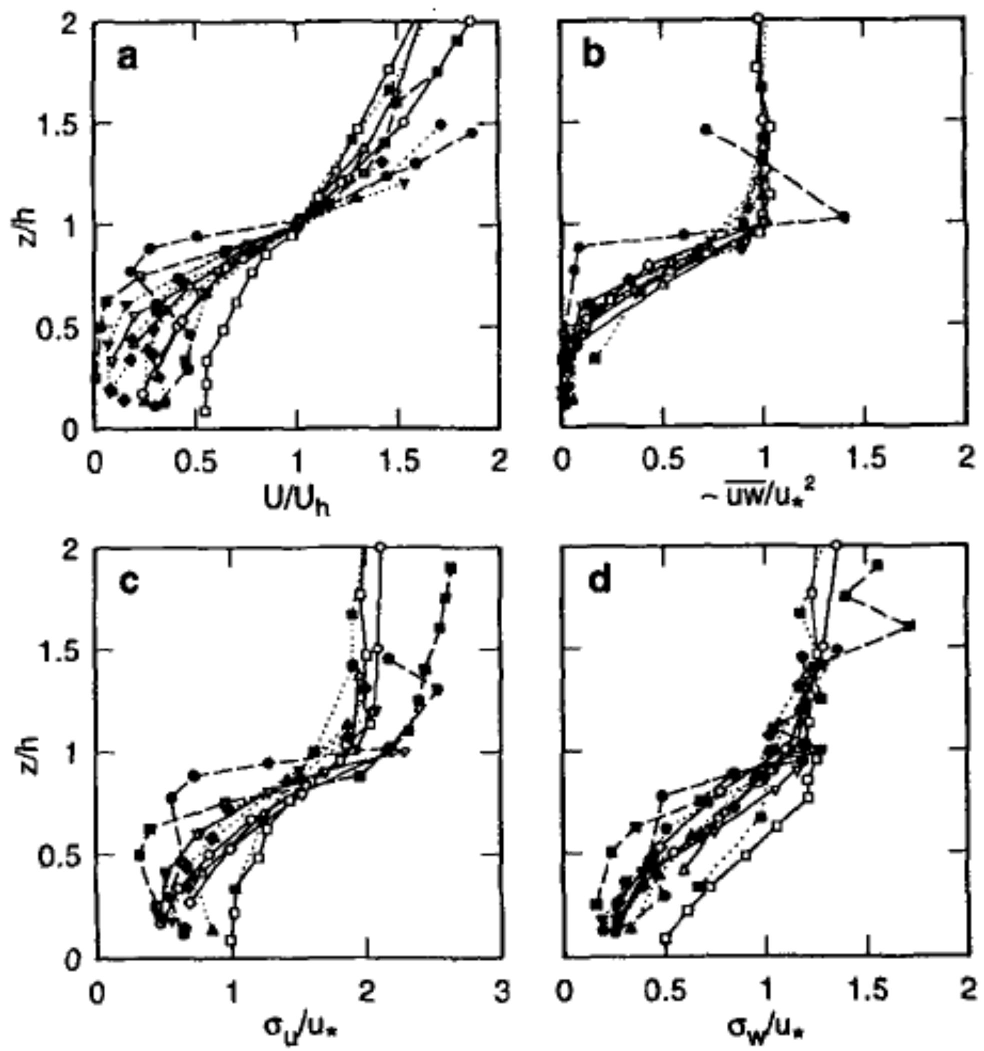
  No stem or trunk zone
- Study from Raupach et al. for vegetation canopy as reference



Raupach et al. (1996)

Canopy Turbulence

- Vertical inhomogeneity – U, <uw>, σ_u and σ_w decay rapidly with decreasing height
- Clear inflection point for all turbulent moments near canopy top where shear is maximal

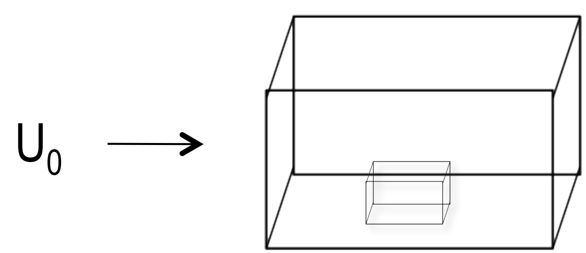


Raupach et al. (1996)

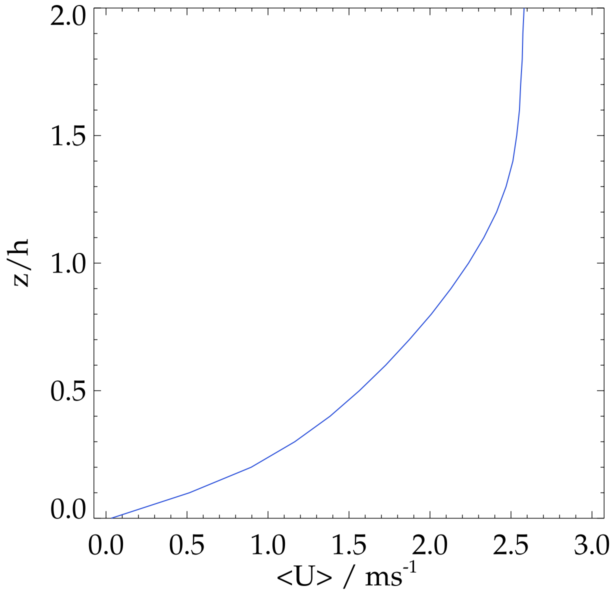
Numerical Simulations

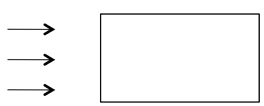
- Open boundary conditions in x,y,z coordinates
- $\Delta x = \Delta y = 5$ m, $\Delta z = 0.5$ m
- Aerodynamic roughness length $z_0 = 0.25$ m at lower surface (isflx=1)
- Initial conditions:

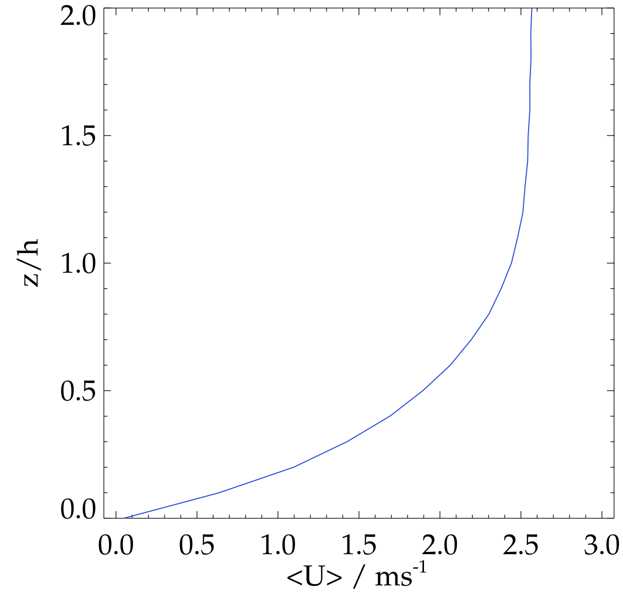
  $u(x,y,z,t_0) = U_0$, $v(x,y,z,t_0) = w(x,y,z,t_0) = 0$
- Block (10 m x 10 m x 5 m) in middle of domain using immersed boundaries
- Horizontal averaging at t = 30 min normalised with canopy height h = 5 m

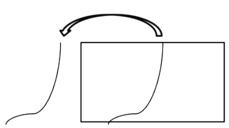


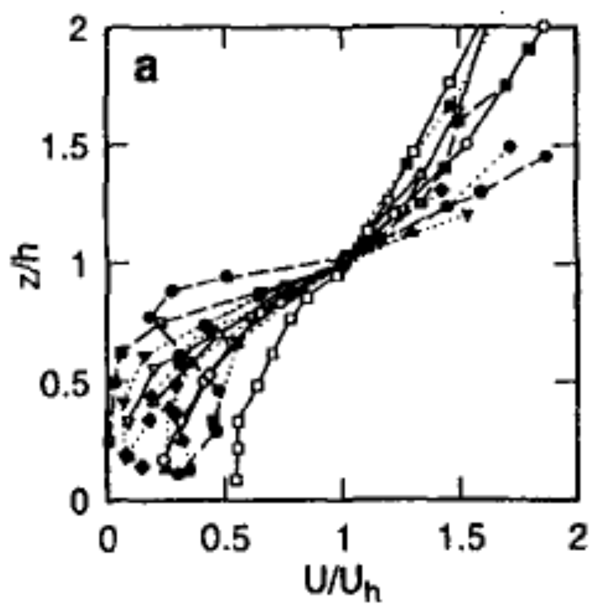
Mean Velocity





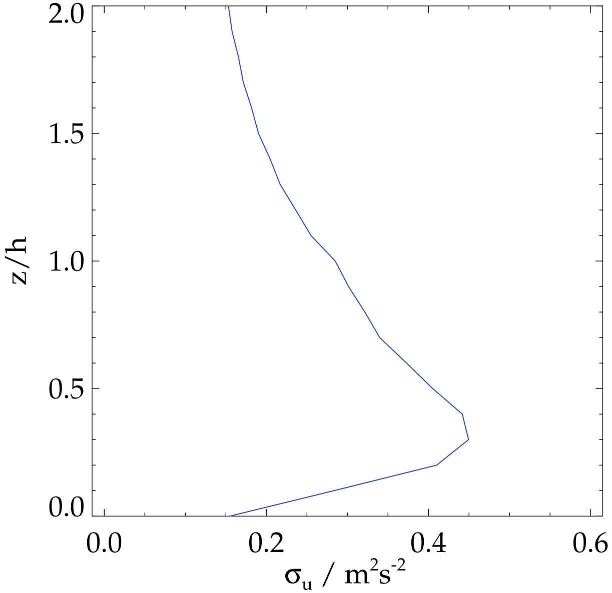


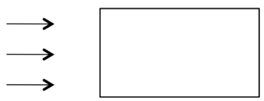


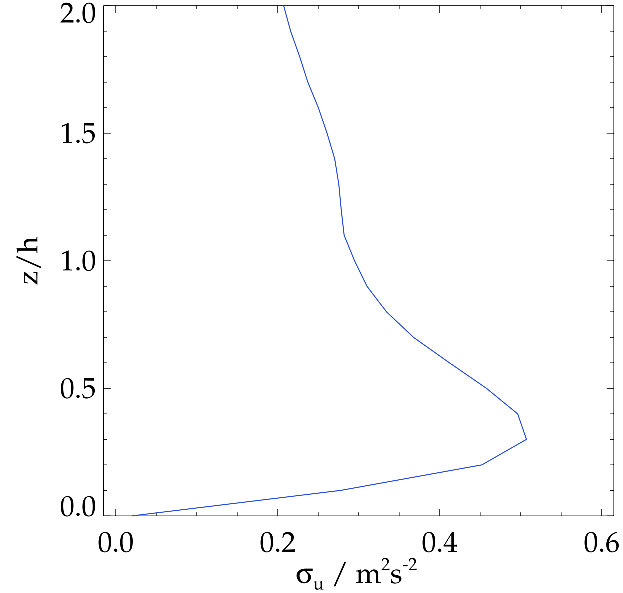


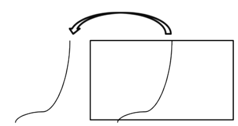
Raupach et al. (1996)

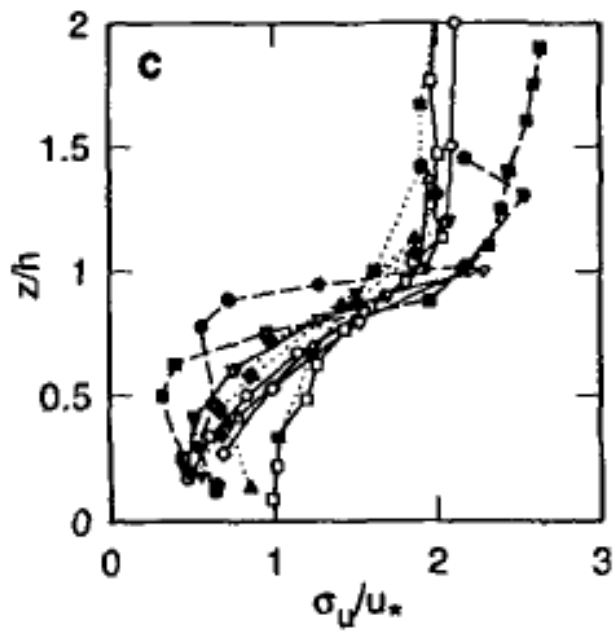
Standard Deviation σ_u





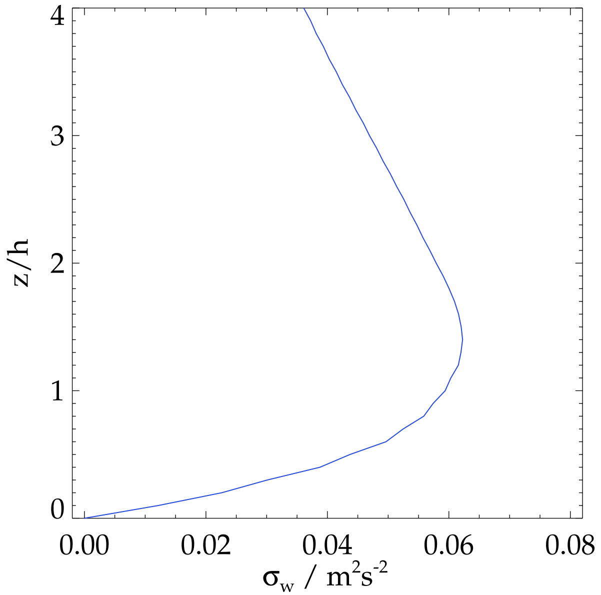


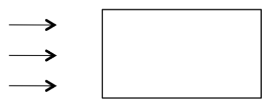


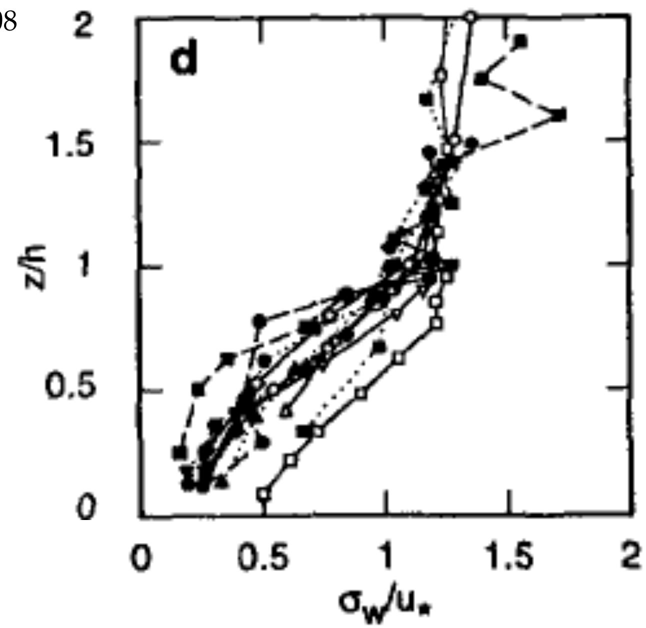


Raupach et al. (1996)

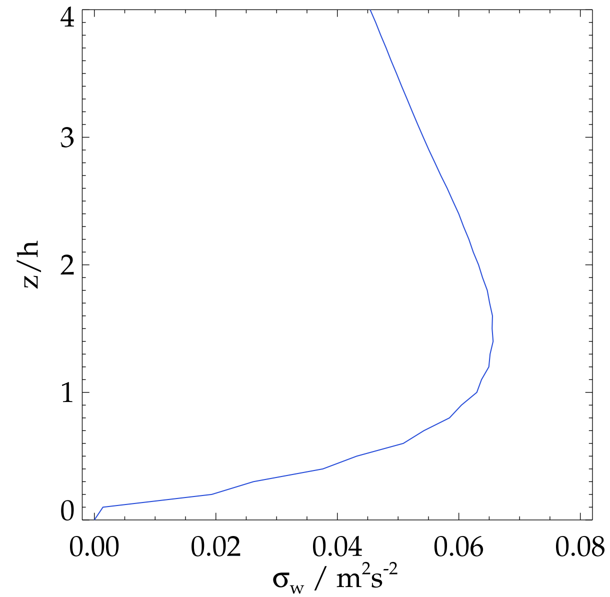
Standard Deviation σ_w

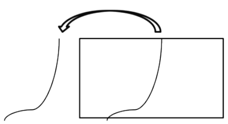




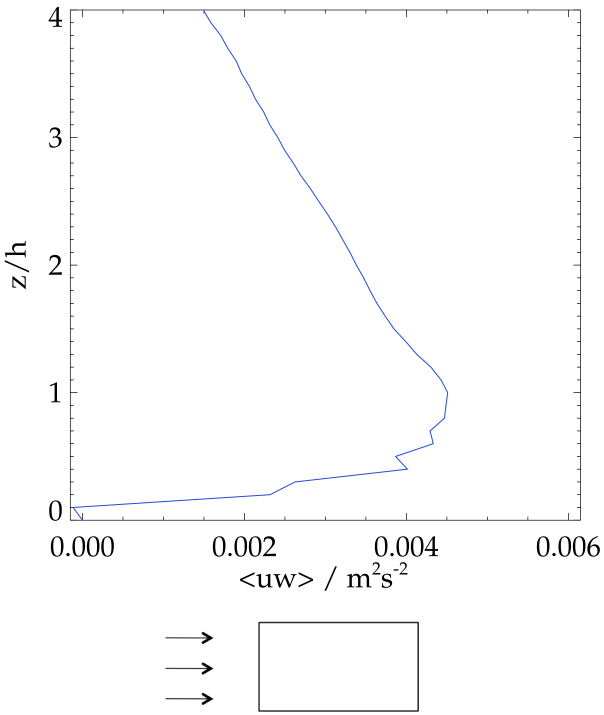


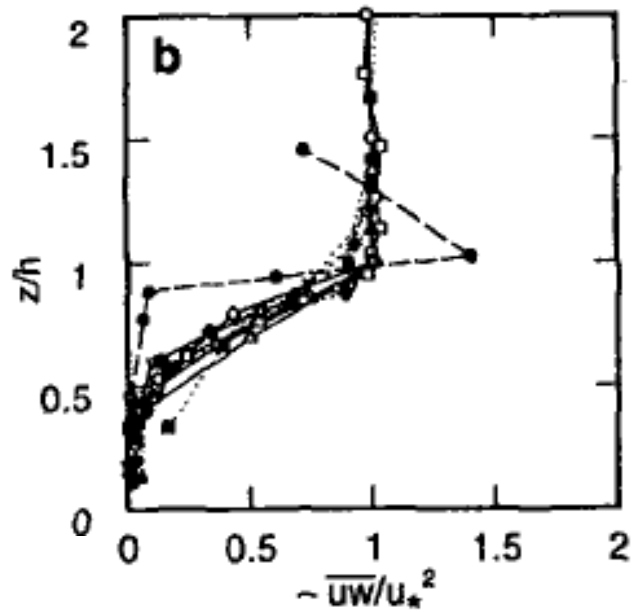
Raupach et al. (1996)



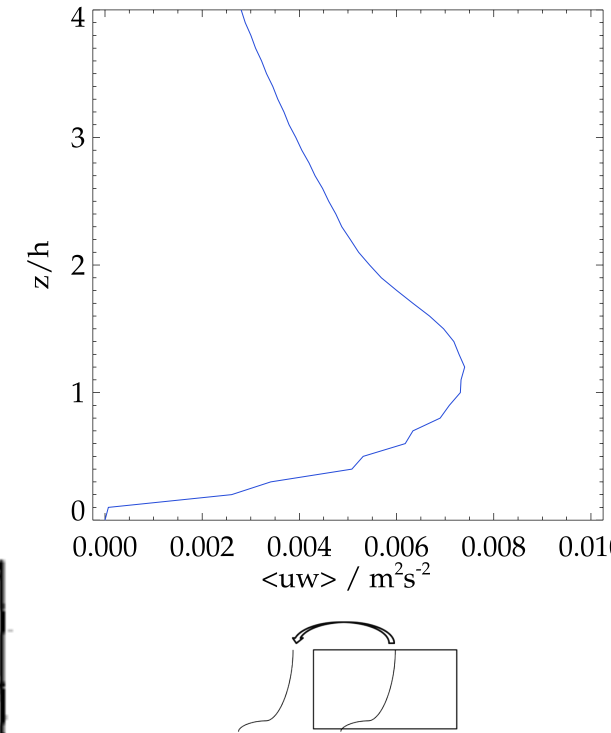


Reynolds Shear Stress

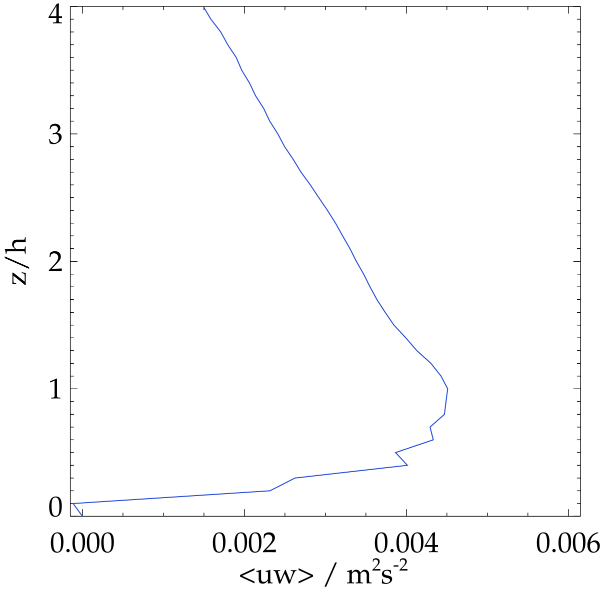


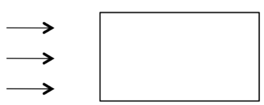


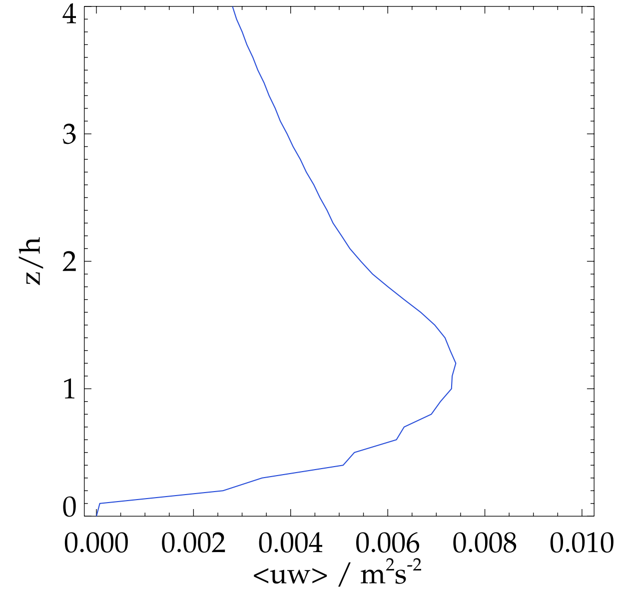
Raupach et al. (1996)

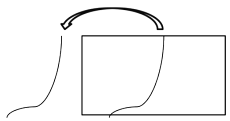


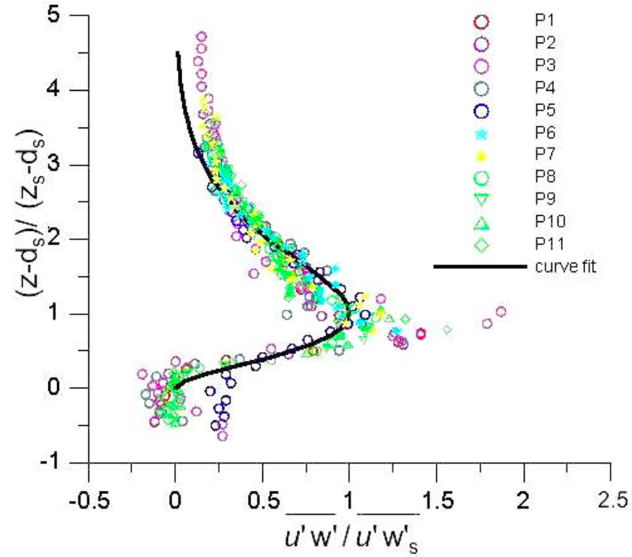
Reynolds Shear Stress











Kastner-Klein and Rotach (2004)

Conclusions

- Turbulent moments decrease within canopy
- Strong inflection point close to canopy height except for σ_u - inflection point below canopy height
- Possible reason: one building not sufficient to model an urban canopy
- Further tests: horizontal averaging only behind building or time averaging
- No significant differences between the two inflow profiles

Summary

- PSI must predict dispersion of radionuclides to estimate dose rate
- Currently used Gaussian dispersion model not appropriate to consider
  - Varying atmospheric background states
  - Dispersion of plume in complex topography

  ⟶ shall be replaced
- Several inflow conditions were tested
  - Atmospheric flow depends on inflow profiles
  - Turbulent moments except for σ_u agree with literature references

Outlook

- Further investigations of inflow profiles
- Perform simulations with:
  - a higher building
  - several buildings of different heights
  - idealised mountain
- Inverse FT as inflow profile?

- Simulations for convective and stable stratification
- Vertical grid stretching
- Dispersion of passive scalars

Thank you for your attention!