Turbulence structure in a diabatically heated forest canopy composed of fractal Pythagoras trees

Josef Schröttle

Universität München (LMU)

Andreas Dörnbrack

Institut für Physik der Atmosphäre (DLR)

Piotr K. Smolarkiewicz

National Center for Atmospheric Reseach, Boulder (NCAR)

Outline

I. **Motivation**

II. **Method**

a) Ensemble of Fractal Trees

b) Heated Immersed Boundaries

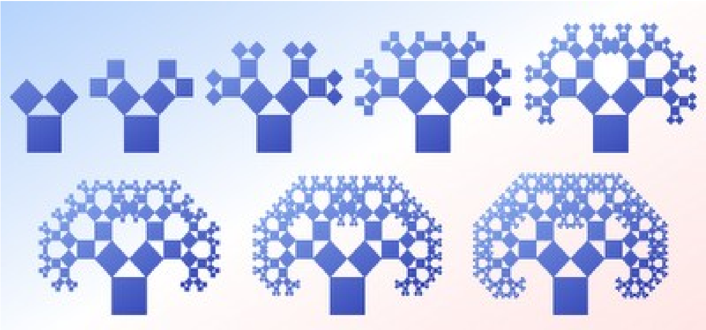
c) Stretched Grid – 100m to 10cm

III. **Results**

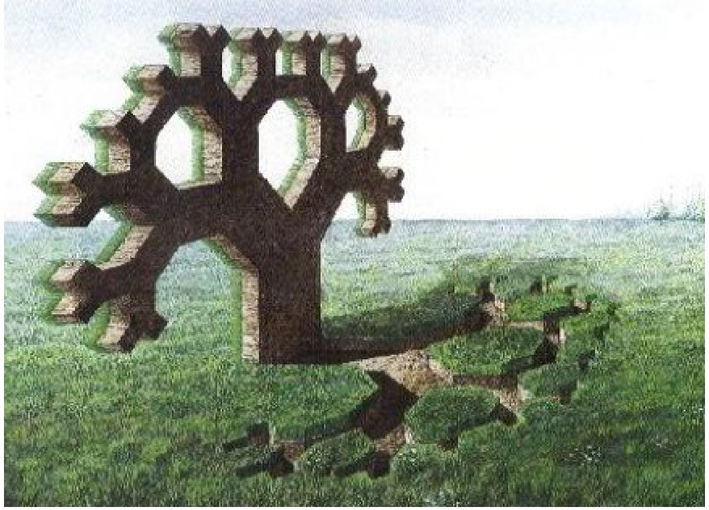
a) Plant Scale Approach

b) Diabatic Flow Structure

IV. **Outlook**

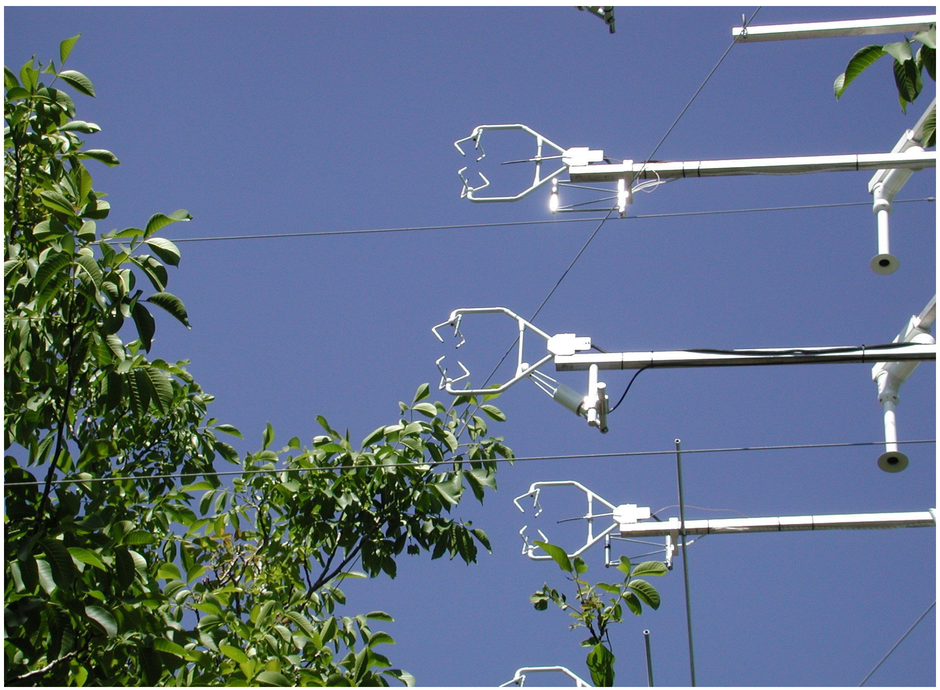


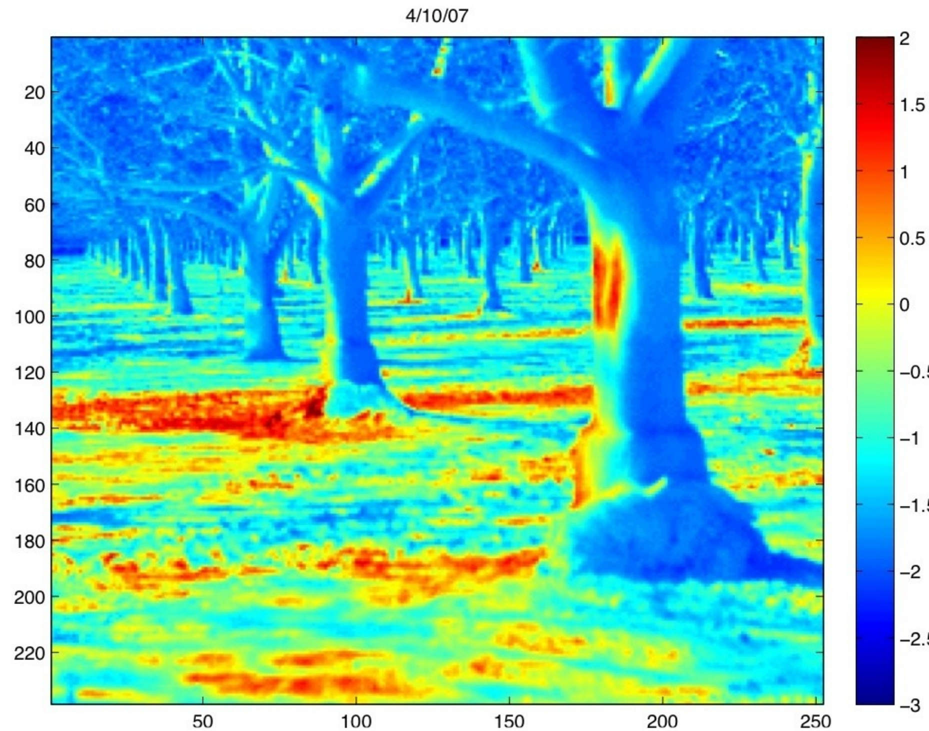
Pythagoras Tree (below) and algorithm described (above)



Motivation

In ***Boundary Layer Meteorology*** measurements are taken at the Microscale from meters ***down to a few cm***.





http://www.eol.ucar.edu/deployment/field-deployments/field-projects/chats-project

Eddy Covariance Sensors in a Walnut Canopy (left) and infrared image of heterogeneously heated trees and trunk space (right)

Field Scale Approach

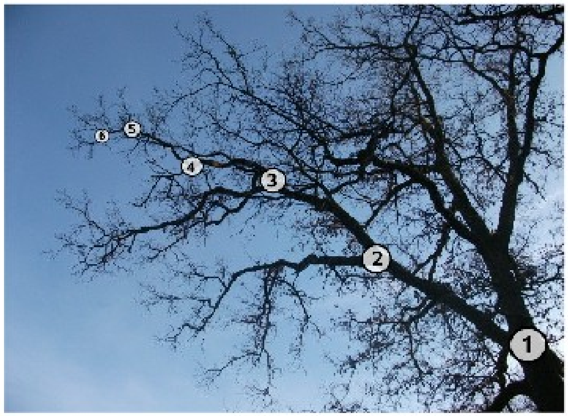
„Forest as a porous body of horizontally uniform **leaf area density:** ***LAD(z)*** with constant drag coefficient $\boldsymbol{c_D}$"

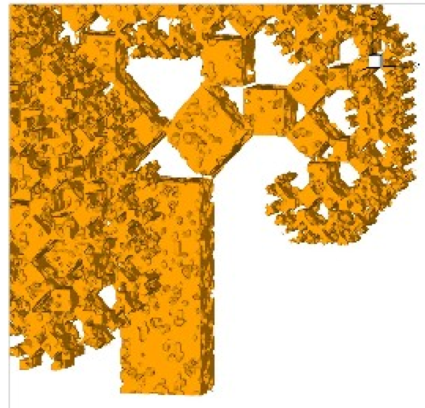
(Shaw & Schumann 1992)

	Shaw & Schumann (BLM, 1992)	**Dupont & Brunet (JFM, 2009)**	**Finnigan, Shaw & Patton (JFM, 2009)**
ΔX	2 m	2 m	1 m
H	60 m	200 m	100 m
LAI	2, 5	2, 5	
T	10 min		2 hours

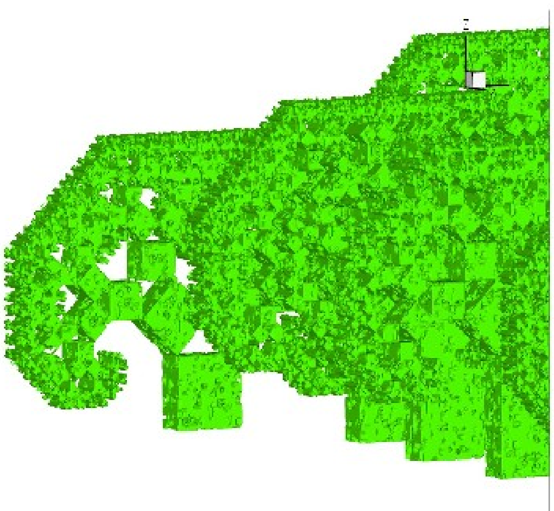
Is it possible to **close** the **scale gap** by state-of-the art multiscale numerical simulations?

How to resolve tree elements?





Nature reminds us of **fractal geometry** e.g. lightnings, coral reefs, clouds and of course trees!



We use a mathematical algorithm, to generate **Pythagoras trees** of arbitrary fractality.

Fractal Tree

A fractal tree **has already been simmulated** in a **RNS!**

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Journal of Computational Physics 225 (2007) 427–448

JOURNAL OF COMPUTATIONAL PHYSICS

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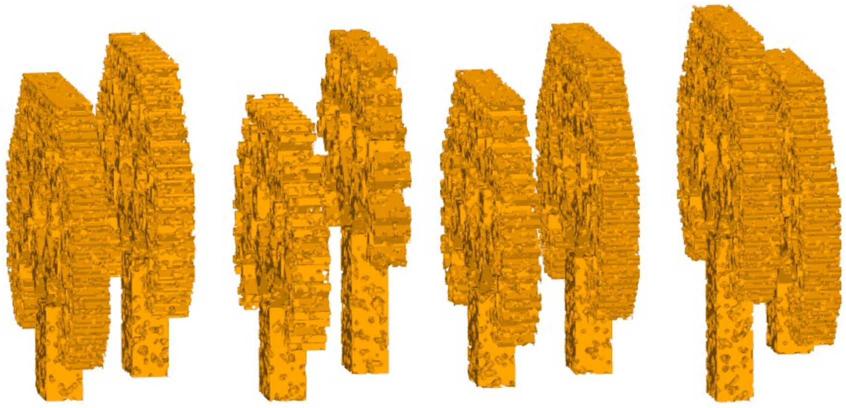
Modeling turbulent flow over fractal trees with renormalized numerical simulation

Stuart Chester [a], Charles Meneveau [a,*], Marc B. Parlange [a,b]

➡ tree drag C_T converges after **3 branch** generations

Plant Scale Approach

- **Ensemble** of **16 trees**,
  vary in a gaussian way:
  - Height
  - Fractality
  - Position
  - Porosity



- **Thermal Stability of ambient air** ***(Shaw 1988)***
- **Heated Tree Crown** ***(EAGLE Campagne 3K)***
- **Vertically Stretched grid** across **surface layer**
  (100m,10m,10cm)

EULAG with Immersed Boundaries

$$\nabla \bullet (\rho_b \mathrm{v}) = 0$$

$$\frac{d\mathrm{v}}{dt} = -\nabla \pi' + g\frac{\theta'}{\theta_b} + F' - \beta(\mathrm{v} - 0)$$

$$\frac{d\theta'}{dt} = H - \mathrm{v} \bullet \nabla \theta_e - \beta(\theta - \theta_c)$$

$$\psi' = \psi - \psi_e \qquad \psi = u, v, w, \theta, \ldots.. \qquad \pi' = \frac{p - p_e}{\rho_b}$$

Boussinesq Approximation

$\rho_b = 1.025\ \mathrm{kg/m^3}$
$\Theta_b = 300\ \mathrm{K}$
$p_b = 1000\ \mathrm{hPa}$
$\Theta_c = \Theta_e + 3.15\ \mathrm{K}$

- **Nonhydrostatic**, Anelastic, Navier-Stokes, etc.
- „Multidimensional Positive Definite Advection Transport“ (**MPDATA**)
- **LES** type closure (1.5 order, prognostic tke)
- Sucessfully used over a **wide range of scales in GFD**

„EULAG, a computational model for multi-scale flows“, Prusa et all. 2008

Experimental Setup

Stretched vertical coordinate

$\Delta x = \Delta y = 5$ cm

Δz = **12cm**, …, **12m**

Domainsize

Gridpoints 384 x 384 x 384

19.2 m x 19.2 m x 108 m

Periodic lateral boundaries

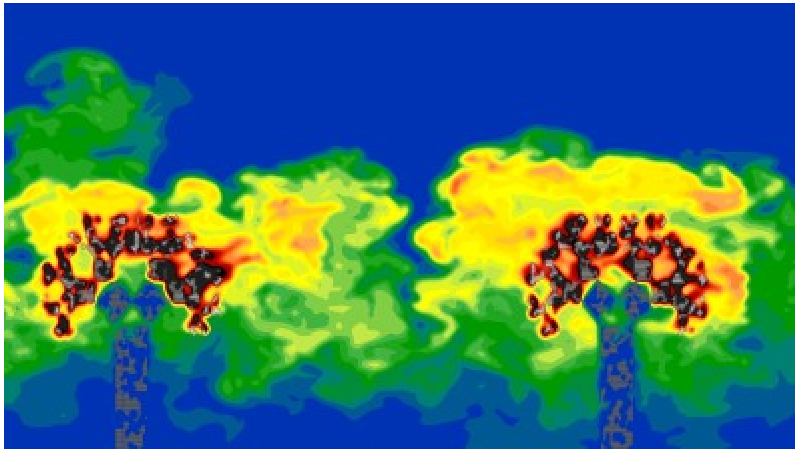
Timesteps

$\Delta t = 0.002$ s

nt=180 000, Time=360s

Moving average:

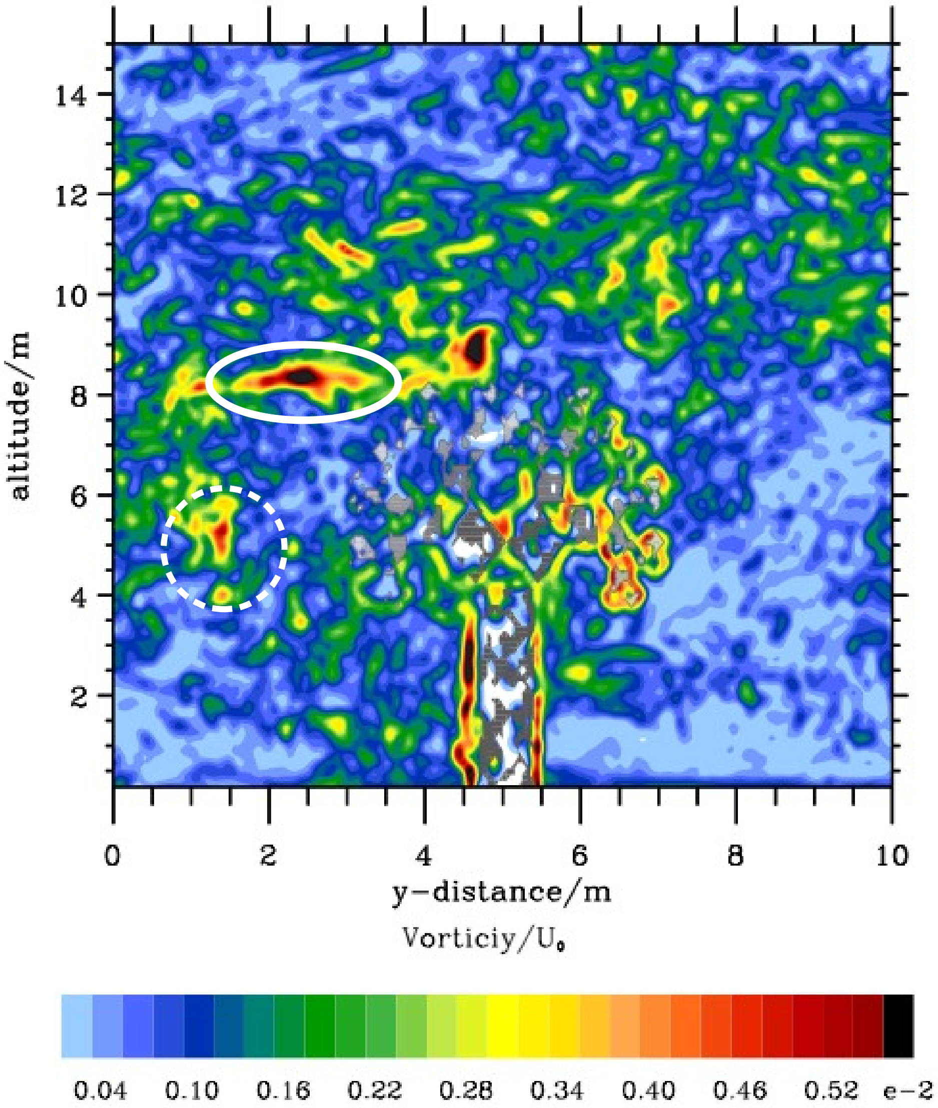
Online statistics over last 5 min

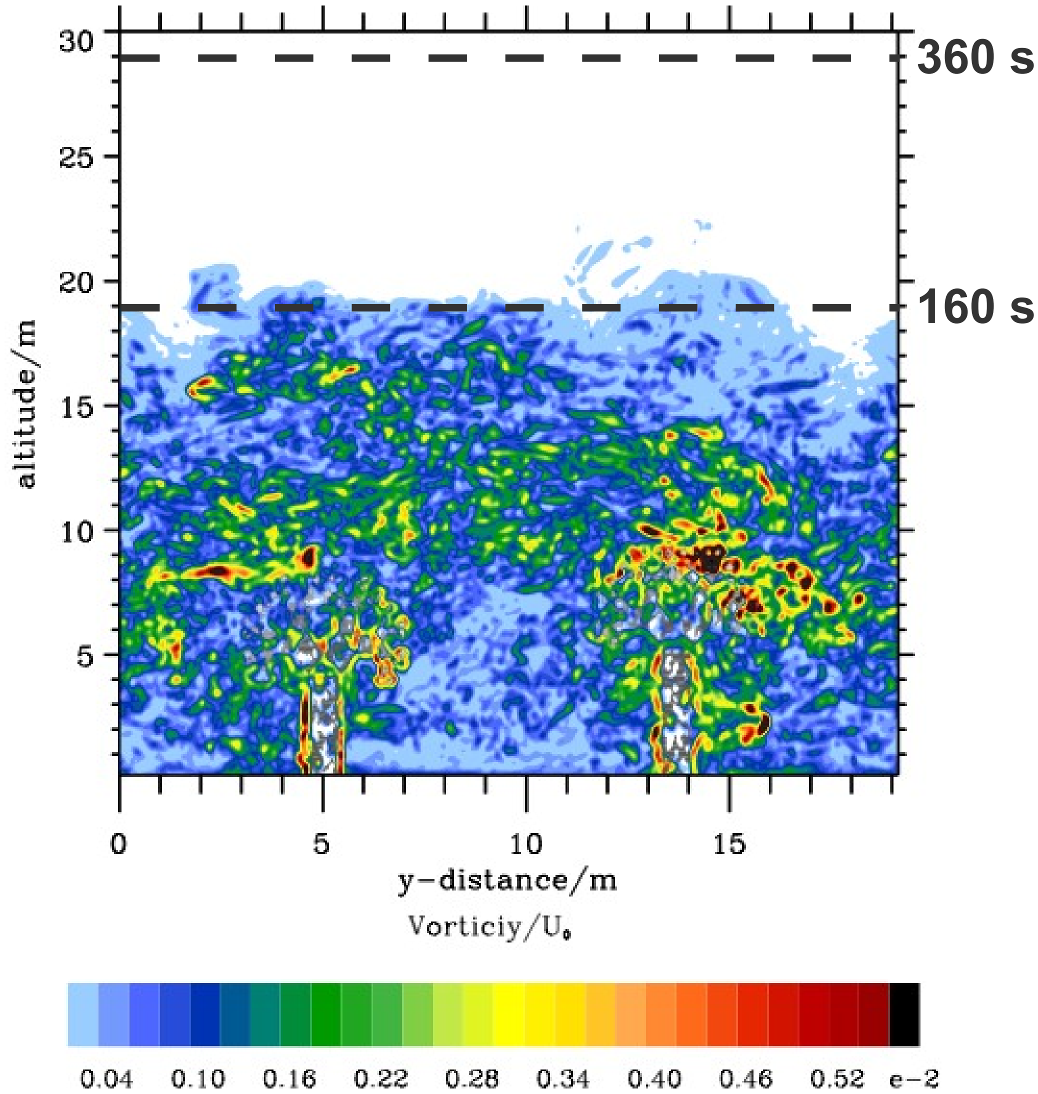


Imrsb. w/ a prescribed Temp. are an extension to „Building resolv. LES & comparison with wind-tunnel studies“, Smolar. JCP 2007

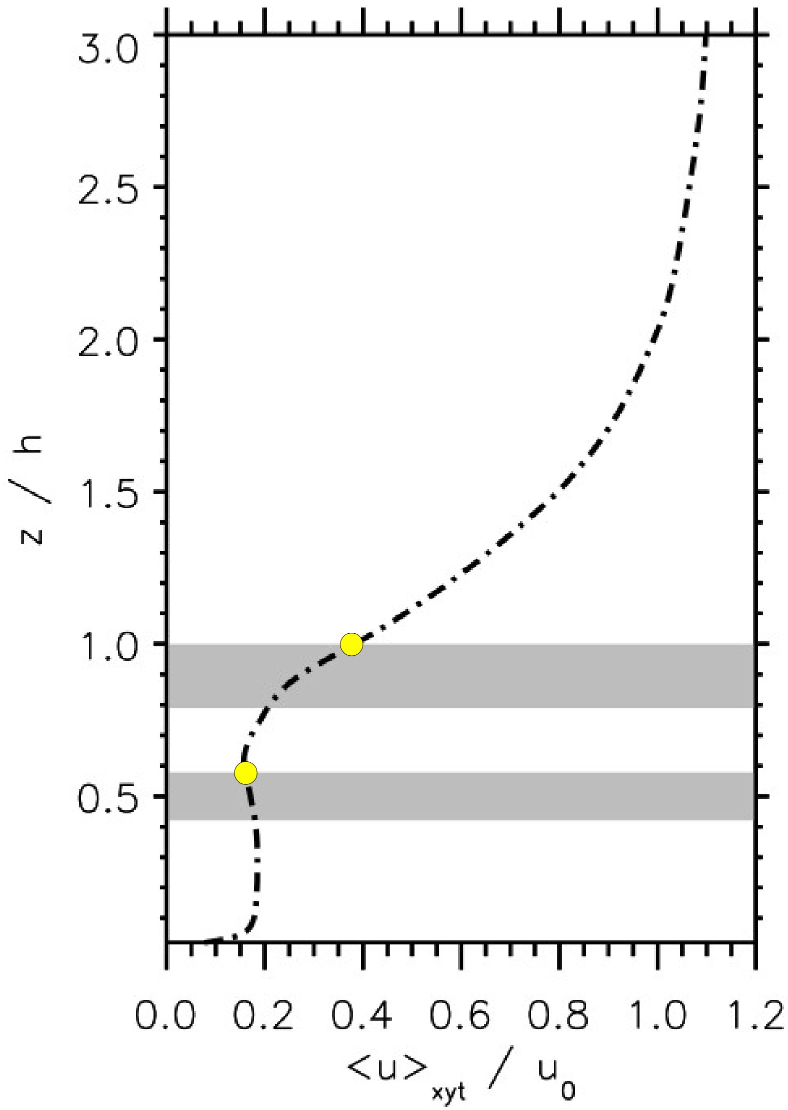
Runs	*N* [1/s]	*ΔT(tree)* [K]	*U* [m/s]
1) neutral	0	0	2.8
2) n+heat	0	3.15	2.8
3) stable	0.05	0	2.8
4) s+heat	0.05	3.15	2.8

Neutral (Snapshot 160s)





Velocity Profile



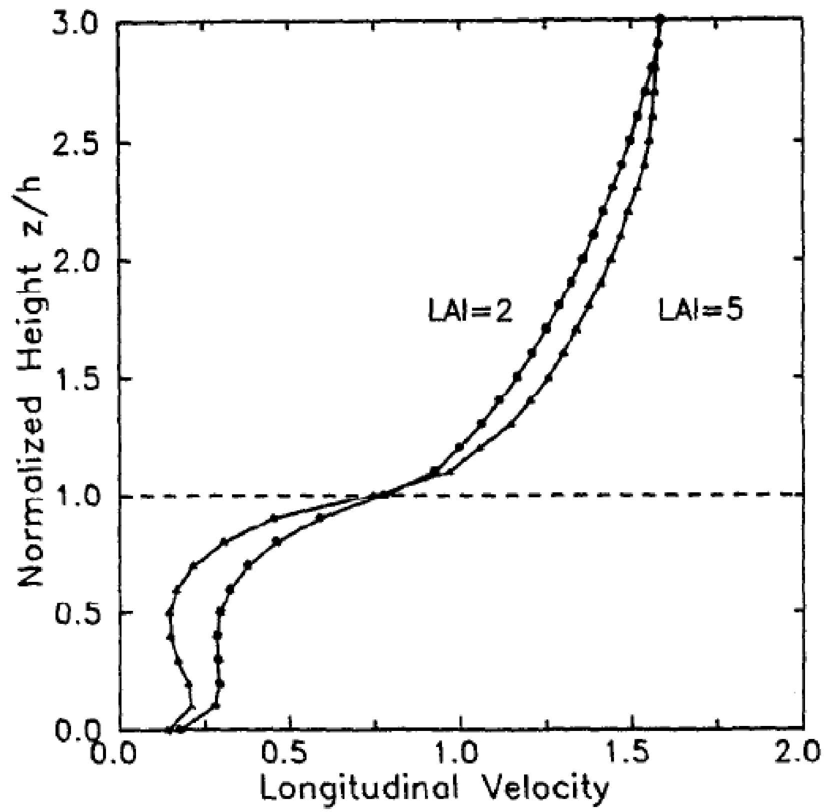
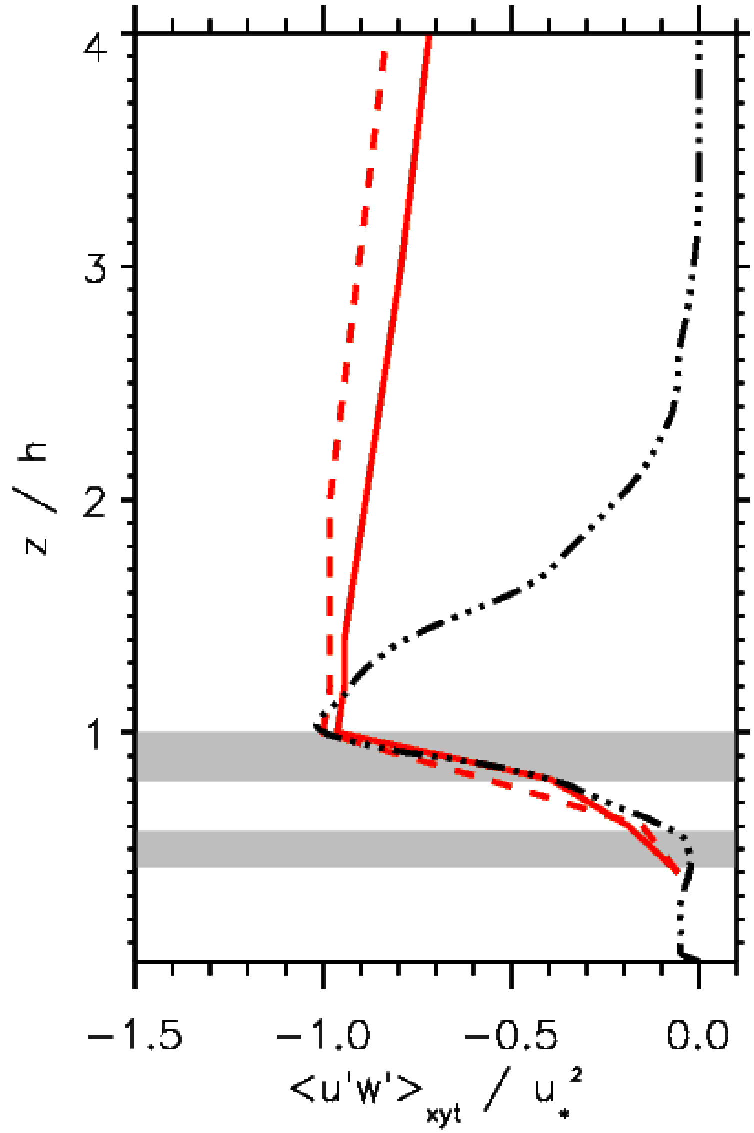


Fig. 3. Spatial mean longitudinal velocity profiles for two values of LAI under weakly unstable conditions. Velocity is normalized by the vertically averaged longitudinal velocity.

Shaw & Schumann, BLM 1992
Schröttle & Dörnbrack, 2011
Inflection Point

Momentum Transport



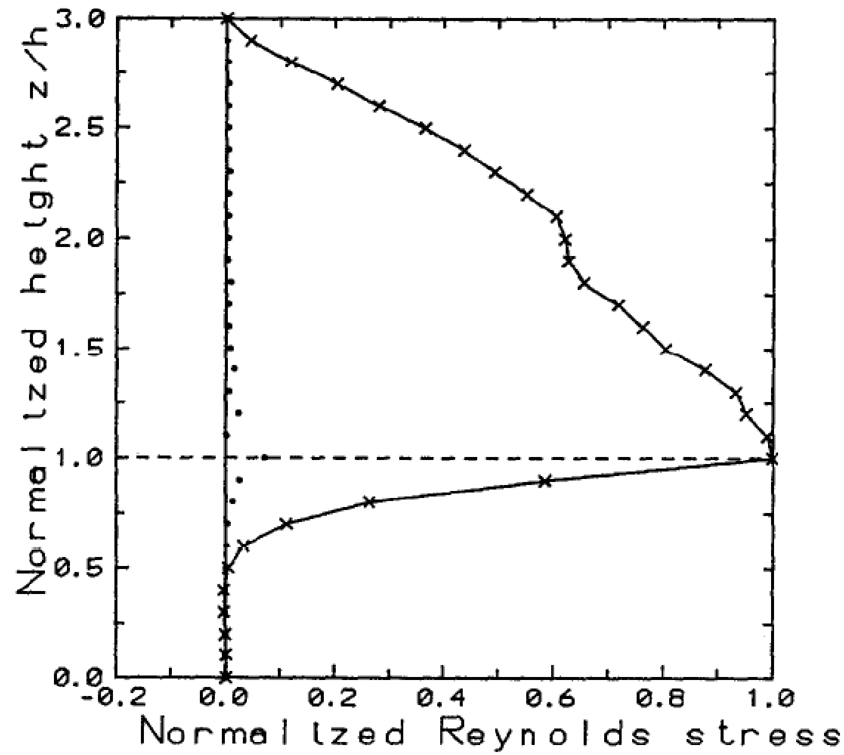
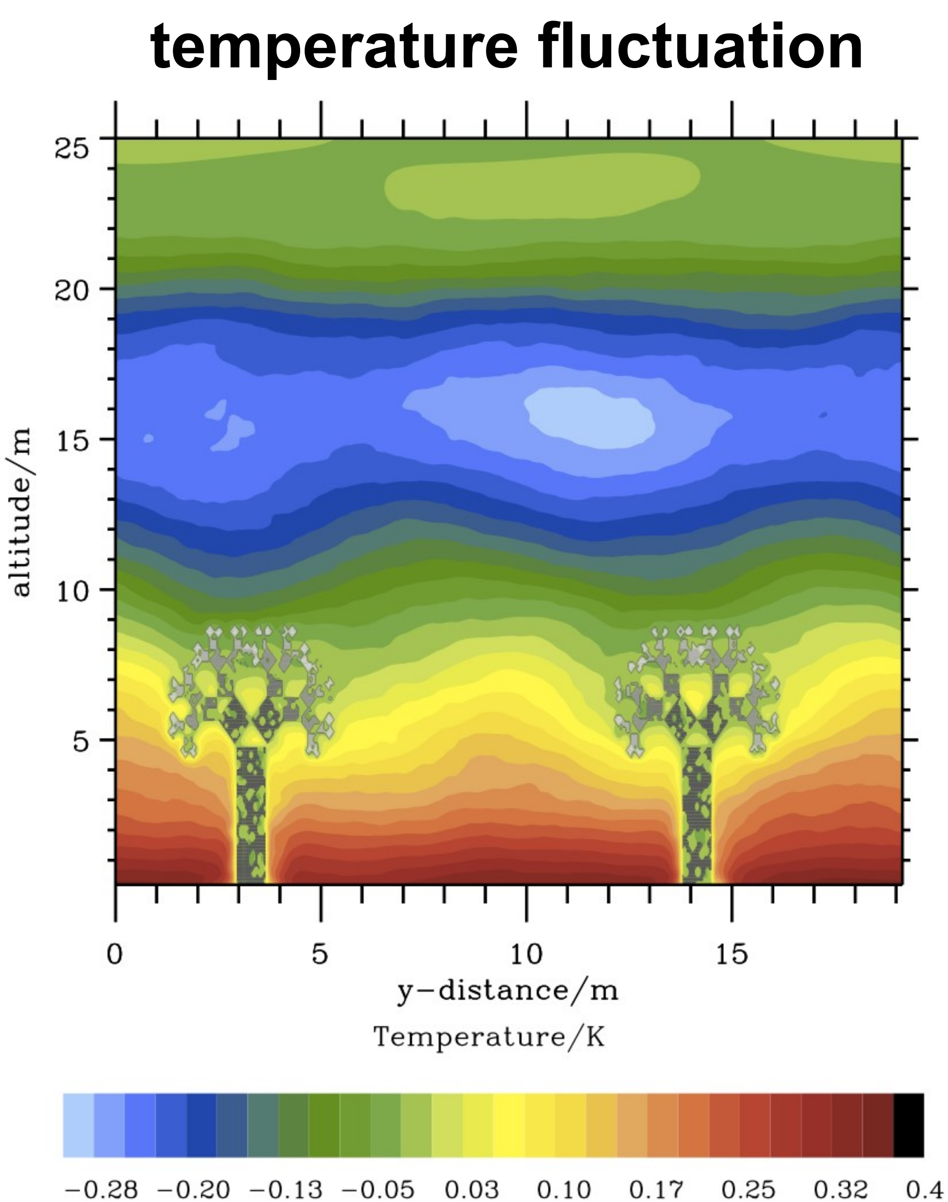
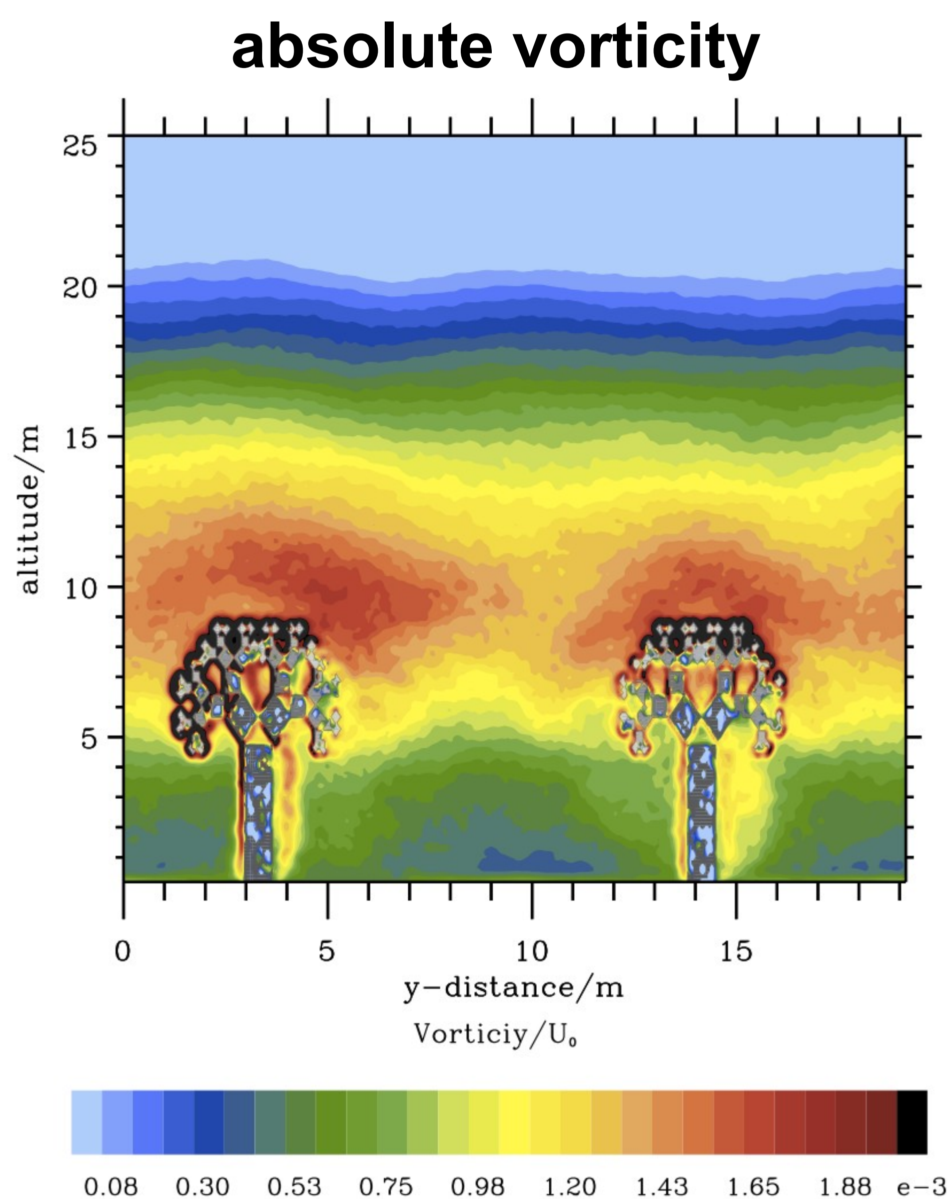


Fig. 4. Vertical profile of the spatial mean Reynolds stress for a LAI of 5 and weakly unstable conditions, and normalized to its value at the top of the canopy. The solid line is the sum of resolved and subgrid-scale components of the Reynolds stress. The dots are the SGS component.

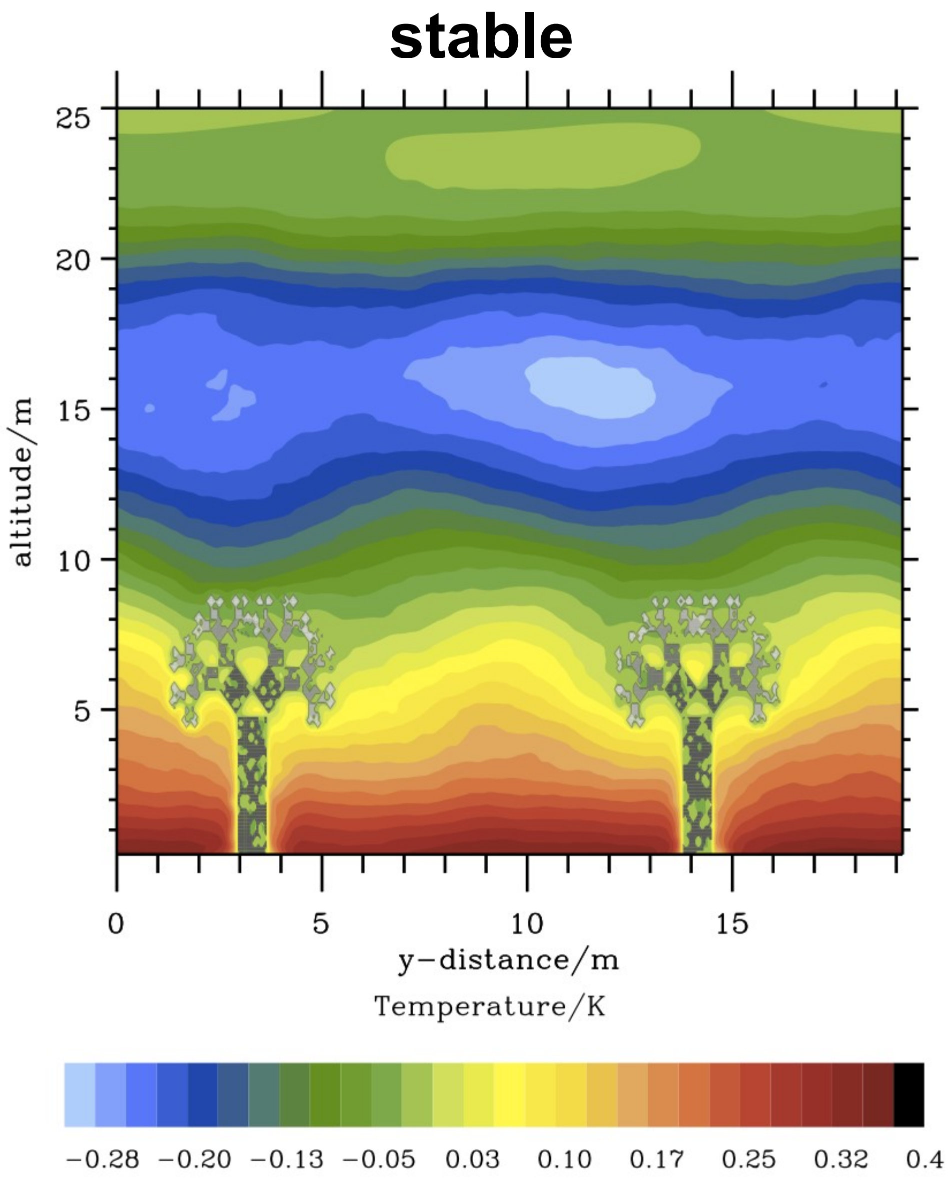
Shaw & Schumann, BLM 1992
Brunet Windtunnel, BLM 1994
Finnigan LES, JFM 2009
Schröttle & Dörnbrack, 2011

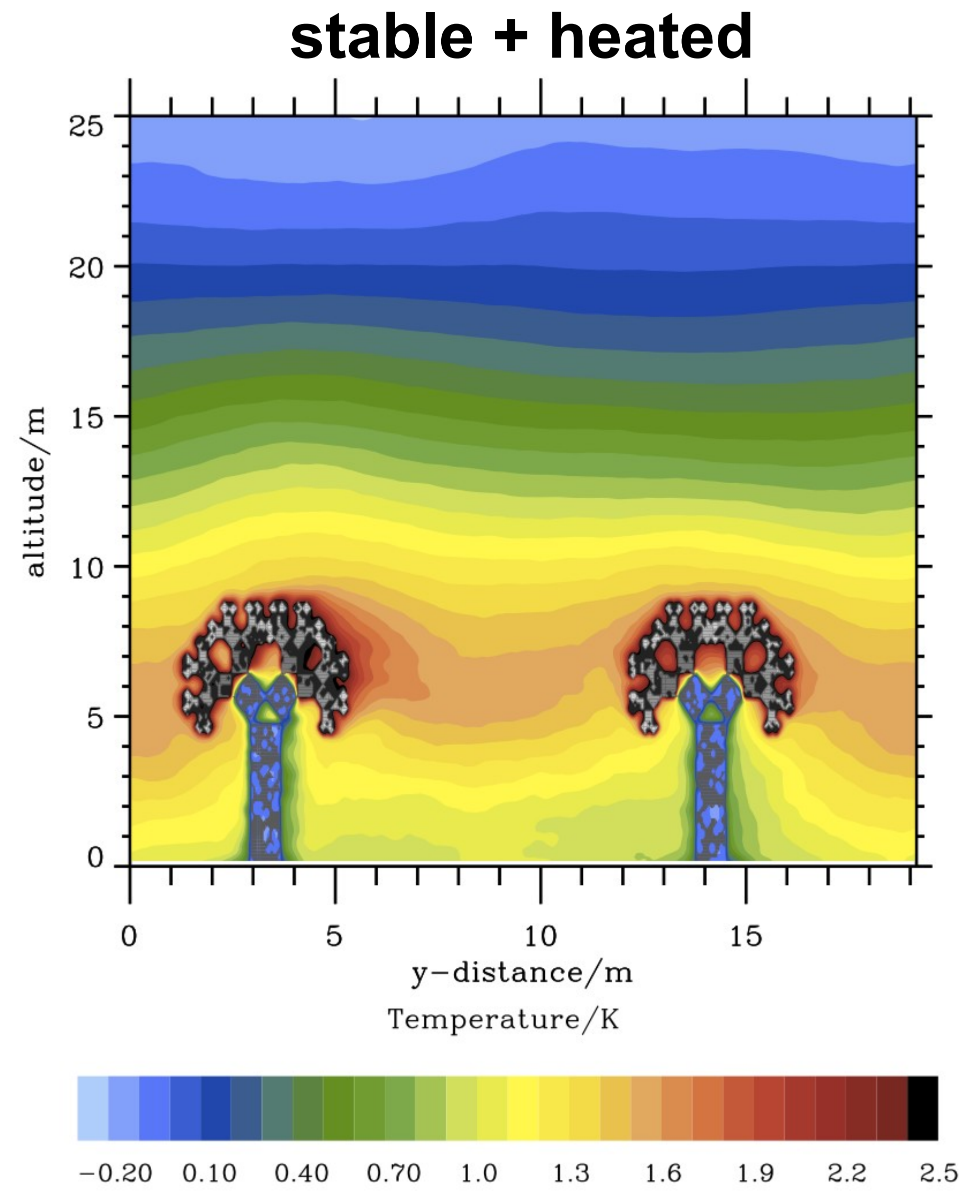
Stable Run (average 360s)





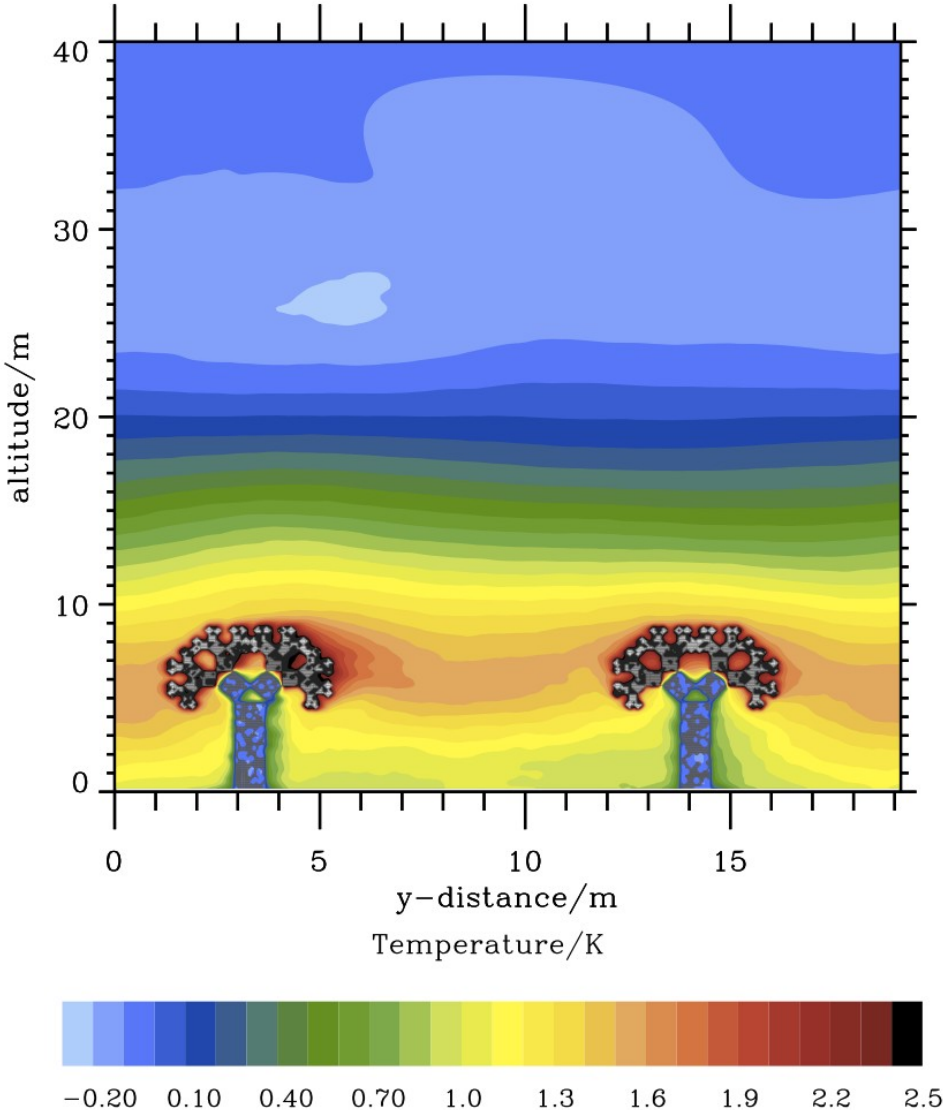
Temperature Fluctuation (average 360s)



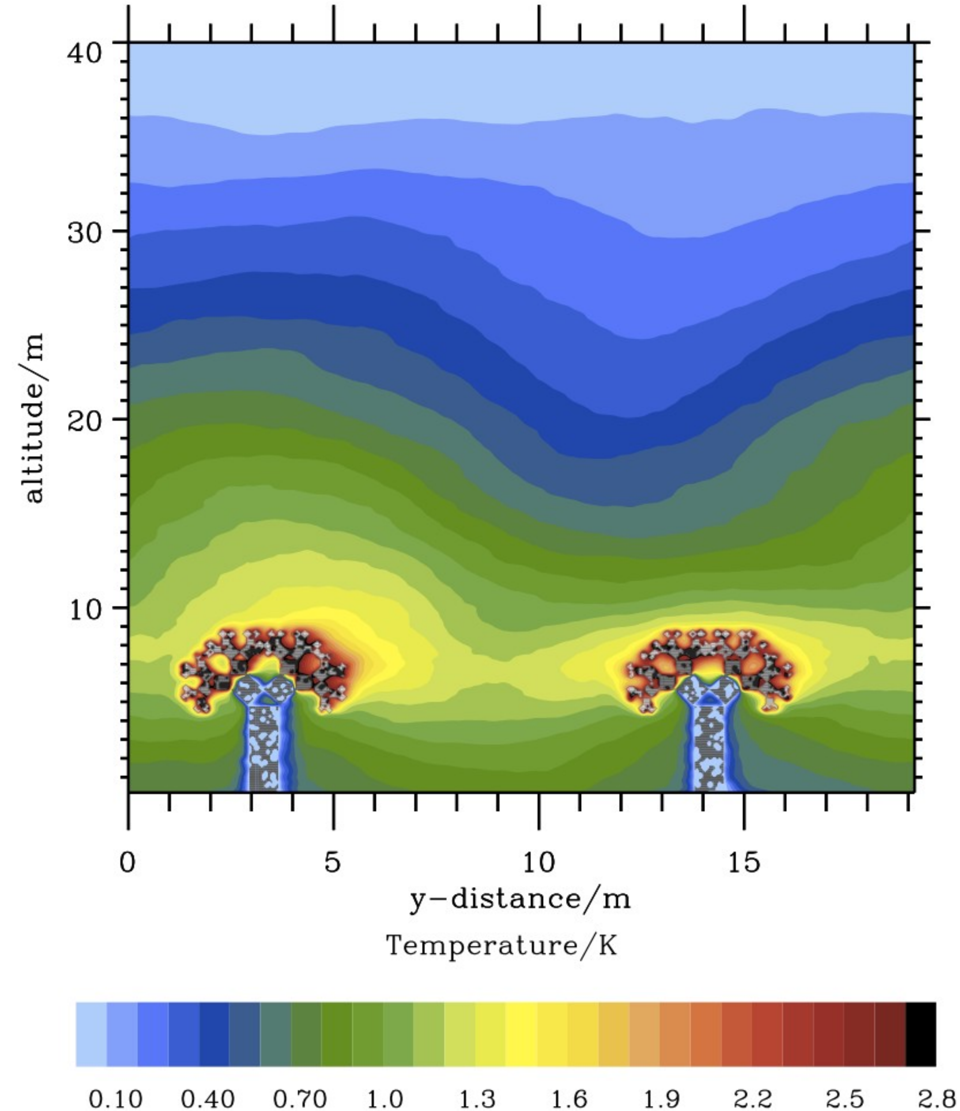


Temperature Fluctuation (average 360s)

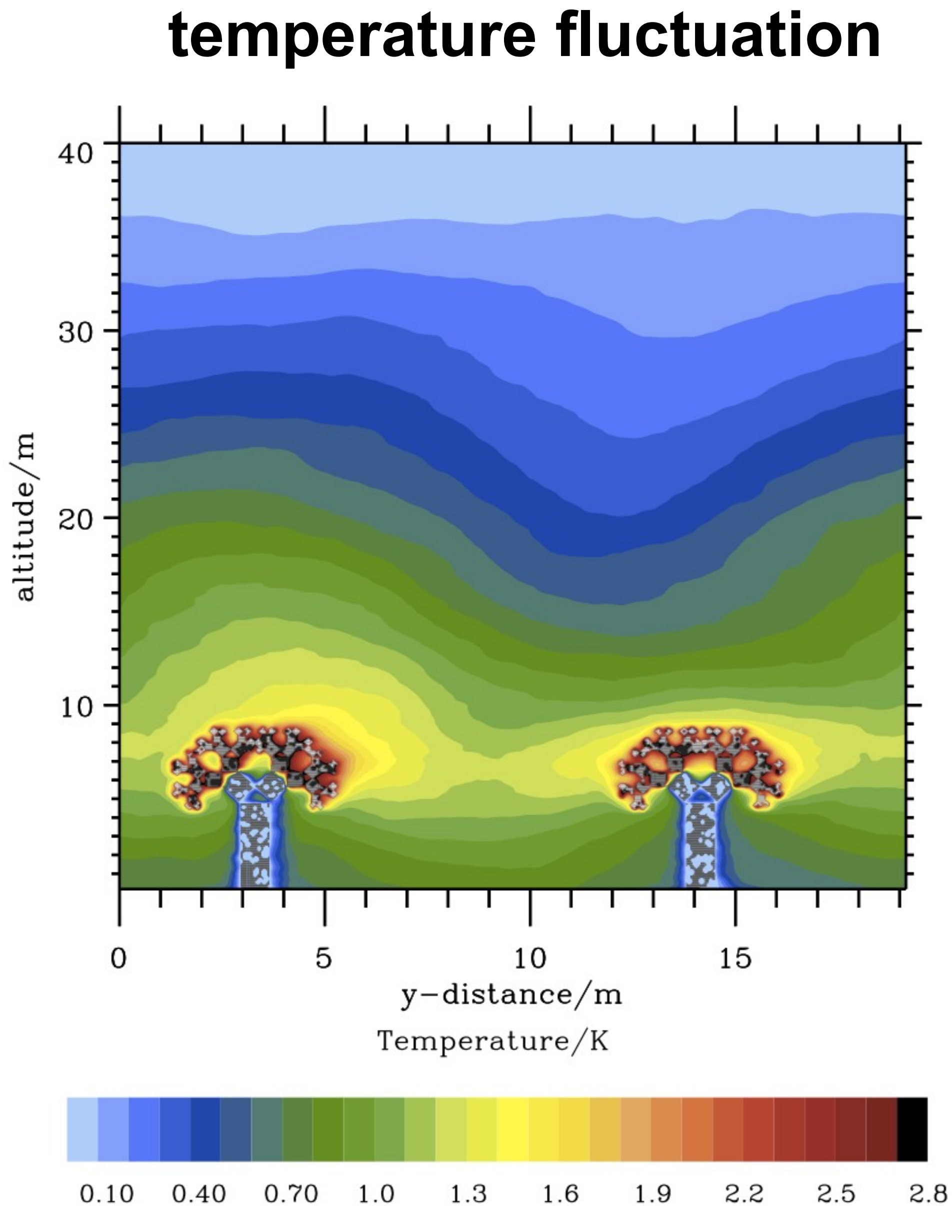
stable + heated

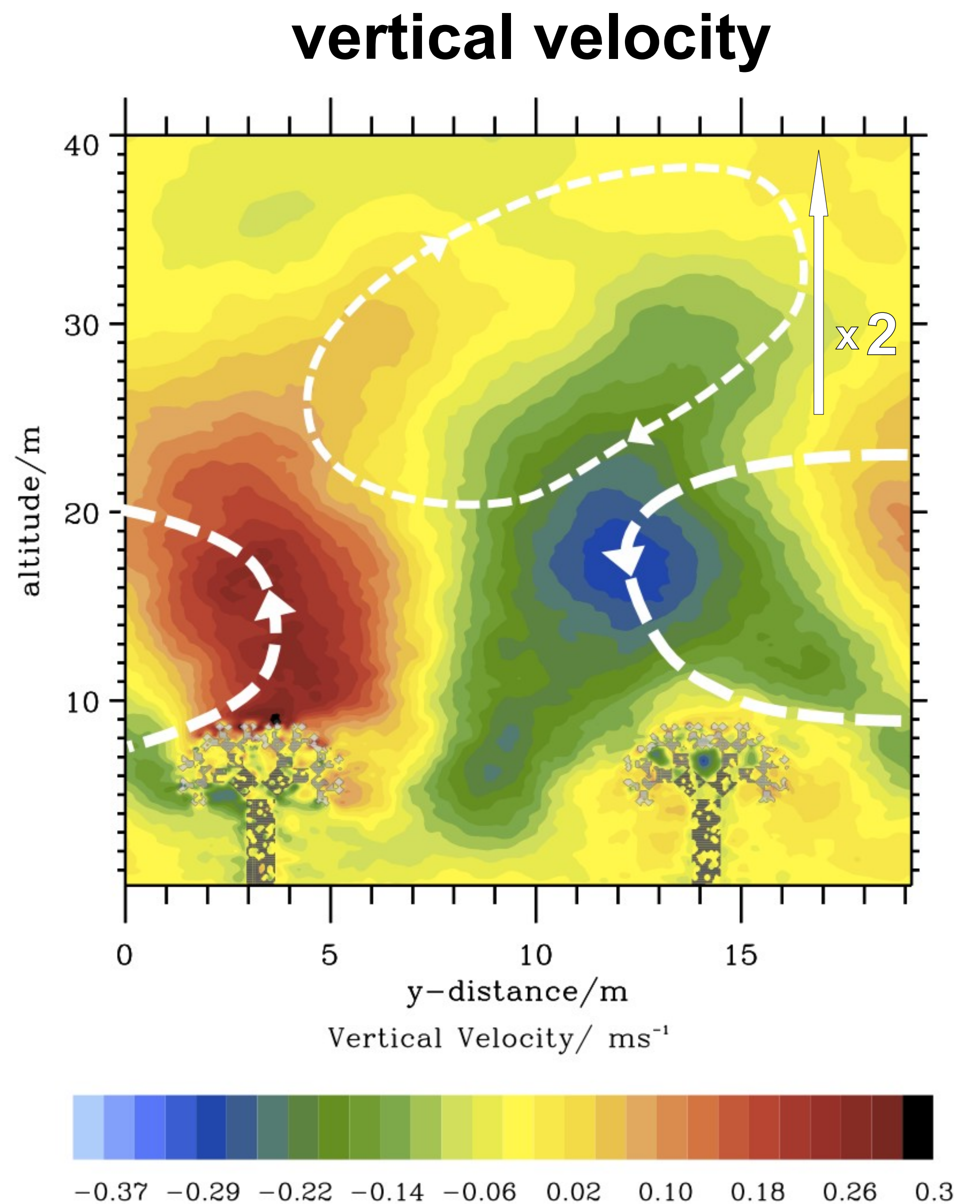


neutral + heated

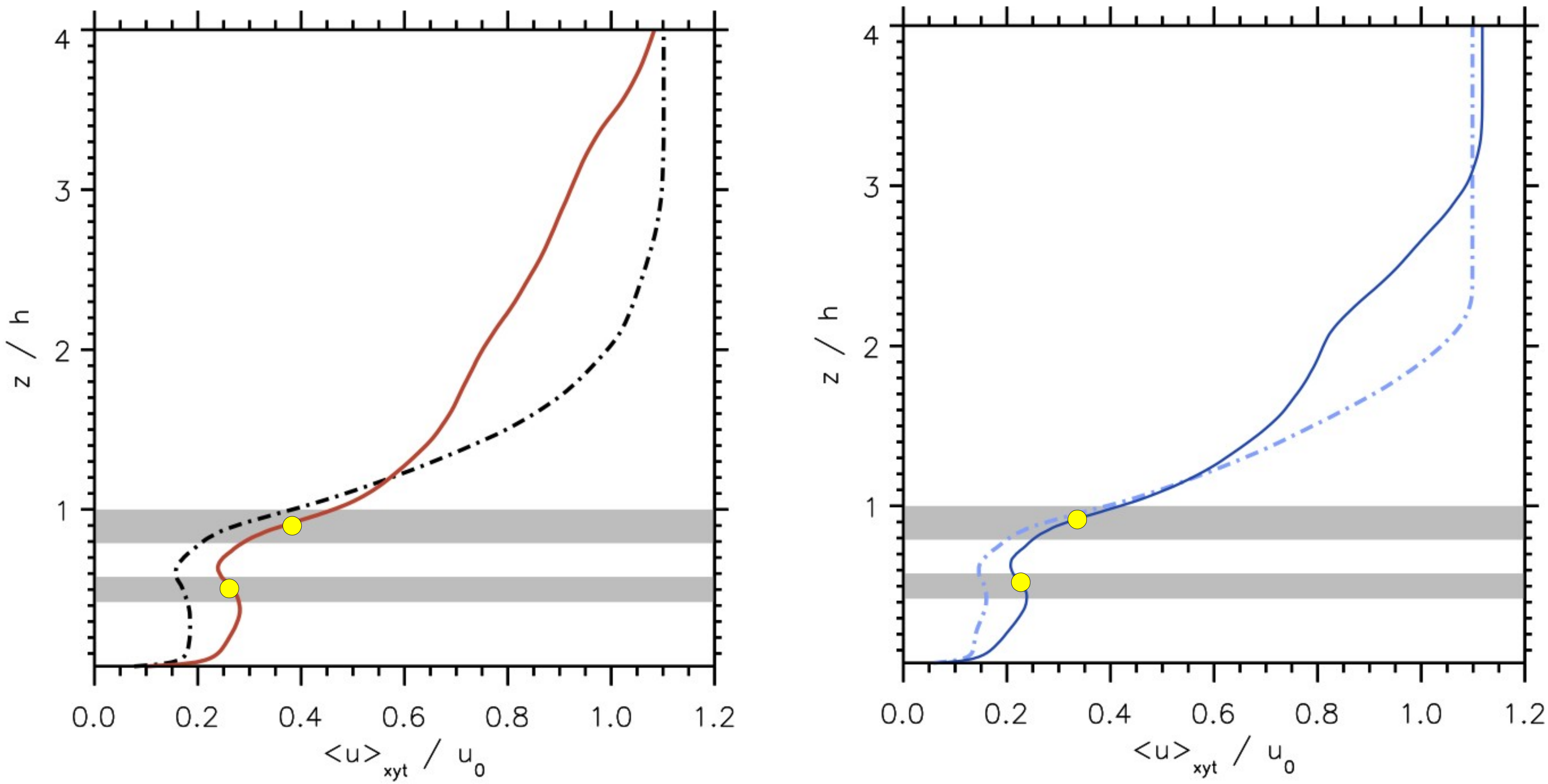


Neutral + Heated Run (average 360s)





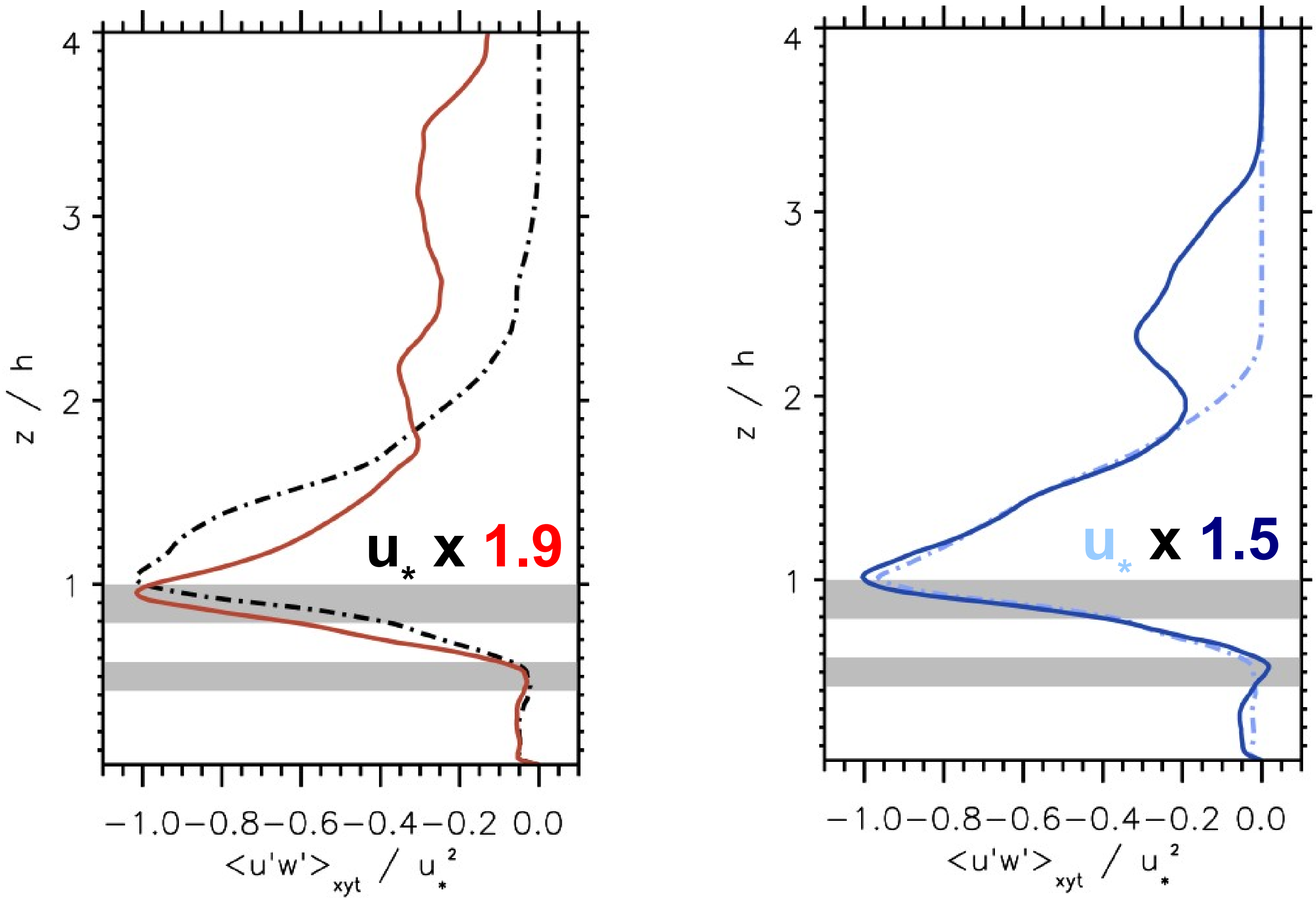
Velocity Profile for Diabatic Heating



neutral stratification
neutral + heated

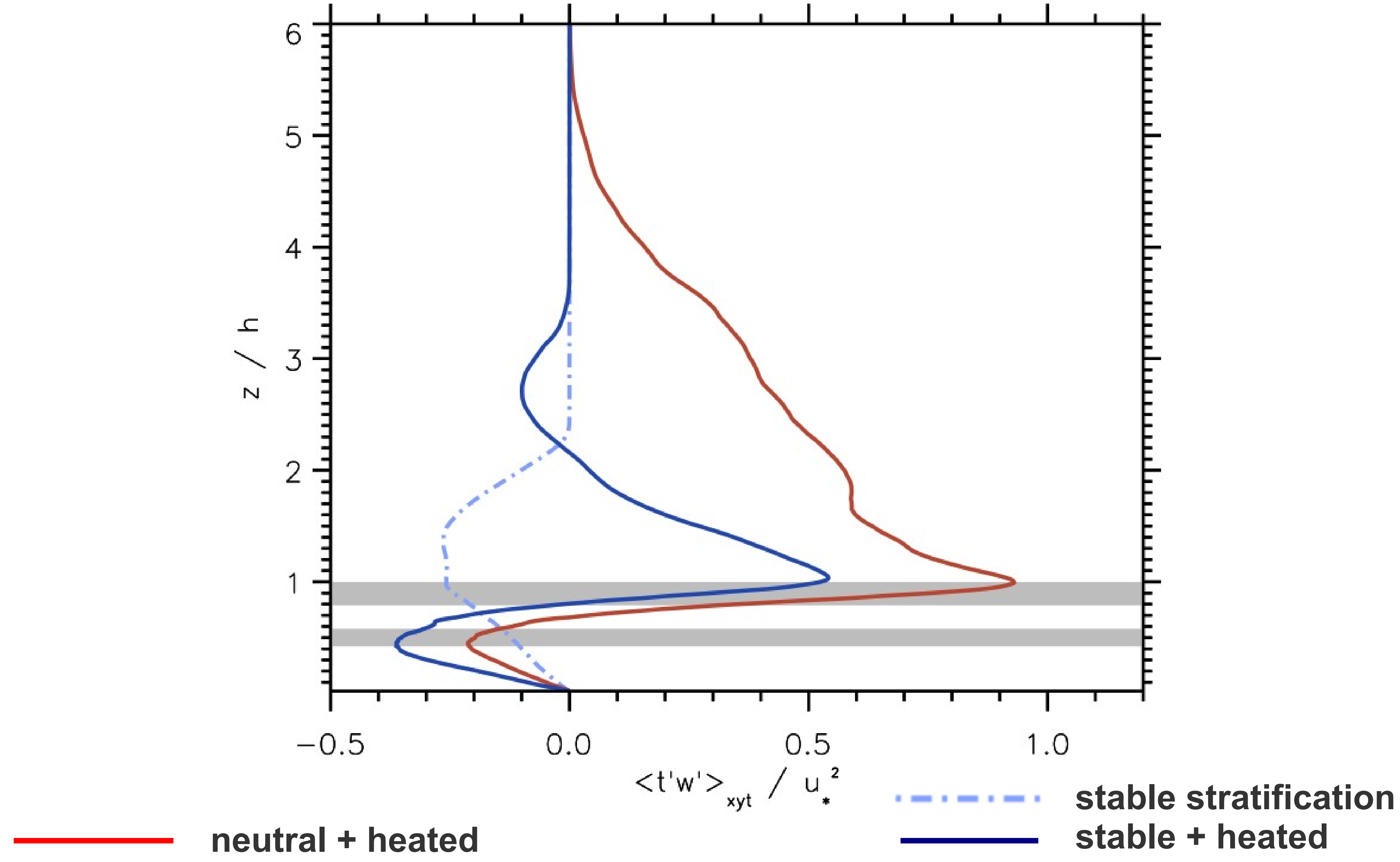
stable stratification
stable + heated

Momentum Transport for Diabatic Heating



neutral stratification
neutral + heated
stable stratification
stable + heated

Heat Flux for varying Stratification



Conclusions

- **Shear**, **vorticity bands**, **plumes** and **wake vortices** are generated by the small scale tree elements.

- We are using **fractal trees** and **immersed boundaries,** mean quantities, such as <u>, <u'w'>, <u'u'>, <w'w'> agree with former **field scale** simulations.

- Heat flux profile of the neutral + heated run reminds of a **convective boundary layer** with an **entrainment zone** for the stable + heated run. A stable stratification developes in the trunk space.

- **Diabatic heating** enhances the **moment transport** by a **factor of 2** for neutral and by a **factor of 1.5** for stable conditions. Shear layers develope aloft the tree canopy.

Outlook

- **Increase resolution** and find **impact of fractality** on e.g. **energy spectrum**

- **Ergodic Therorem** cannot be applied here, so we have to use continuous methods in time e.g. **wavelets**

- **Visualize in 3D**, **momentum transport** (sweeps, ejections) & compare data with **observations**!

Thank you for your attention!

josef.schroettle@physik.uni-muenchen.de