Turbulence structure in a fractal forest under varying atmospheric conditions

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Outline

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b) Heated Immersed Boundaries

c) Resolved Flow: 100m to 5cm

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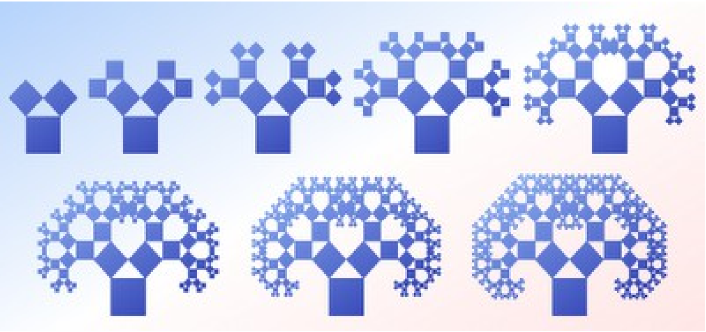
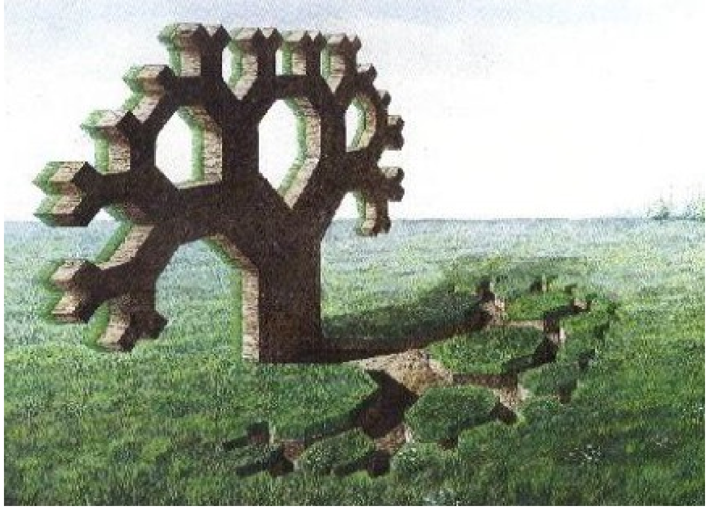
IV. Conclusions

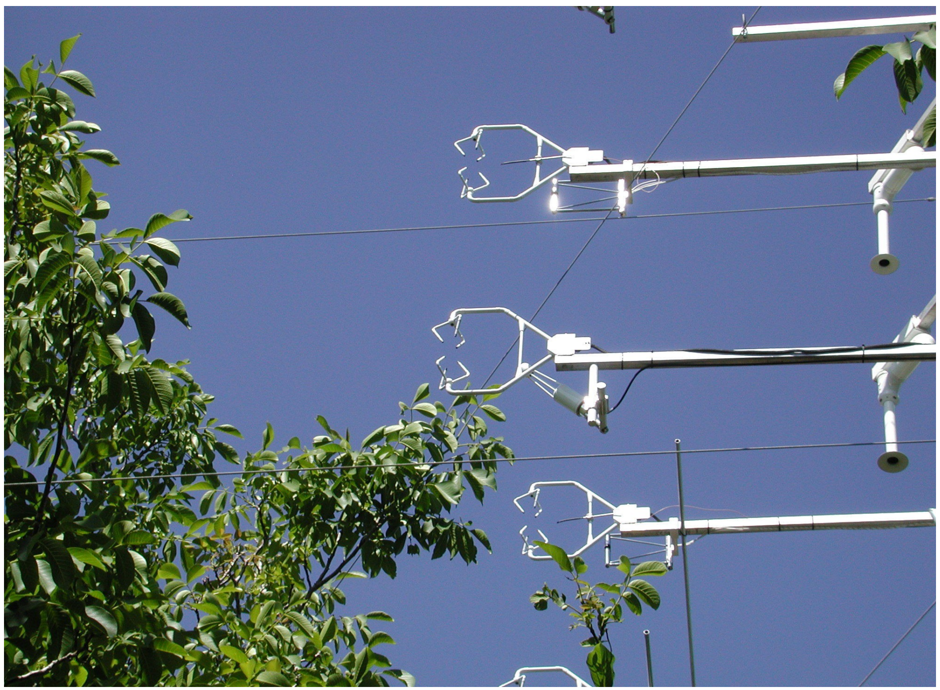


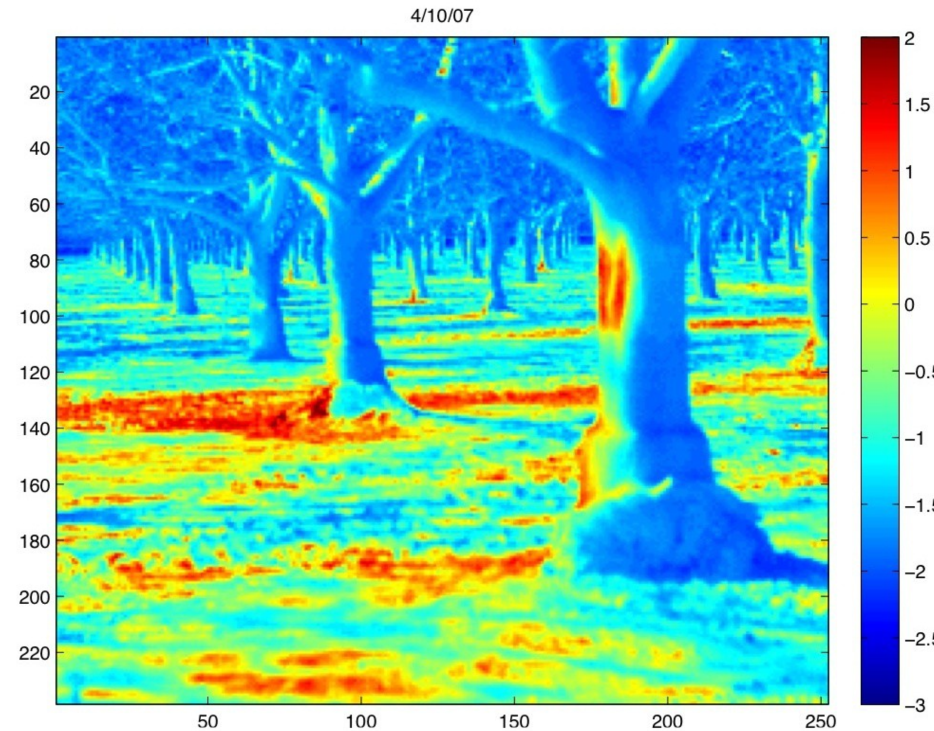
Pythagoras tree (below) and algorithm described (above)



Motivation

In **forests** measurements are taken at the microscale from meters ***down to a few cm***.





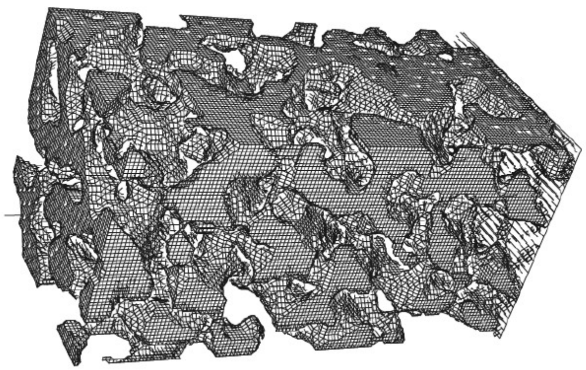
http://www.eol.ucar.edu/deployment/field-deployments/field-projects/chats-project

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)



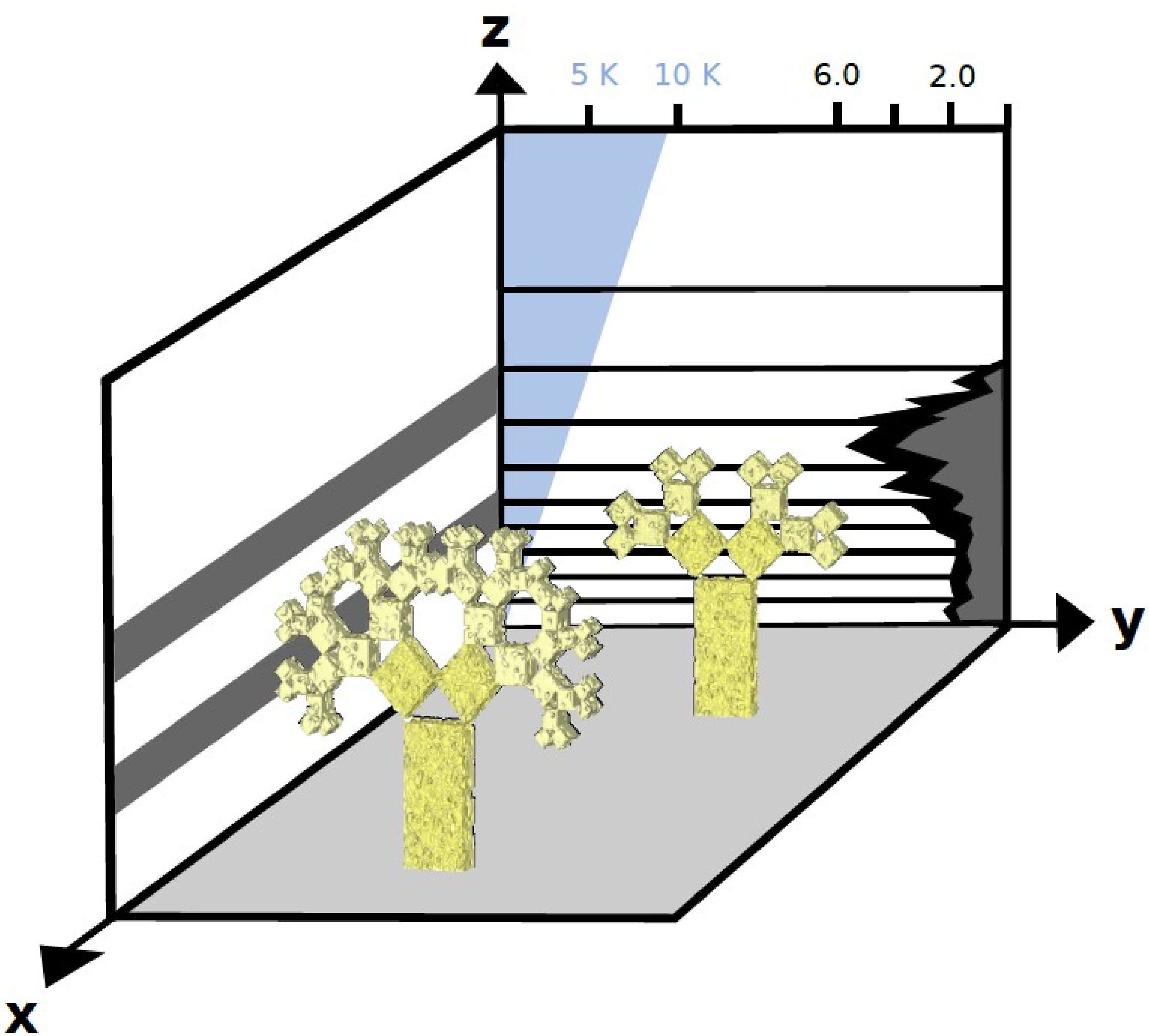
$$\boldsymbol{F_D} = -c_D \, LAD(z) |u| \boldsymbol{u}$$

Field-scale simulations, where resolution is of $O(1\,m)$

- Shaw & Schumann (1992)
- Dupont & Brunet (2009)
- Finnigan et al. (2009)

Is it possible to resolve the **turbulence structure** correct over this wide range of scales by state-of-the art **multiscale numerical simulations?**

Plant Scale Approach



- **Ensemble** of **16 trees**, vary in a Gaussian way:

  height, fractality, position, scale-dependent porosity
- **Thermal Stability of ambient air** ***(Shaw et al. 1988, Gao et al. 1989)***
- **Heated Tree Crown** ***(EAGLE, CHATS: 3K)***
- **Vertically Stretched grid** across **surface layer** (100m,10m,10cm)

EULAG, LES with Immersed Boundaries

$$\nabla \cdot \boldsymbol{v} = 0$$

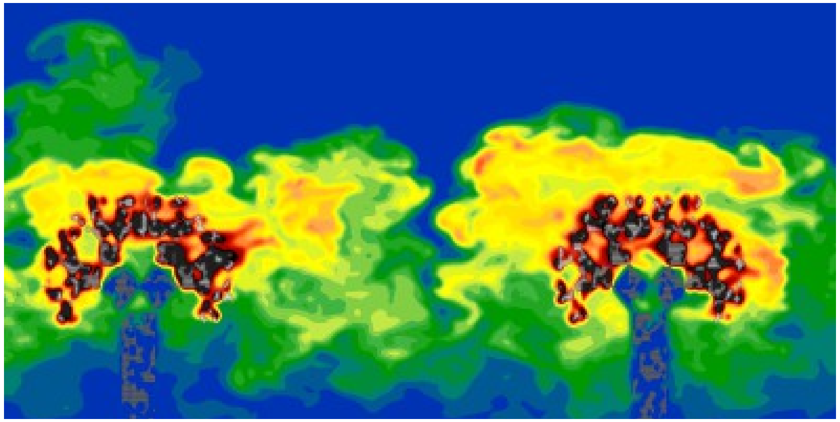
$$\frac{d\boldsymbol{v}}{dt} = \nabla \frac{p'}{\rho_b} - \boldsymbol{g}\frac{\theta'}{\theta_b} + \boldsymbol{D}^{v} - \beta(\boldsymbol{v} - \boldsymbol{v}_F)$$

$$\frac{d\theta'}{dt} = \boldsymbol{v} \cdot \nabla \theta_e + \boldsymbol{D}^{\theta} - \beta(\theta - \theta_F)$$

$$\frac{de}{dt} = S(e) - \beta(e - e_F)$$

Boussinesq Approximation

ρ_b = 1.025 kg/m^3
Θ_b = 300 K
p_b = 1000 hPa
Θ_F = Θ_e + 3.15 K



Imrsb. w/ a prescribed temp. are an extension to the ones used for 'Building resolv. LES & comparison with windtunnel studies' (Smolarkiewicz et al. JCP 2007)

'EULAG, a computational model for multi-scale flows' (Prusa et al. 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

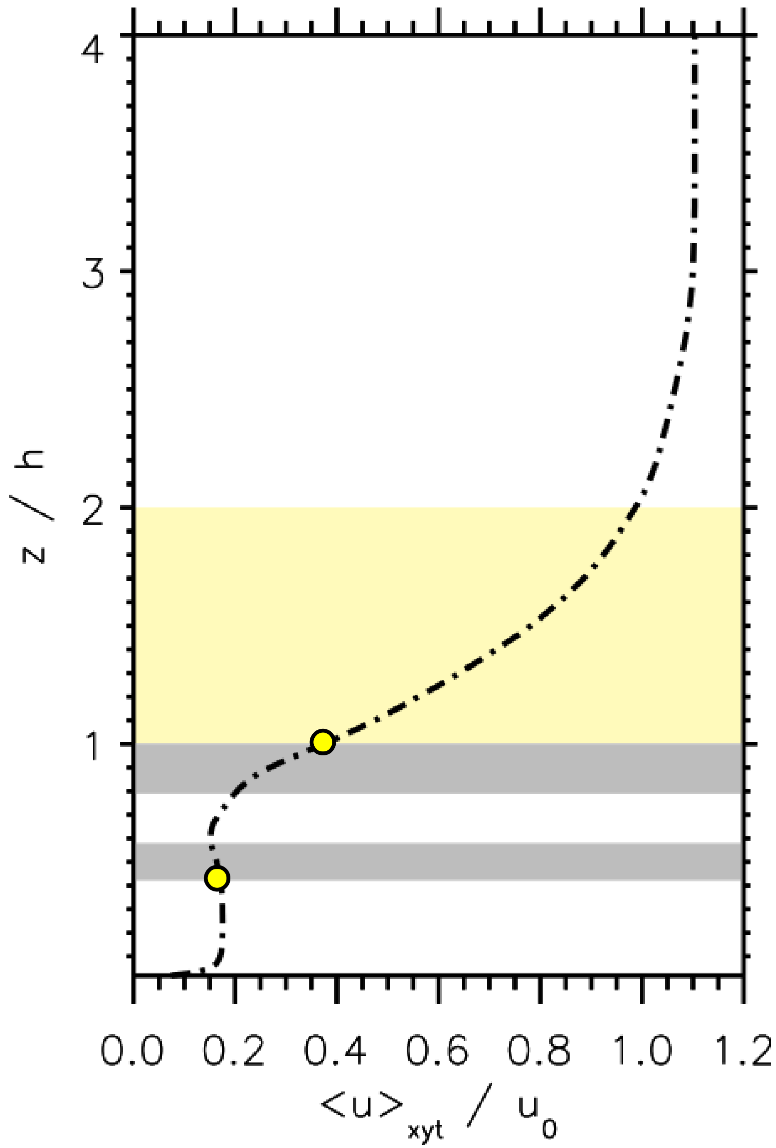
Moving average:

Online statistics over last 5 min

Runs	*N [1/s]*	*ΔT [K]*	*LAI*	*U [m/s]*
1) neutral	0	0	2.8	2.8
2) n+heat	0	3.15	2.8	2.8
3) n+heat	0	3.15	1.9	2.8
4) stable	0.05	0	2.8	2.8
5) s+heat	0.05	3.15	2.8	2.8

'Turbulence structure in a diabatically heated forest canopy composed of fractal Pythagoras trees' (Schröttle & Dörnbrack, TCFD 2012)

Velocity Profile



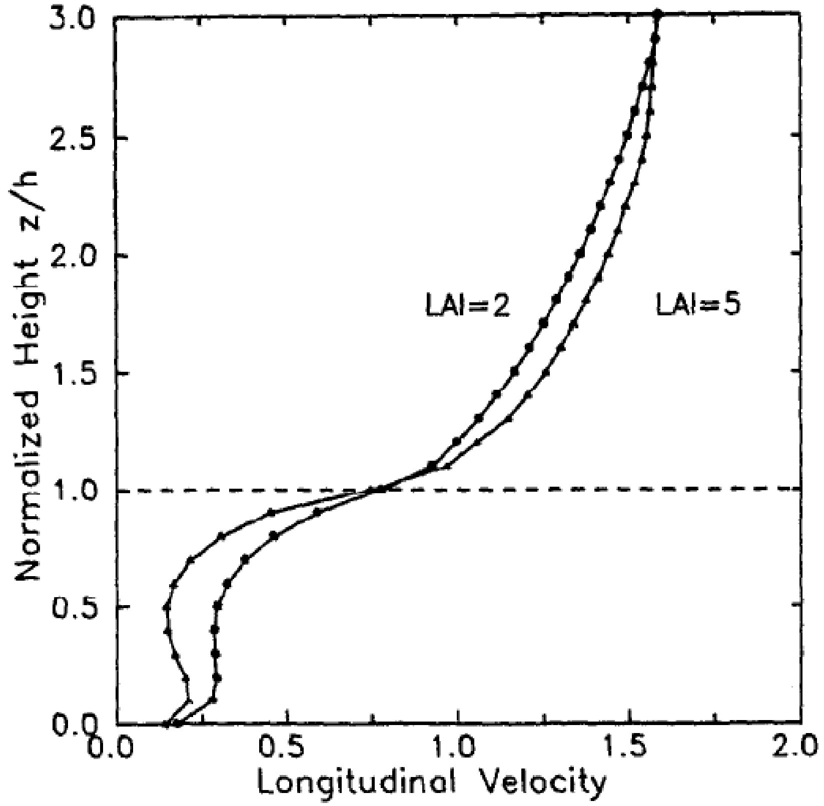
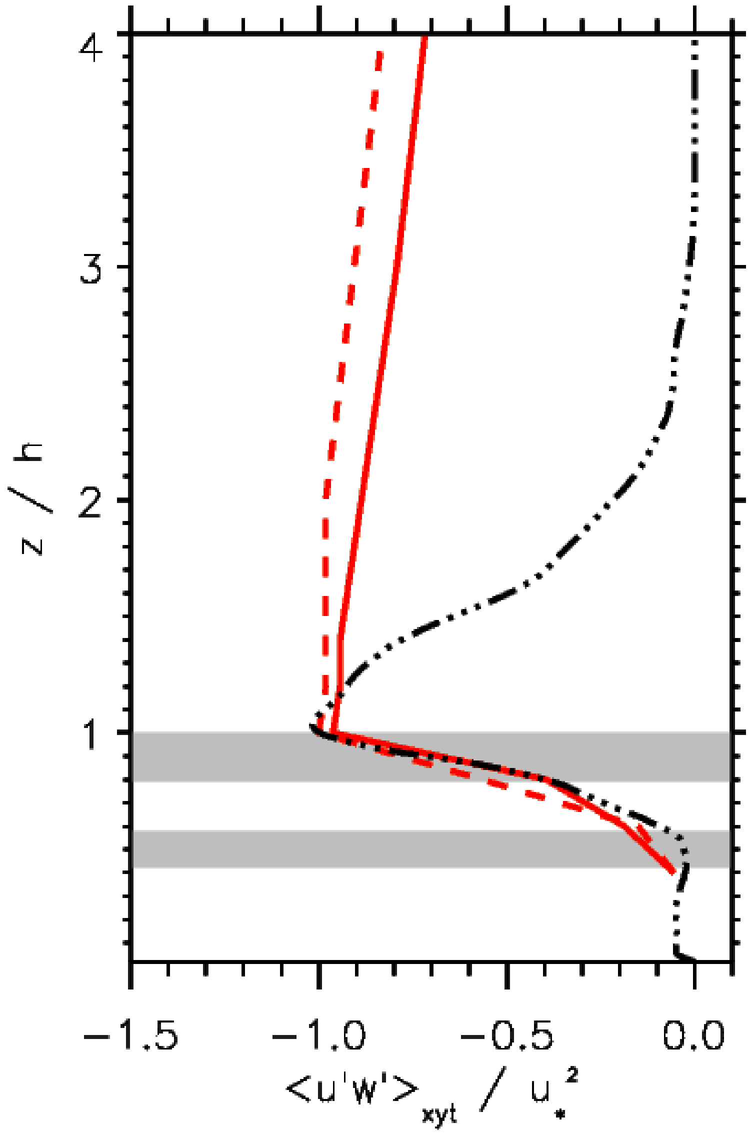


Fig. 3. Spatial mean longitudinal velocity profiles for two values of LAI under weakly unstable conditions. Velocity is normalized by the vertically averaged longitudinal velocity.

Shaw & Schumann, BLM 1992
Schröttle & Dörnbrack, 2012
Inflection Point
Vorticity Thickness of IBL

Momentum Transport



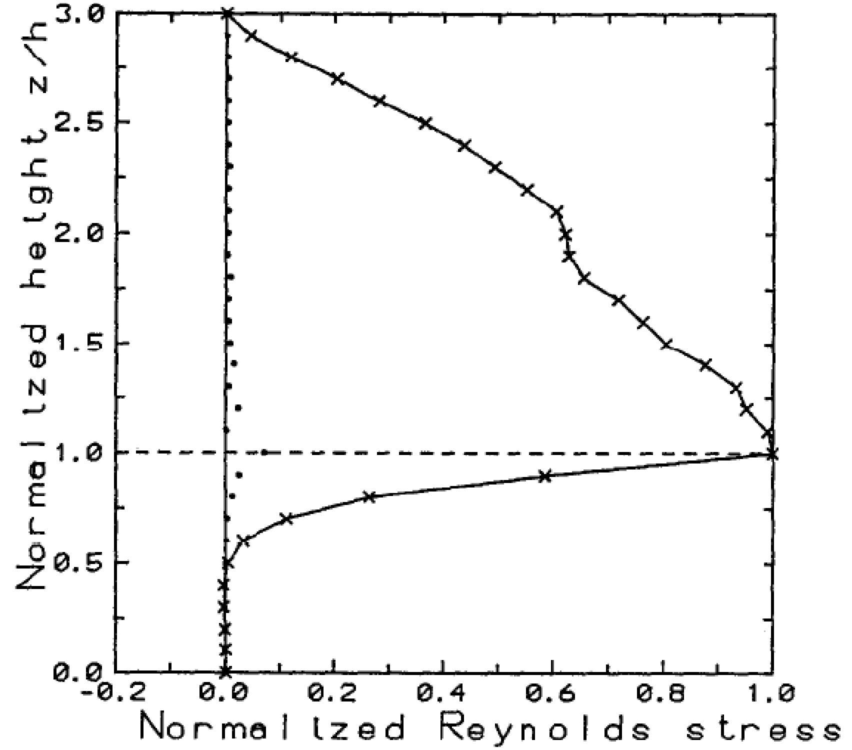
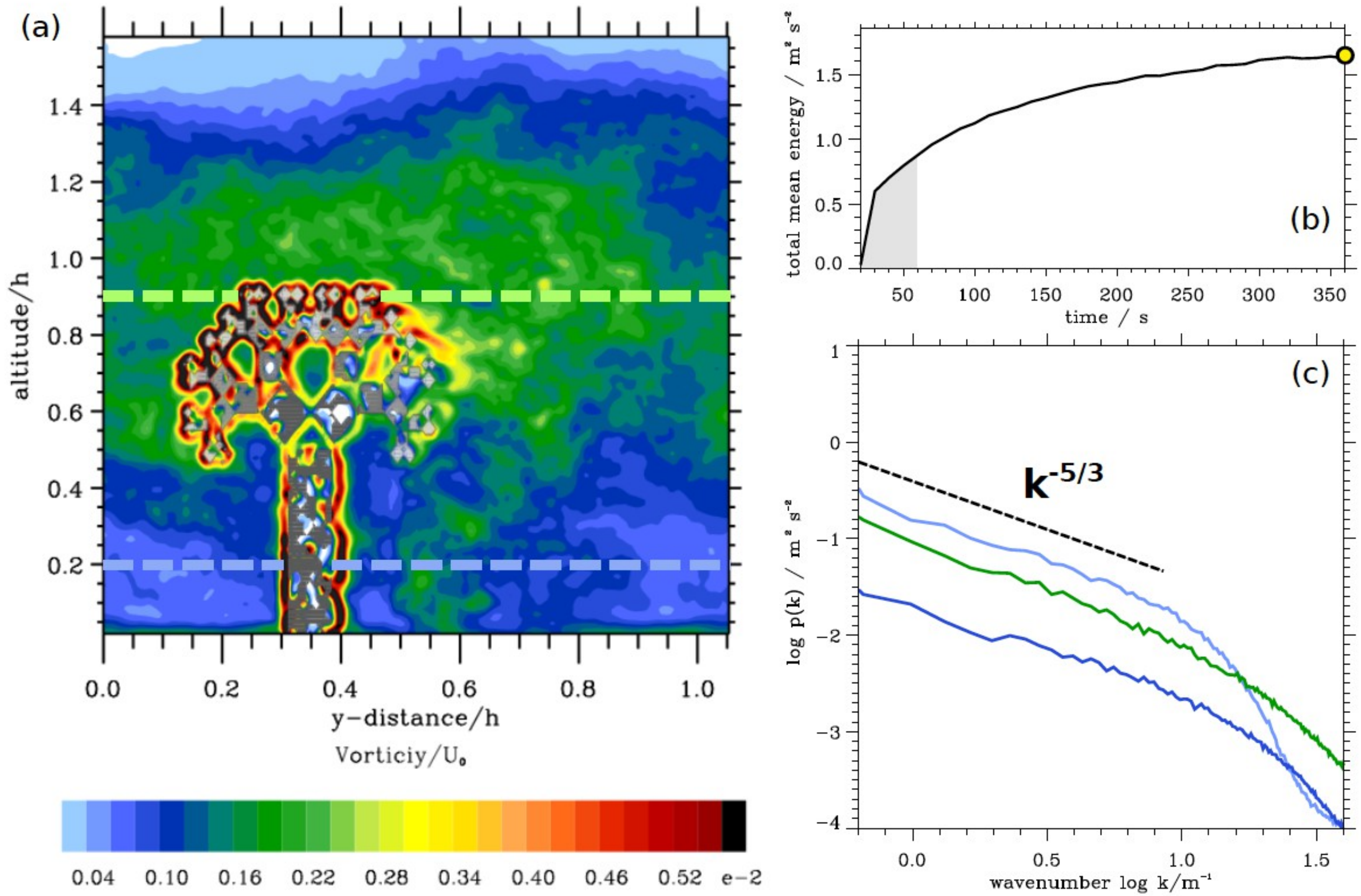


Fig. 4. Vertical profile of the spatial mean Reynolds stress for a LAI of 5 and weakly unstable conditions, and normalized to its value at the top of the canopy. The solid line is the sum of resolved and subgrid-scale components of the Reynolds stress. The dots are the SGS component.

- Shaw & Schumann, BLM 1992
- Brunet Windtunnel, BLM 1994
- Finnigan et al. LES, JFM 2009
- Schröttle & Dörnbrack, 2012

Vorticity, Turbulent Kinetic Energy

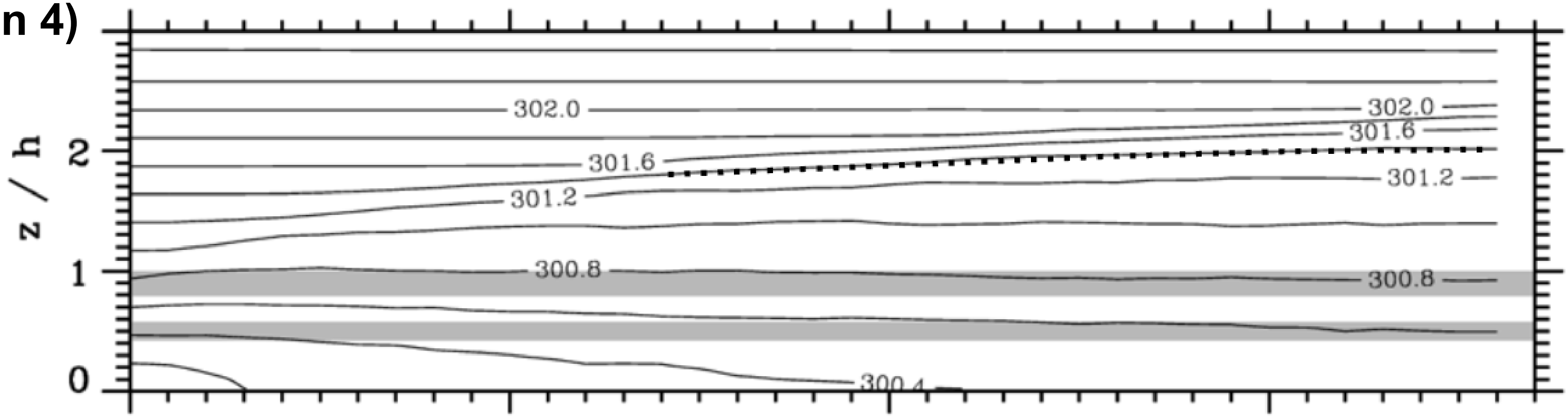


Domain averaged resolved turbulent kinetic energy

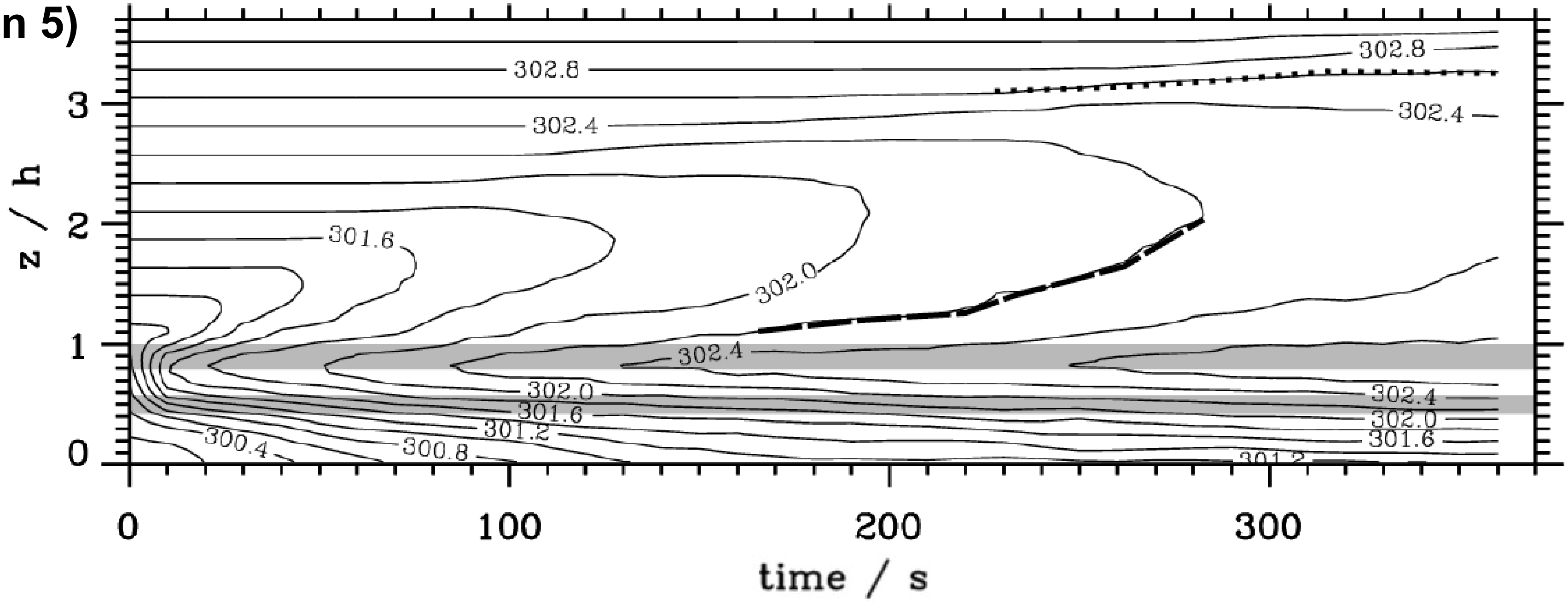
above canopy flow
fractal crown space
trunk space

Stratification, Hovmoeller Diagrams

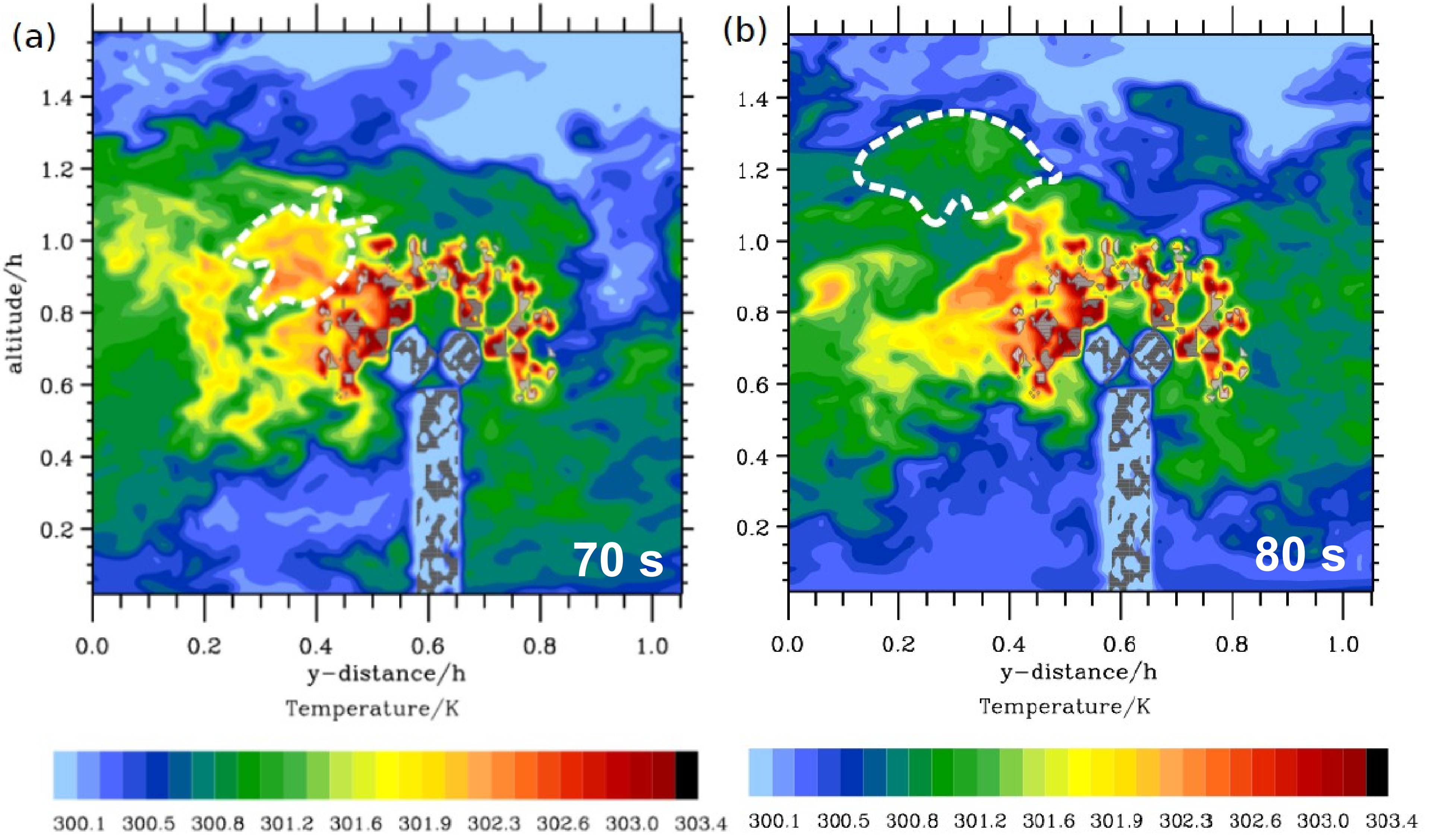
Run 4)



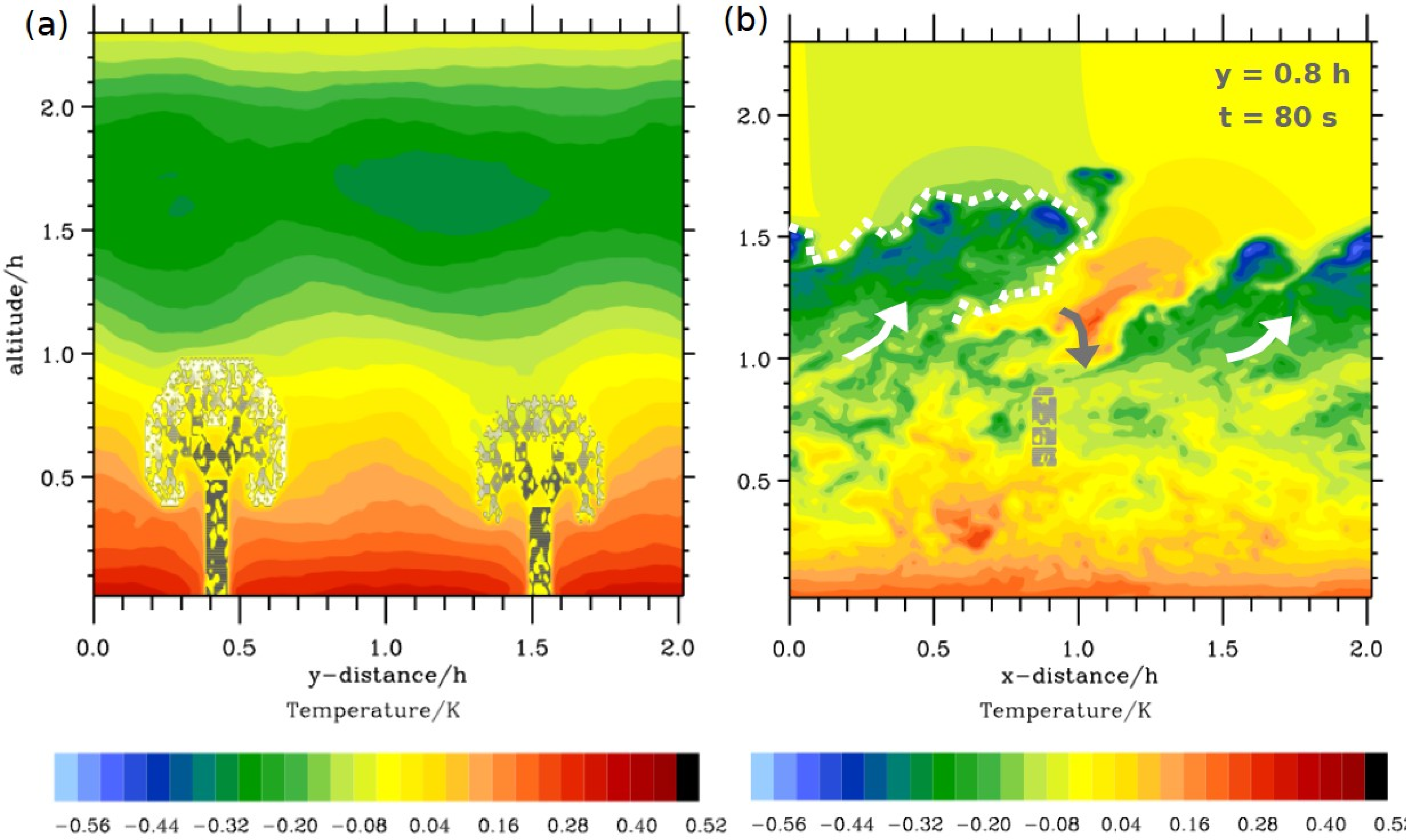
Run 5)



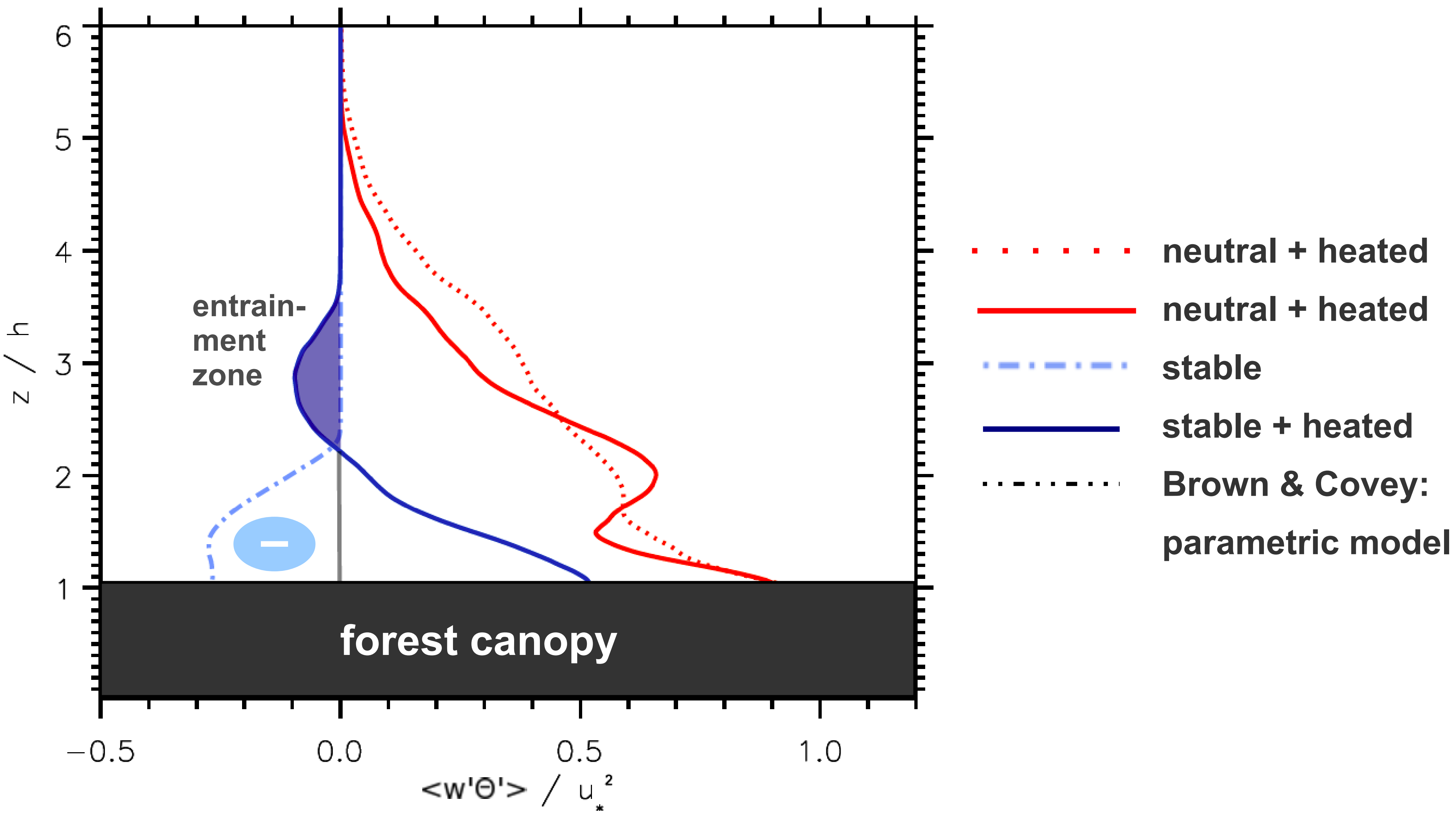
Thermals in diabatically heated canopy



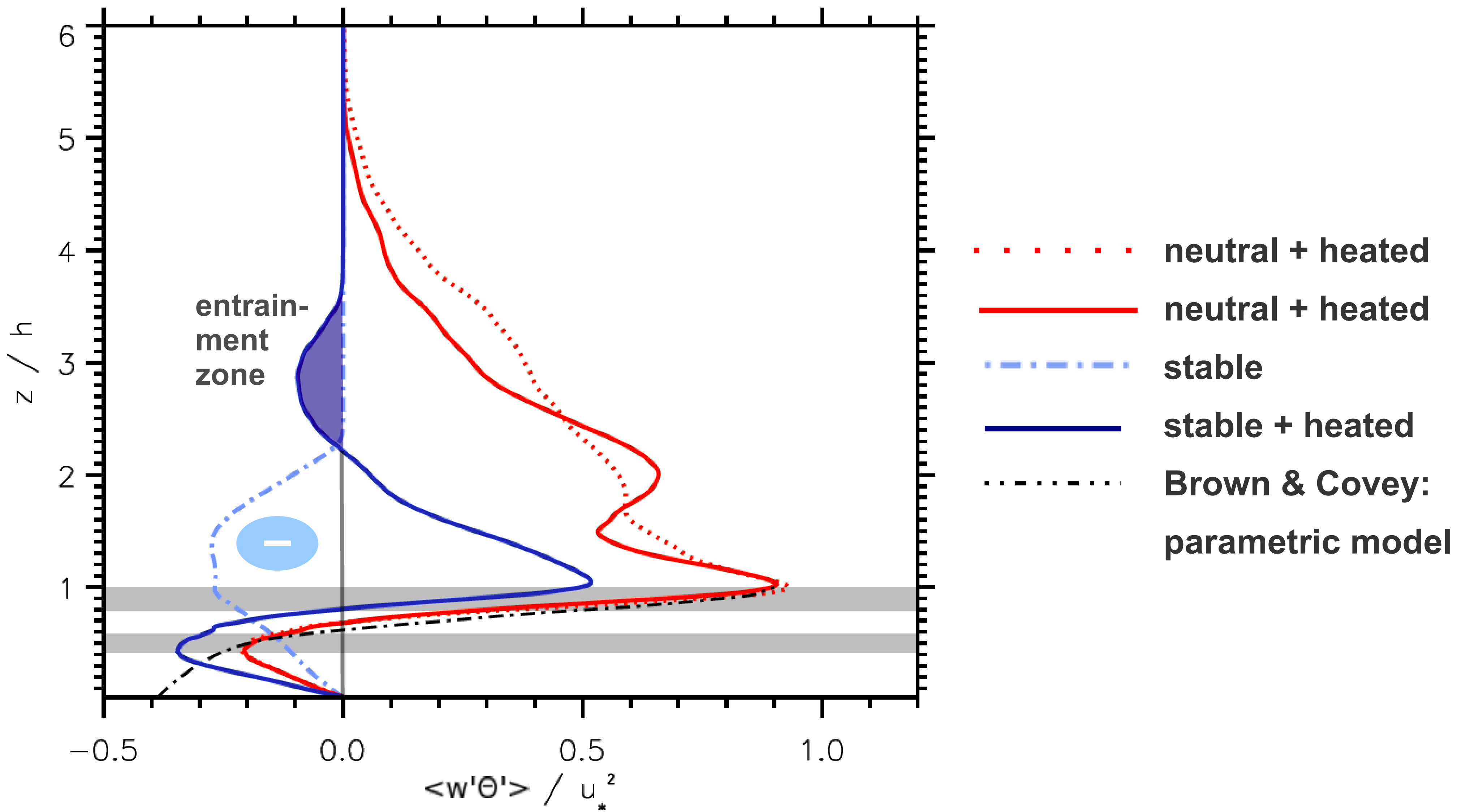
Temperature Ramps in stable conditions



Heat Flux for varying Stratification



Heat Flux for varying Stratification



Conclusions

METHOD

Applicability of **fractal approach** in LES: resolve flow, get **physically correct results** in **neutral** reference run (*Dupont & Brunet 2009, Finnigan et al. 2009, Shaw & Schumann 1992*).

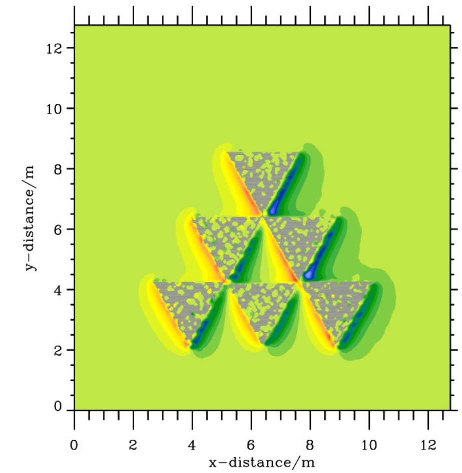
FLOW STRUCTURE & DIABATIC RESULTS

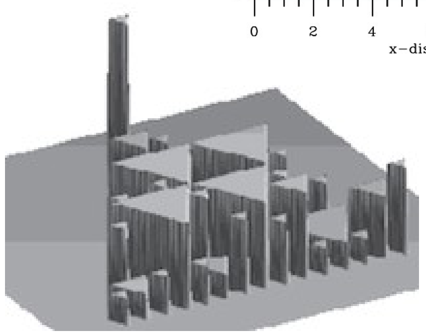
Characteristic power spectra for **trunk-, crown- and above canopy flow** occur. As in field experiments, we capture **wake vortices** inside the canopy (*Cava & Katul 2007*).

Coherent structures in **diabatic runs** are observed as in nature (*Gao et al. 1989*). We can **simulate them in detail in our LES**.

Thank you for your attention!

Outlook





Master student **Sonja Gisinger**: *Sierpinski* city