ETH zürich

EXCLAIM

Facing heterogeneities with increasing resolution

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C2SM Center for Climate Systems Modeling

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Universal log-law

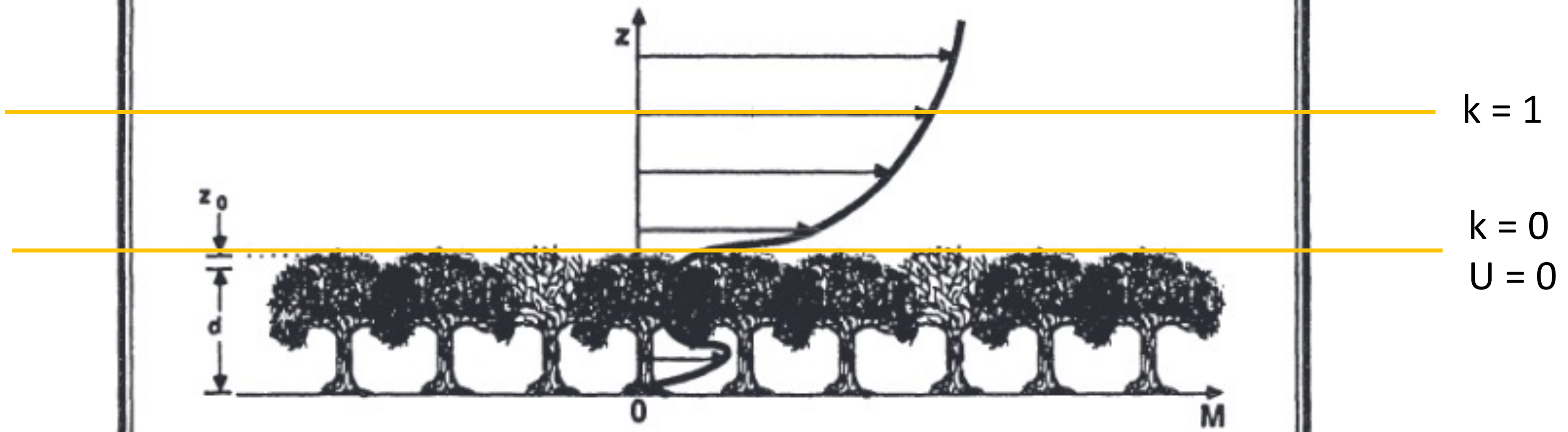
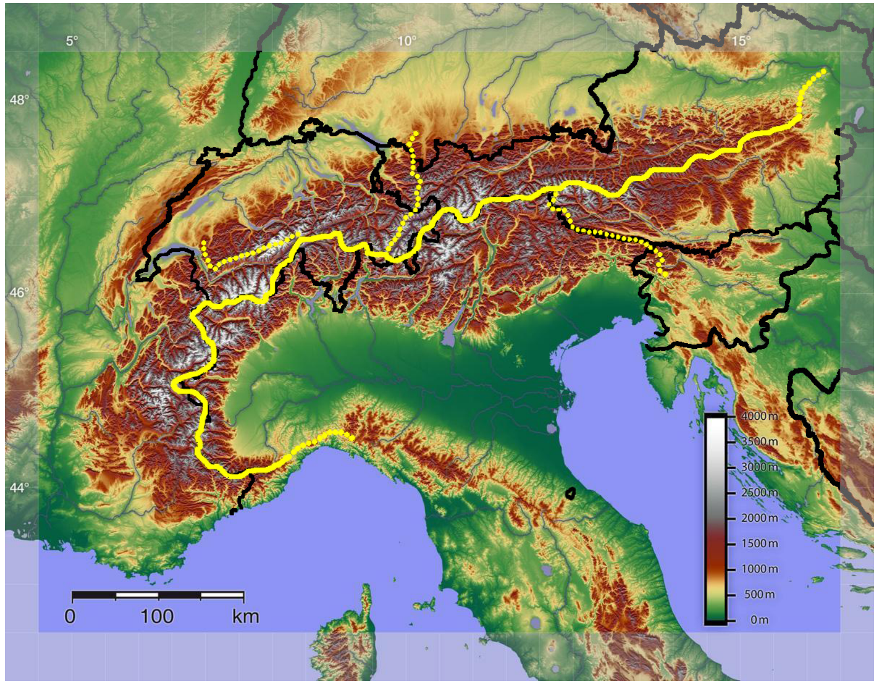


Fig. 9.7 Flow over forest canopy showing wind speed, M, as a function of height, z. The thick canopy layer acts like a surface displaced a distance, d, above the true surface. z_0 = roughness length.

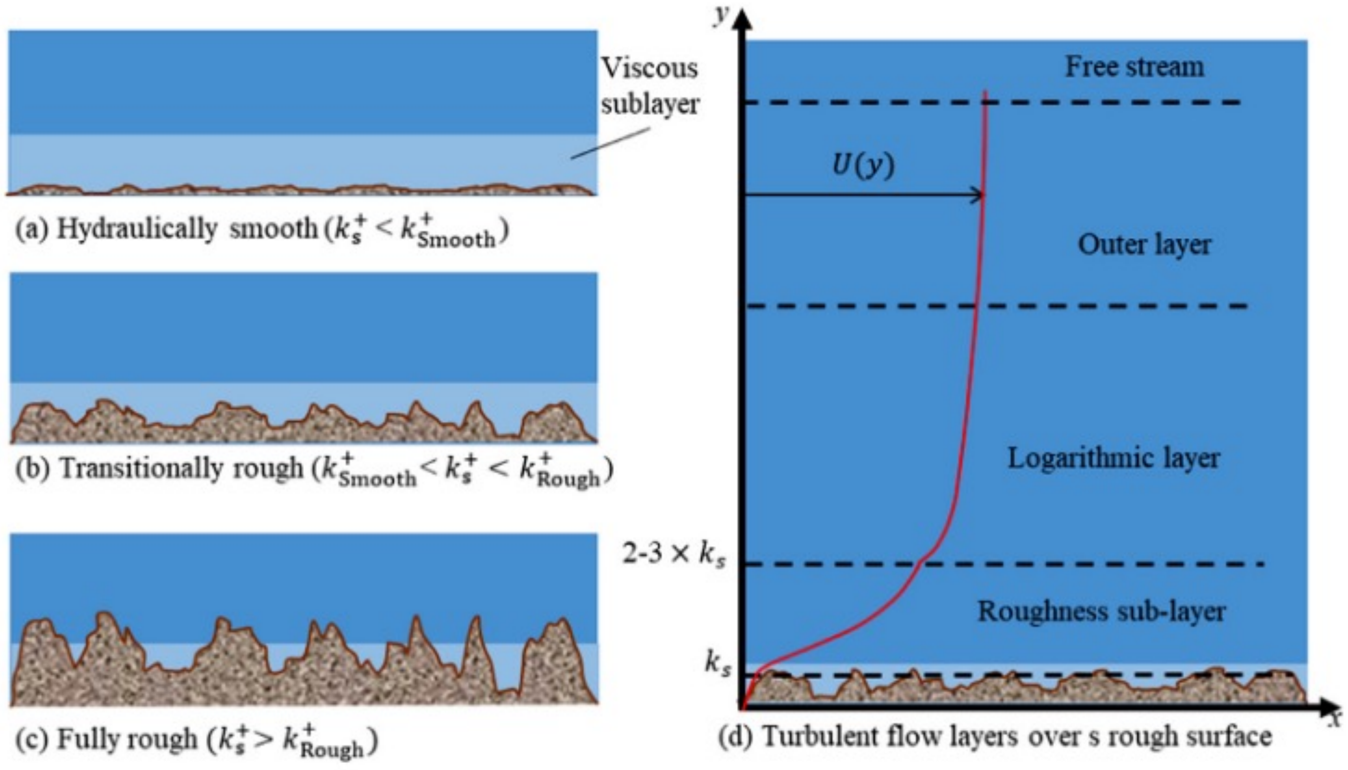
$$U_1 = U_0 + \left(\frac{u^*}{k}\right) ln \frac{(z-d)}{z_0}$$

Works well when the surface underneath is smooth or, in other words the flow is locally homogeneous

But the world where we live



… has rough surfaces



- homogeneous (isotropic) turbulence
- Universal log law
- also called Inertial Sub Layer

- heterogeneous turbulence???
- Profile depends on the underlying roughness

M. Kadivar et al. (2021) A review on turbulent flow over rough surfaces: Fundamentals and theories

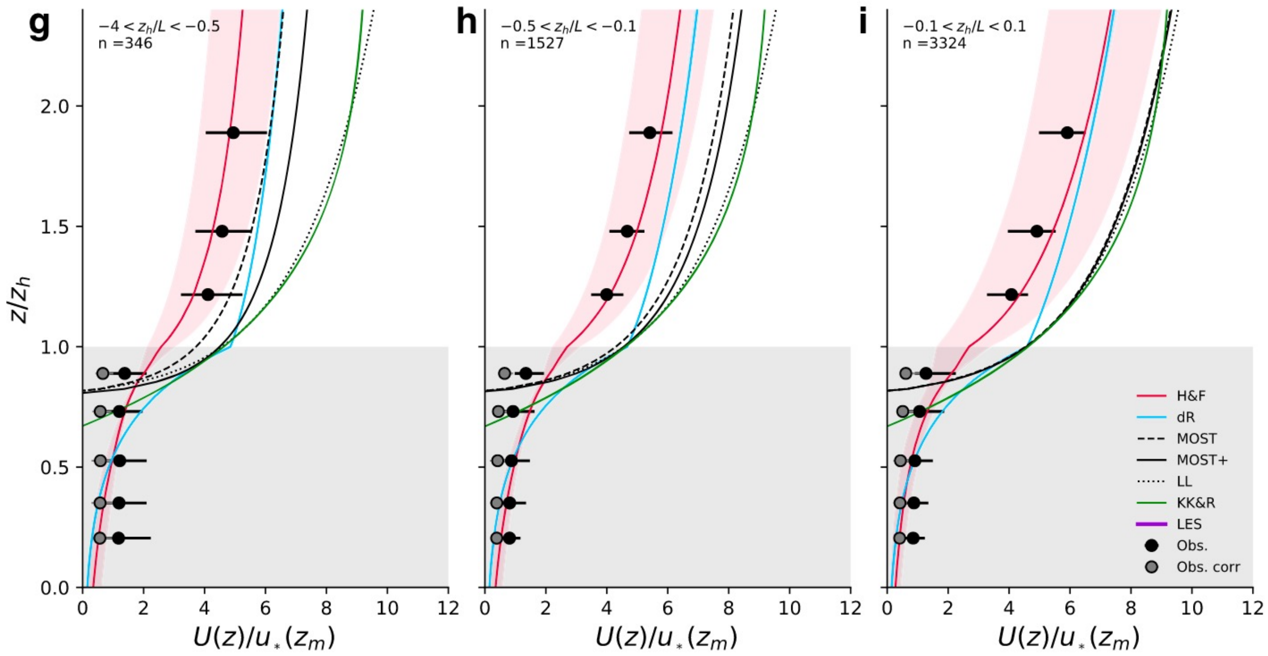
Attempts to extend log-law in RSL over Forest canopies

Seem to work well over urban canopies as well.

Table 2 Methods used to calculate profiles for wind speed, with abbreviation (Abr.) used in the text

Abr.	Name	Equation(s)		Assumptions
LL	Neutral logarithmic law	$u(z) = \frac{u_*}{\kappa} \ln\left(\frac{z-z_d}{z_0}\right)$	(7)	z_0 and z_d use Macdonald et al. (1998)
KK&R	Kastner-Klein and Rotach (2004)	$u(z) = \frac{u_*}{0.6\kappa}\left[1 - 0.6\ln(0.12) - \exp\left[0.6 - 0.072\left(\frac{z-z_d}{z_0}\right)\right]\right]$	(8)	As LL
MOST	Monin–Obukhov similarity theory	$u(z) = \frac{u_*}{\kappa}\left[\ln\left(\frac{z-z_d}{z_0}\right) - \psi_M\left(\frac{z-z_d}{L}\right) + \psi_M\left(\frac{z_0}{L}\right)\right]$	(9)	As LL, stability functions following Garratt (1992)
MOST+	MOST with stability dependent z_0	Equation (9) with $z_0 = z_{0mac} \cdot \exp\left[-\psi_M\left(\frac{z_h-z_d}{L}\right)\right]$, where the aerodynamic roughness length z_{0mac} calculated following Macdonald et al. (1998)	(10)	As MOST, with stability dependent aerodynamic roughness length, constant z_d
dR	De Ridder (2010)	Empirical expression for Eq. (5) $\hat{\psi}_M(z) = \phi_M\left[\left(1 + \frac{\nu}{\mu_M \frac{z-z_d}{z_*}}\right)\frac{z-z_d}{L}\right]\frac{1}{\lambda}\ln\left(1 + \frac{\lambda}{\mu_M \frac{z-z_d}{z_*}}\right)e^{-\mu_M \frac{z-z_d}{z_*}}$, with $z_0 = z_{0mac} \cdot \exp\left[-\psi_M\left(\frac{z_h-z_d}{L}\right) + \hat{\psi}_M(z = z_h)\right]$, λ, μ_M, and ν are assumed to be constants. Forest RSL values: $\lambda = 1.5$, $\mu_M = 2.59$, and $\nu = 0.5$. In the canopy: $u(z < z_h) = u(z = z_h)\exp\left[a\left(\frac{z}{z_h} - 1\right)\right]$ (Macdonald 2000)	(11)	As MOST+, assuming $z_* = z_m$ corresponding to the highest measurement height

They all take <u> = f(z)



Gothenburg Tower, Sweden

Theeuwes et al. (2018) Parametrizing Horizontally-Averaged Wind and Temperature Profiles in the Urban Roughness Sublayer

Is it fair to assume that <u> = f(z) in RSL for modelling purposes?

Zurich city

Inn valley

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Local homogeneity

- Implies that the **mean** quantities are invariant to changes in **x**
- Very powerful assumption
- Demonstrated to exist over smooth surface (Garrat 1992; Schlichting 1960)

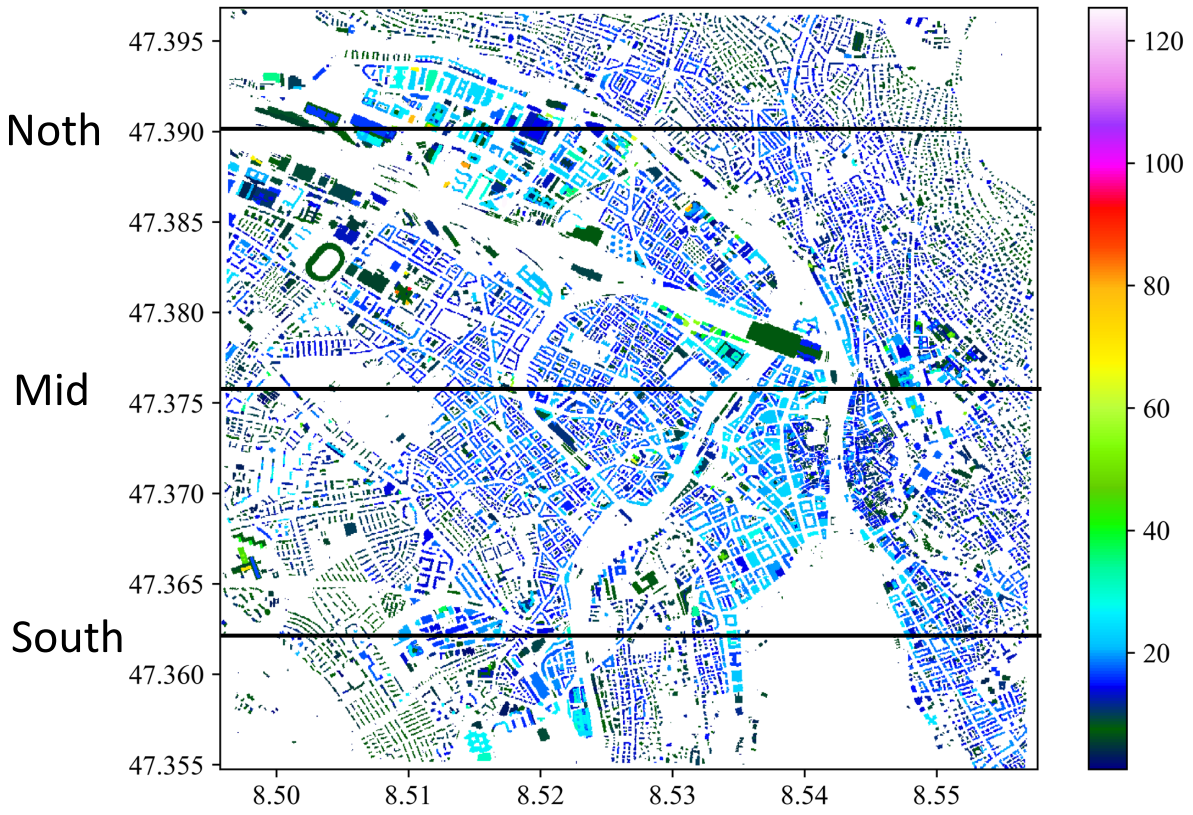
$$\langle \mathrm{u}\,(\mathbf{x}, \mathrm{z})\rangle = \langle \mathrm{u}(\mathrm{z})\rangle = F(\mathrm{z})$$

- Unclear about RSL….that too at O(100m)!
- Moreover, literature rather vague about **mean**.

Therefore the question

What is the scale of homogeneity (or heterogeneity) over rough surfaces?

Building resolving simulations using PALM



- Calm and clear sky conditions
- dx = dy = dz = 4m
- Adaptive time step ~ 0.5s
- Nested simulation 64m->32m->4m. Using results from the innermost domain.
- 30 min averaged. No spatial averaging.

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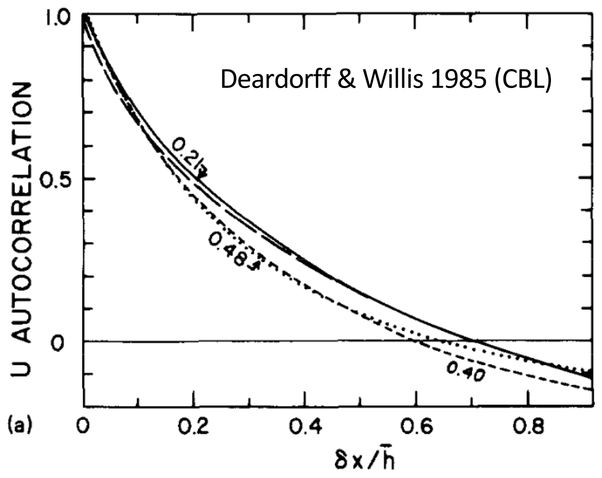
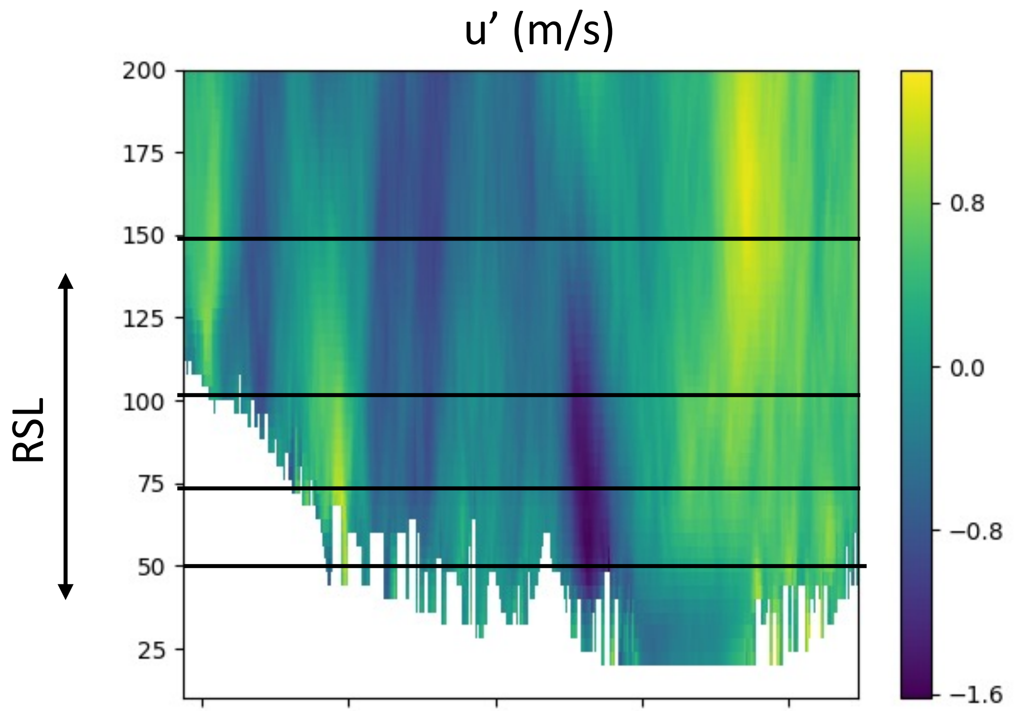
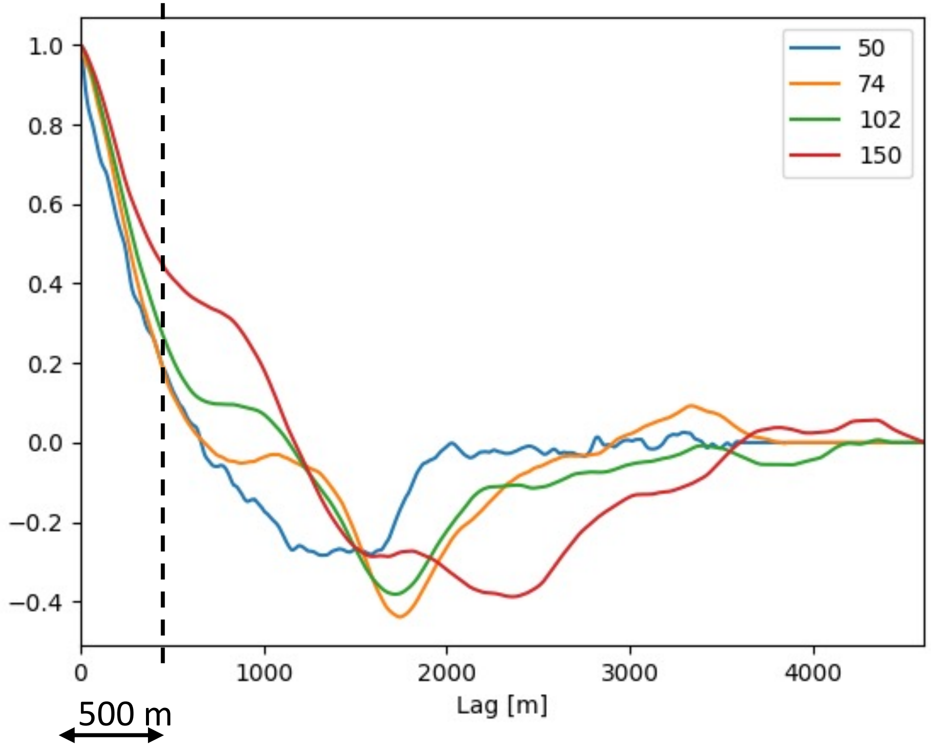
u autocorrelation (south)







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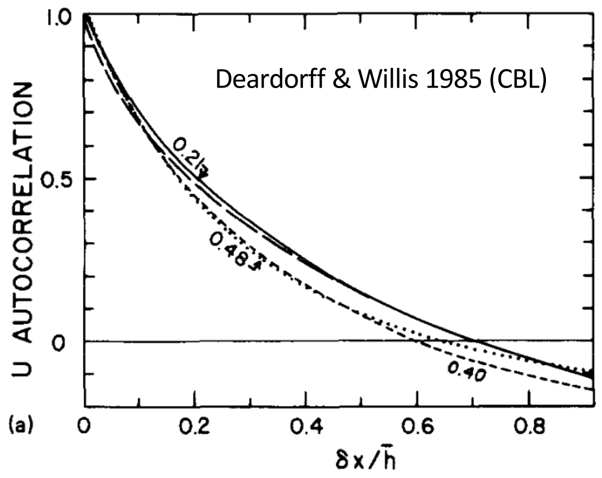
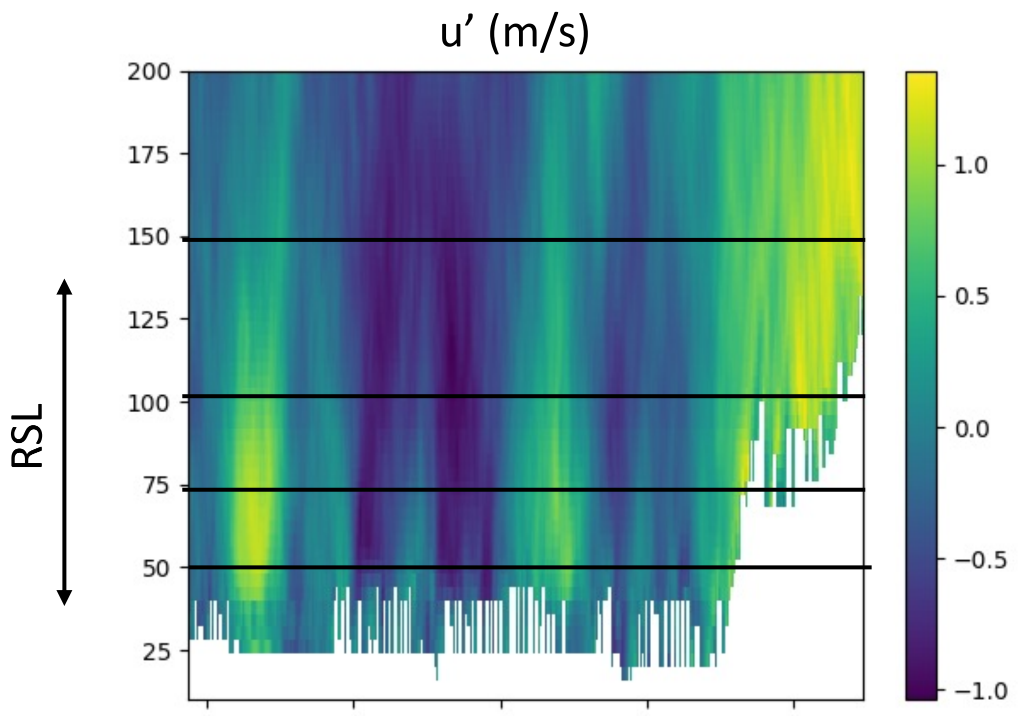
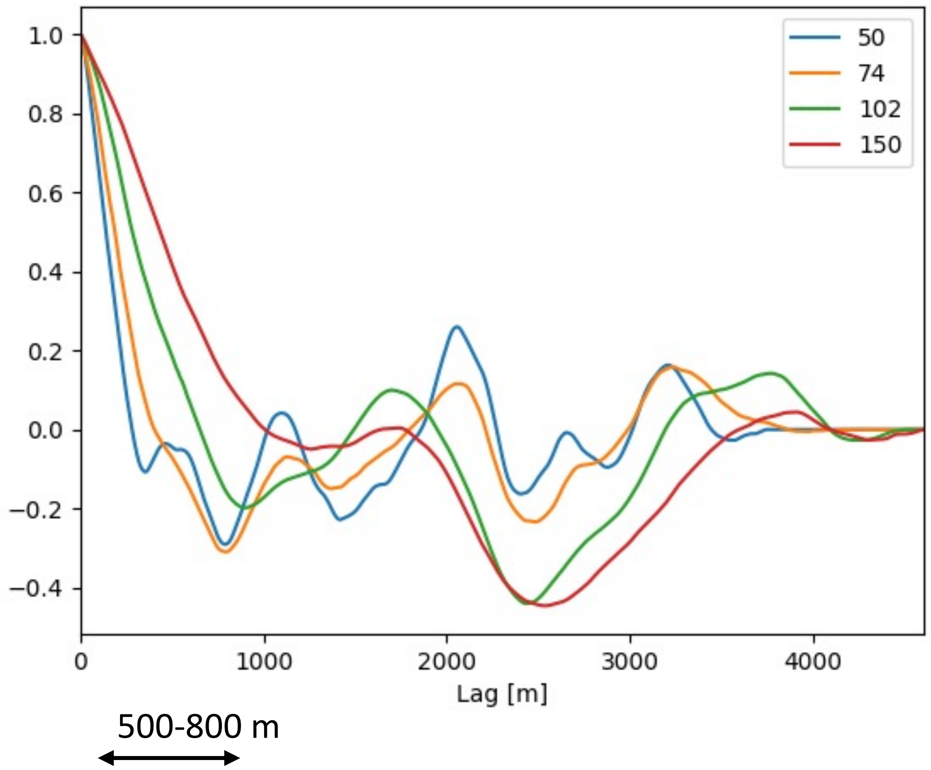
u autocorrelation (middle)







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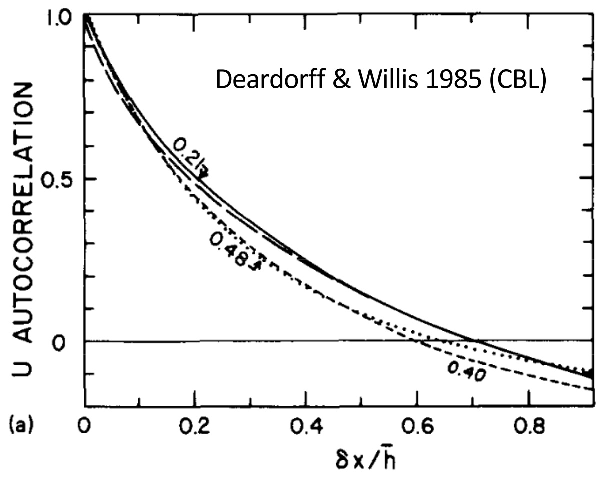
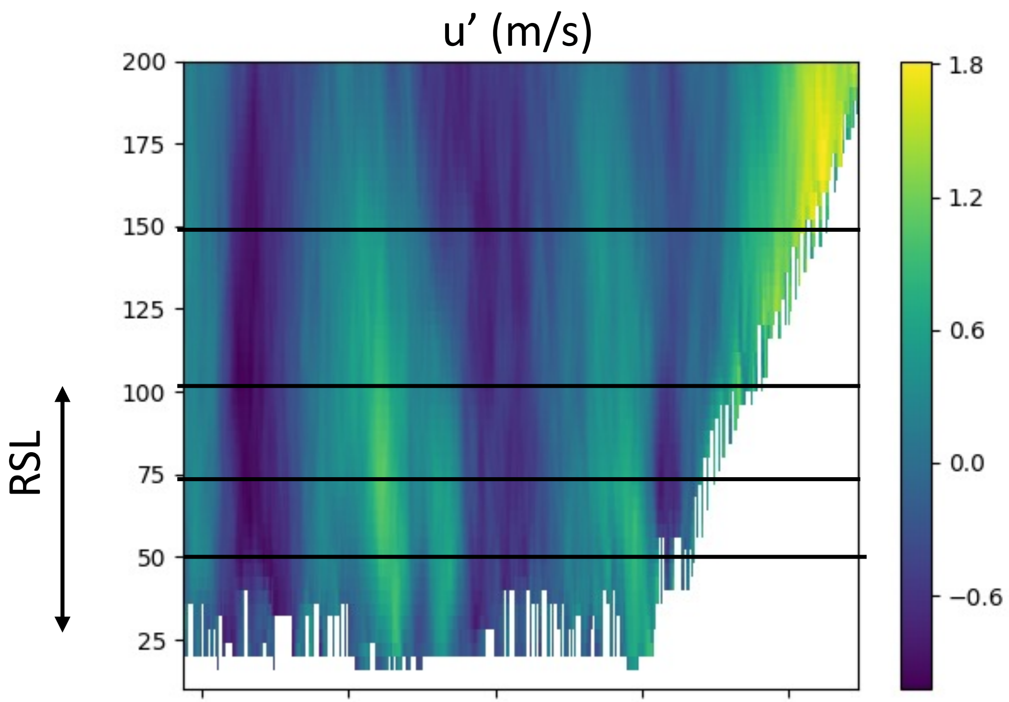
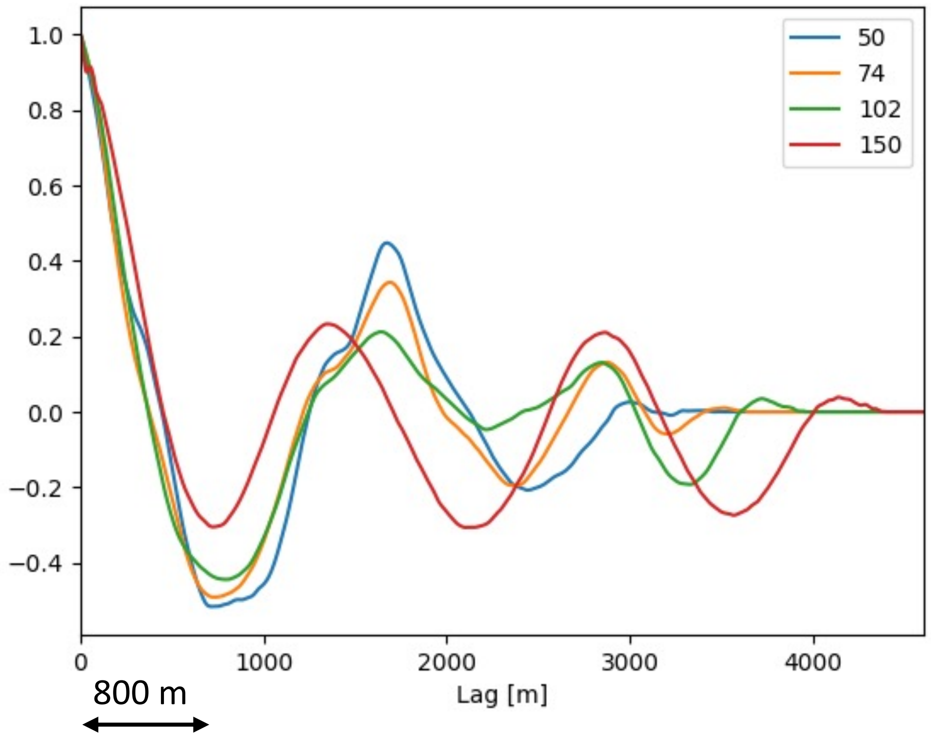
u autocorrelation (north)







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Observations so far…

- <u> seem uncorrelated to itself over scales of 500-800 m
- Implies that the subgrid flow can be regarded homogeneous over grid spacings of 500-800 m within the RSL over Zürich city

- Provided that <> = 30 min averaging
  - It means, at Δx = 500m and dt = 5s averaging u over 360 time steps. Not reasonable!
- Need to investigate for shorter time averaging windows

Let’s switch the scale

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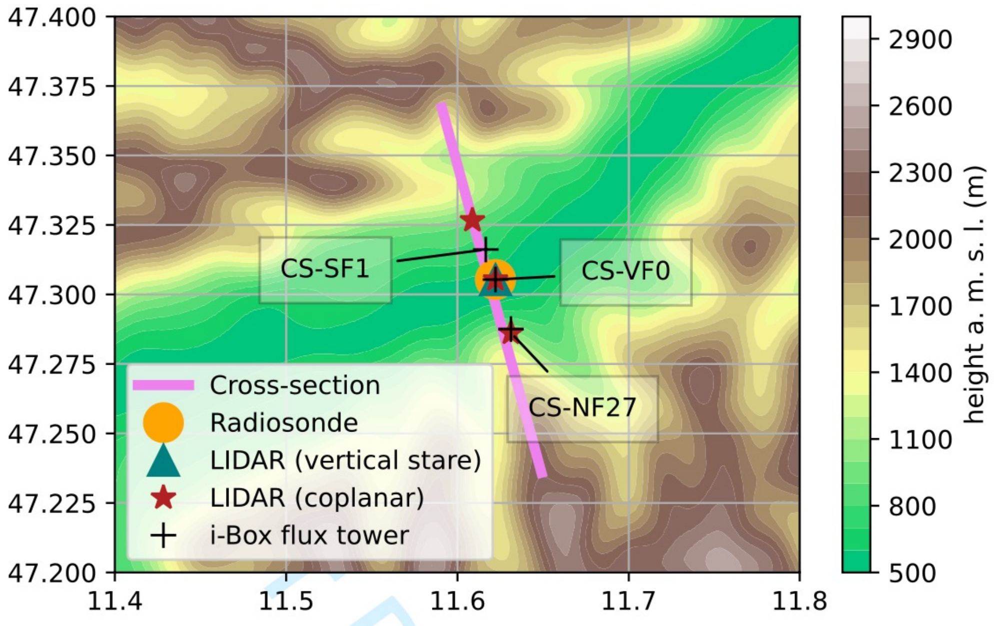
i-Box flux tower (Innsbruck, Austria)



Over the mountains, I always thought that log-law would hold at 100m!

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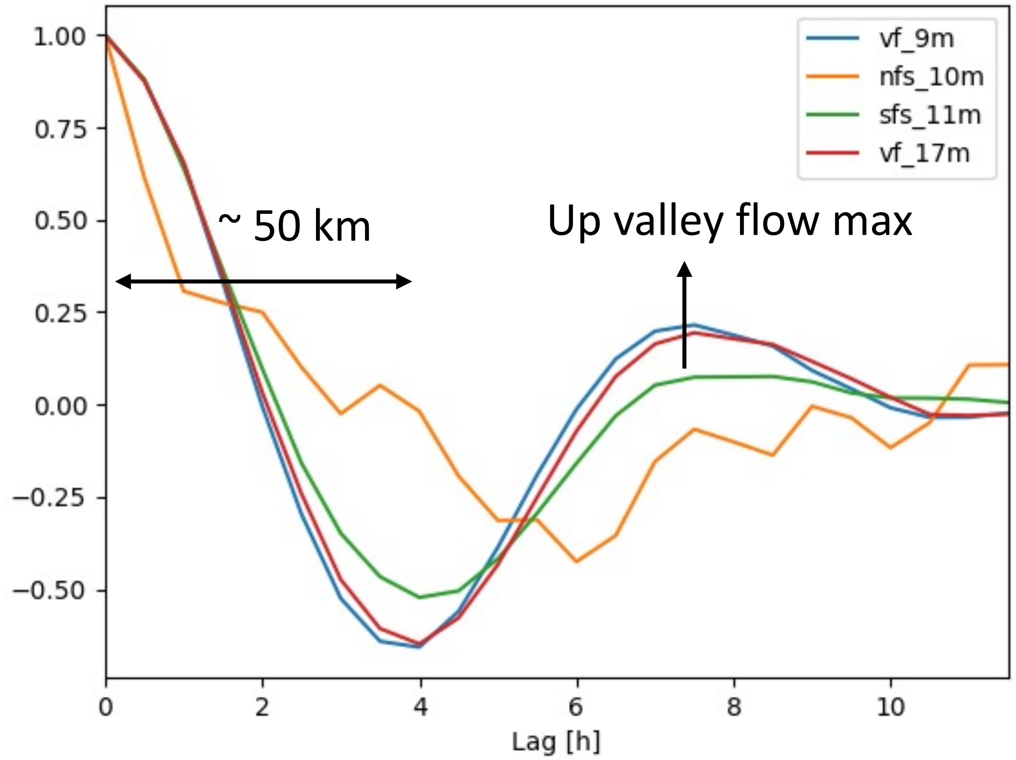
u autocorrelation



- Time series on 13 sept 2019 from 8-18h
- On 4 locations.
- 30 min averaged samples

-Same observation that local homogeneity seem valid for 30 min averages
- Qusetionable for higher resolution (dt = 1 s) samples!

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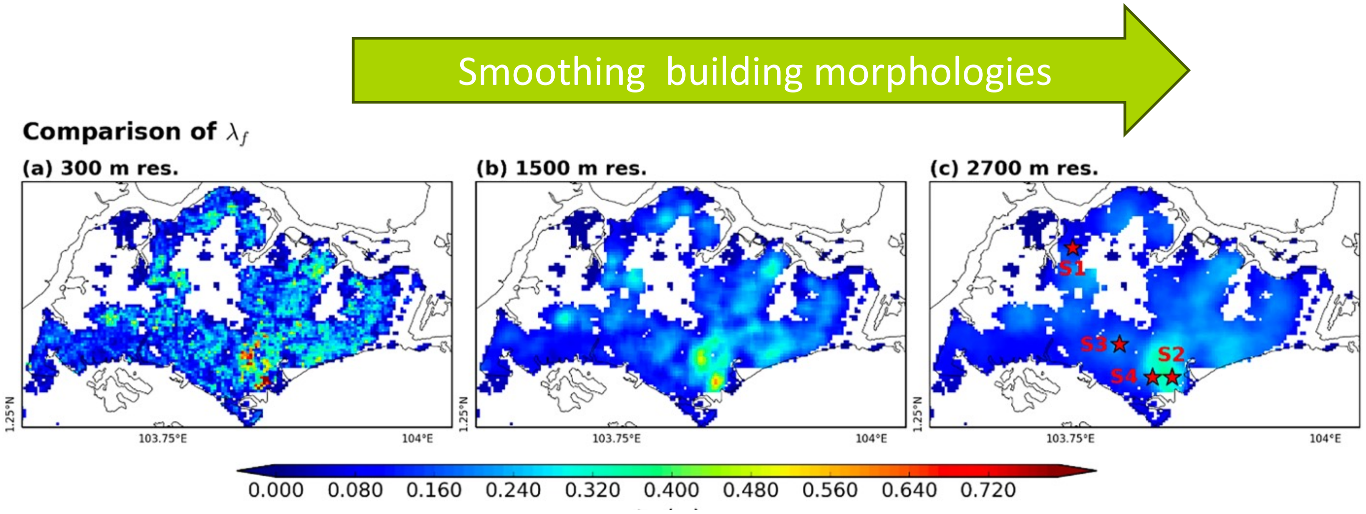
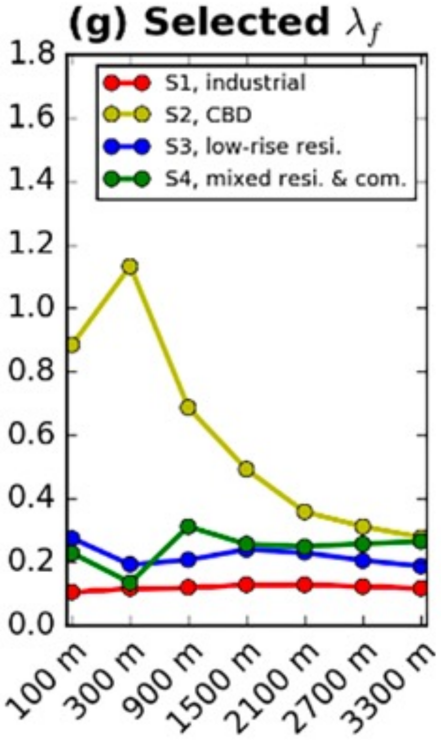
That said, no one stopping us from doing the simulation





heterogeneity disappears for Δx > 2 km thereby more suitable to assume local homogeneity

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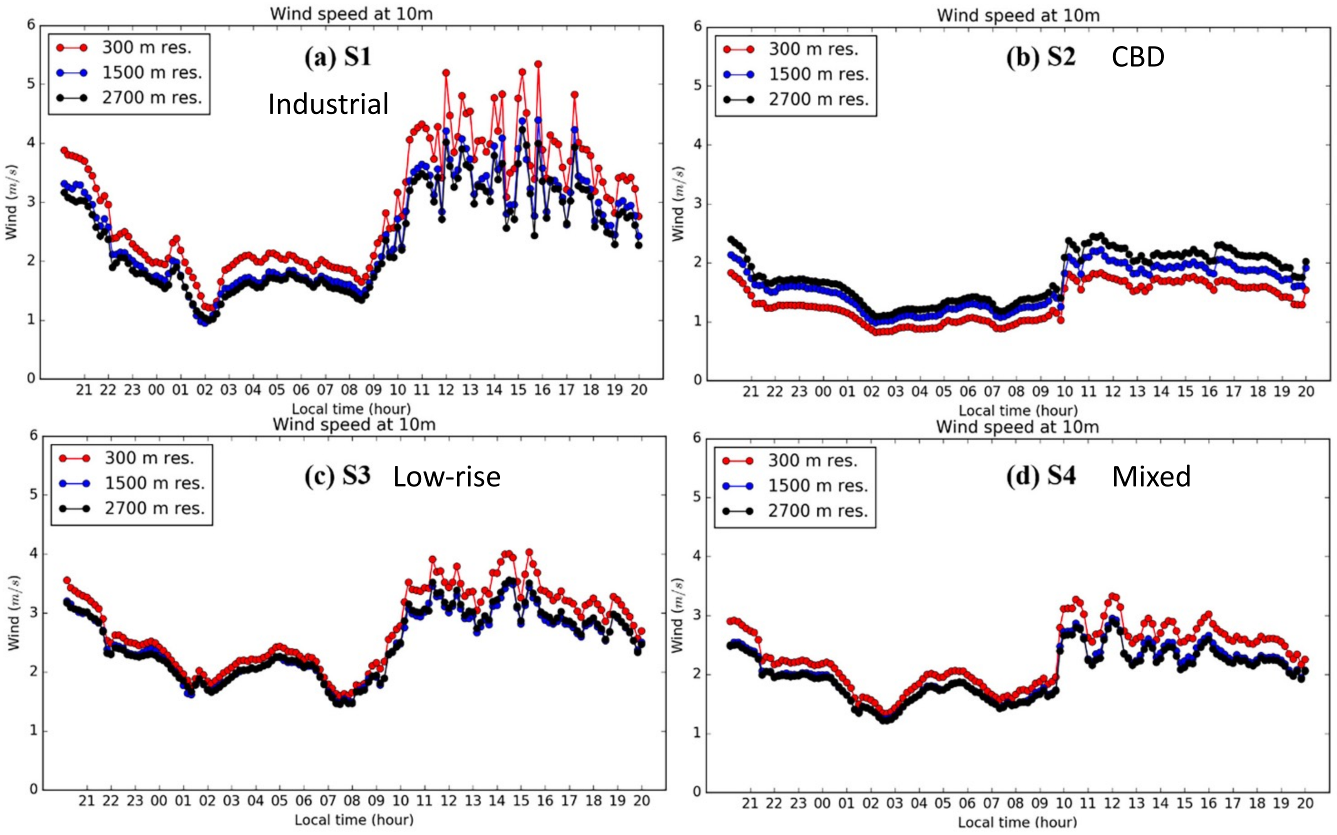
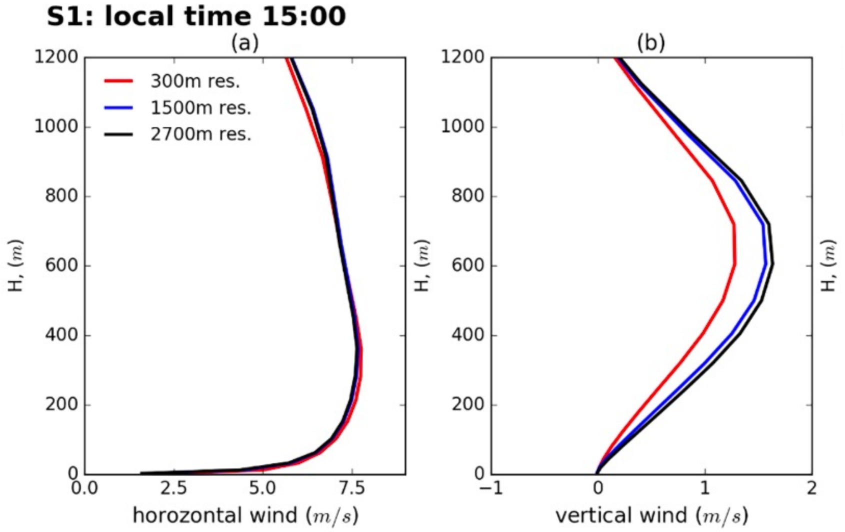
Chen and Dipankar (2021) On the applicability of urban canopy parametrization in building grey zone

so what happens when comparing with the runs where local homogeneity is likely not valid?





- Differences are significant. Gives a motivation to work towards a better surface treatment at O(100m).
- See Jacopo's proposal next

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Chen and Dipankar (2021) On the applicability of urban canopy parametrization in building grey zone

Thank you!