SIMULATIONS OF THE EFFECT OF CANOPY DENSITY PROFILE ON SUB-CANOPY WIND SPEED PROFILES

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Business Cooperative Research Centres Programme

Problem

Prediction of mean wind speed profiles through tree canopies

- Fire spread
- Particle (ember, seeds), pollutant (smoke) transport

Trees, branches, and leaves exert drag on the wind

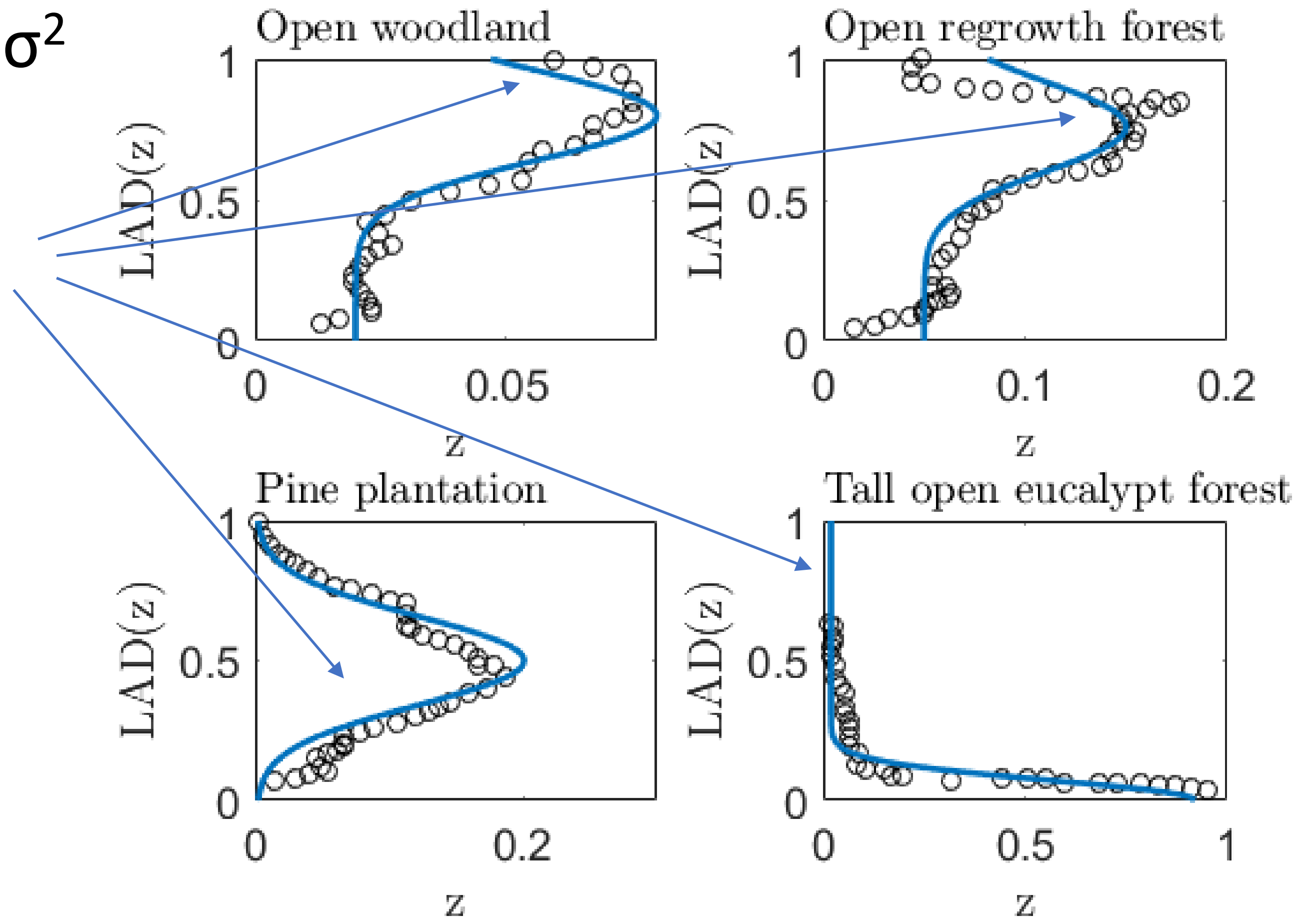
Forest canopy density exhibits great variation depending on tree species

Characterised by leaf area density and leaf area index (total leaf area density)

Different values of A, B, μ, and σ^2

$$A \exp\left(-\frac{(z-\mu)^2}{\sigma^2}\right) + B$$

Problem



Data points extracted from: K Moon, TJ Duff, KG Tolhurst, “Sub-canopy forest winds: understanding wind profiles for fire behaviour simulation” Fire Safety Journal (2016)

Sub canopy modelling: Inoue 1963

Assumption: leaf area density constant with height

Turbulent stress

Drag force

$$\frac{\partial}{\partial z} l^2 \frac{\partial}{\partial z} u + c_d LAI\, u^2 = 0\,,$$

$$l = 2\beta^3 / c_d LAI$$

$$LAI = \int_0^h \alpha dz = \alpha h$$

$$u = U_h \exp \frac{\beta (z - h)}{l}\,,$$

Standard log law

Shear layer caused by canopy

$$u = \frac{u_*}{\kappa} \log \frac{z-d}{z_0} + \int \frac{1-\hat{\phi}(z)}{z} dz$$

Above the canopy: Harman and Finnigan (2007)

Important parameters:

d – displacement length

z_0 – roughness length

β – shear stress to velocity ratio

c_d – drag constant

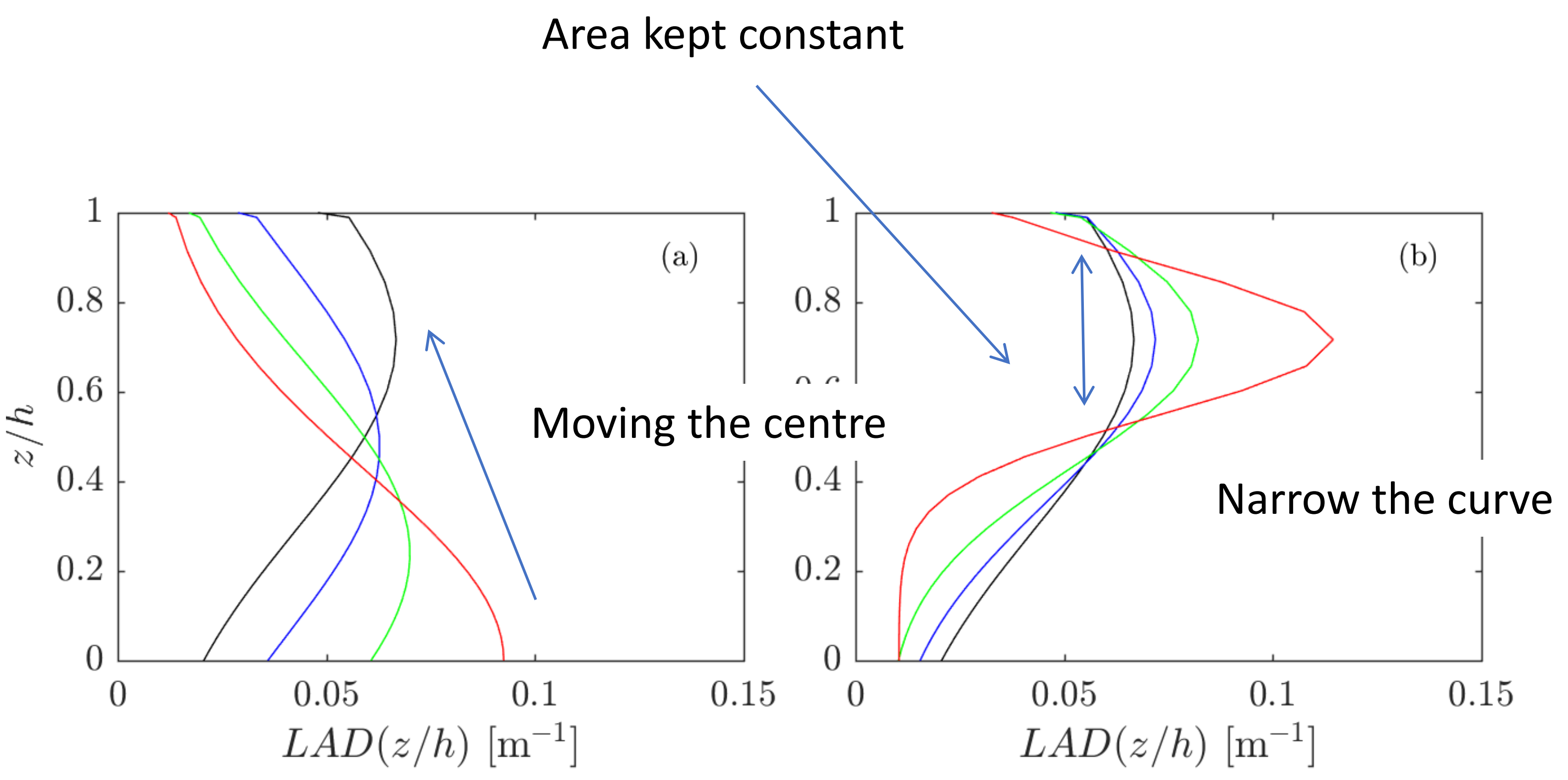
LAI – leaf area index

Simulation approach

Can use Large Eddy Simulation over a modelled canopy

- Computational fluid dynamics
- Large flow structures are resolved
- Turbulence is (partially) modelled
- Validated against experiment
- Tree canopies: aerodynamic drag depending on LAD

LAD profiles

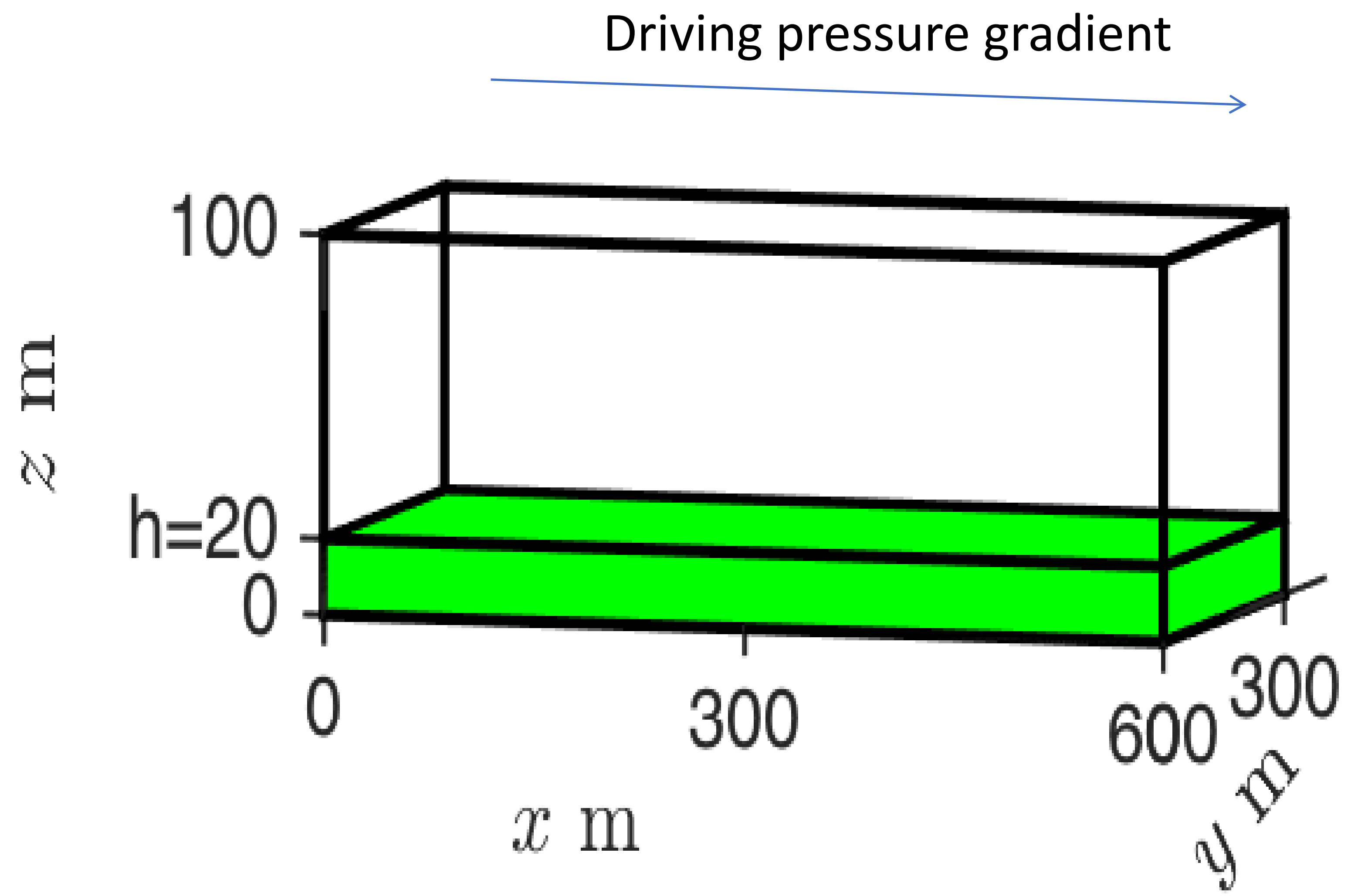


$$LAI = \int_0^h \left[A \exp\left(-\frac{(z-\mu)^2}{\sigma^2}\right) + B \right] dz\,,$$

Leaf area density

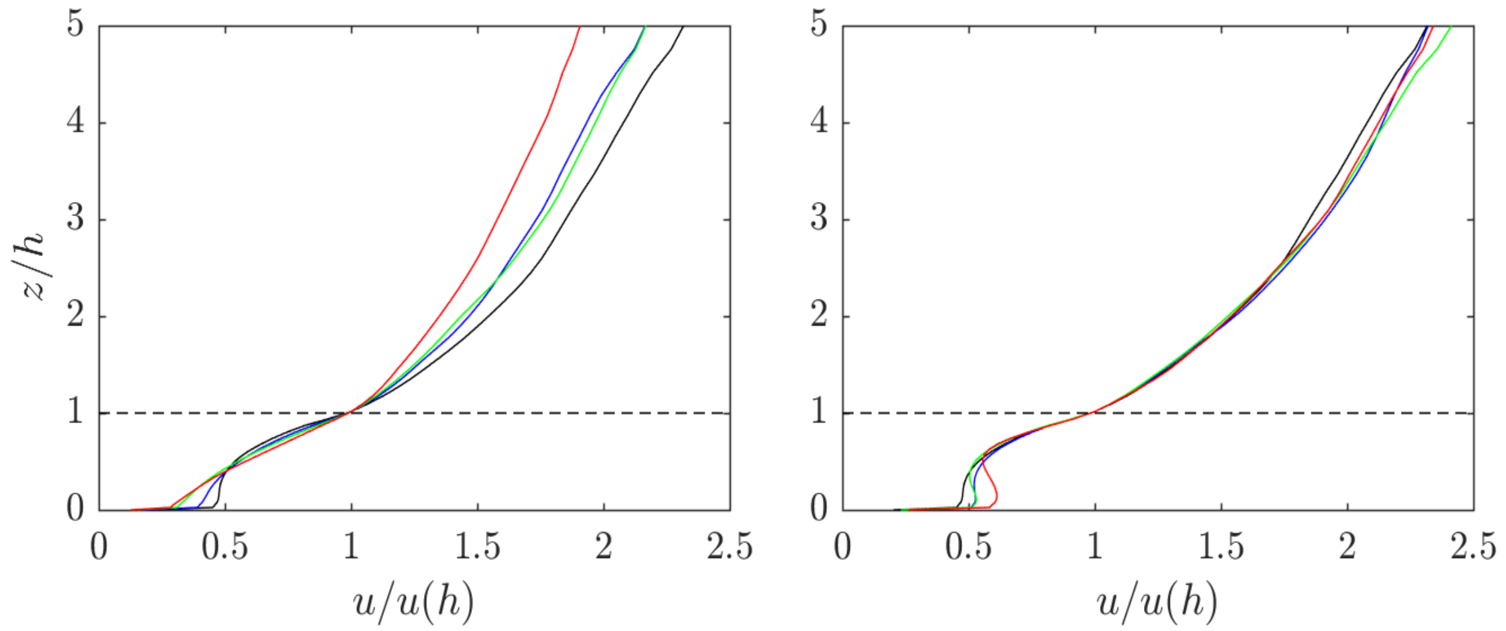
Simulation domain

The canopy is shaded in green



Results

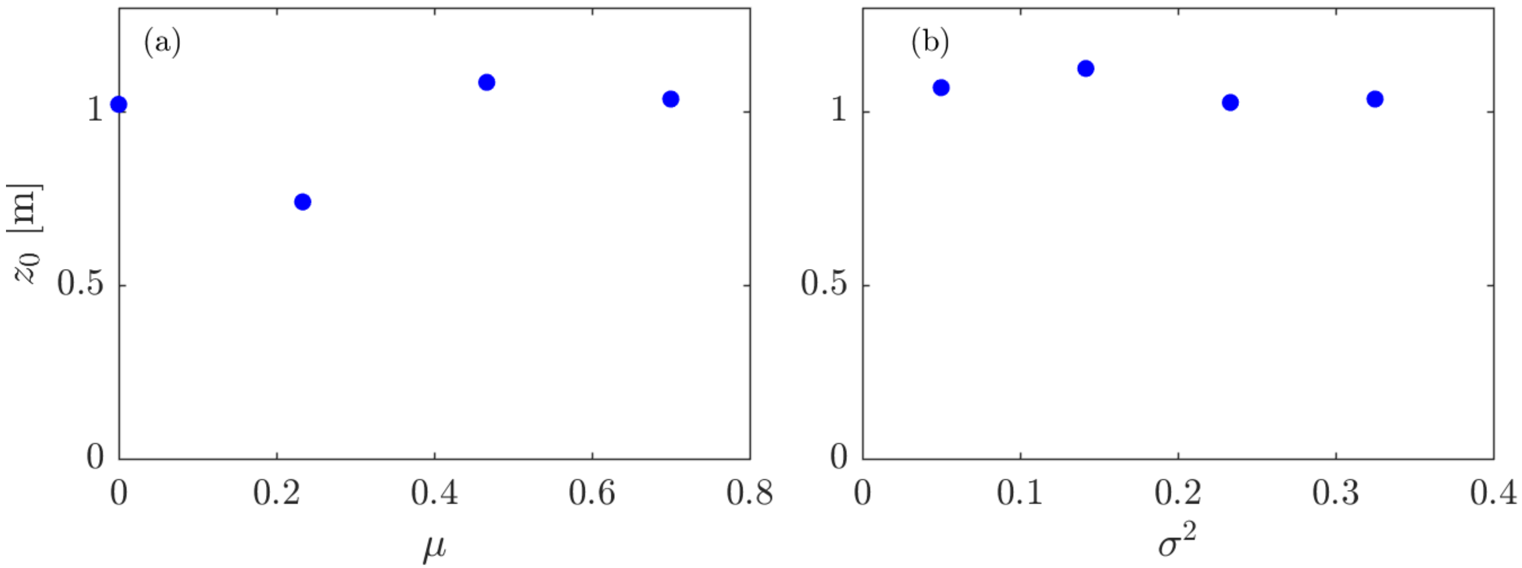
Mean u-velocity profiles



Mean u-velocity profiles normalised by the canopy top value. In (a) σ^2=0.325 is held constant and μ= 0.00 (red), 0.233 (green), 0.467 (blue), and 0.700 (black). In (b) μ=0.70 is constant and σ^2=0.325 (black – the same curve as in (a)), 0.233 (blue), 0.142 (green), and 0.050 (red).

Results

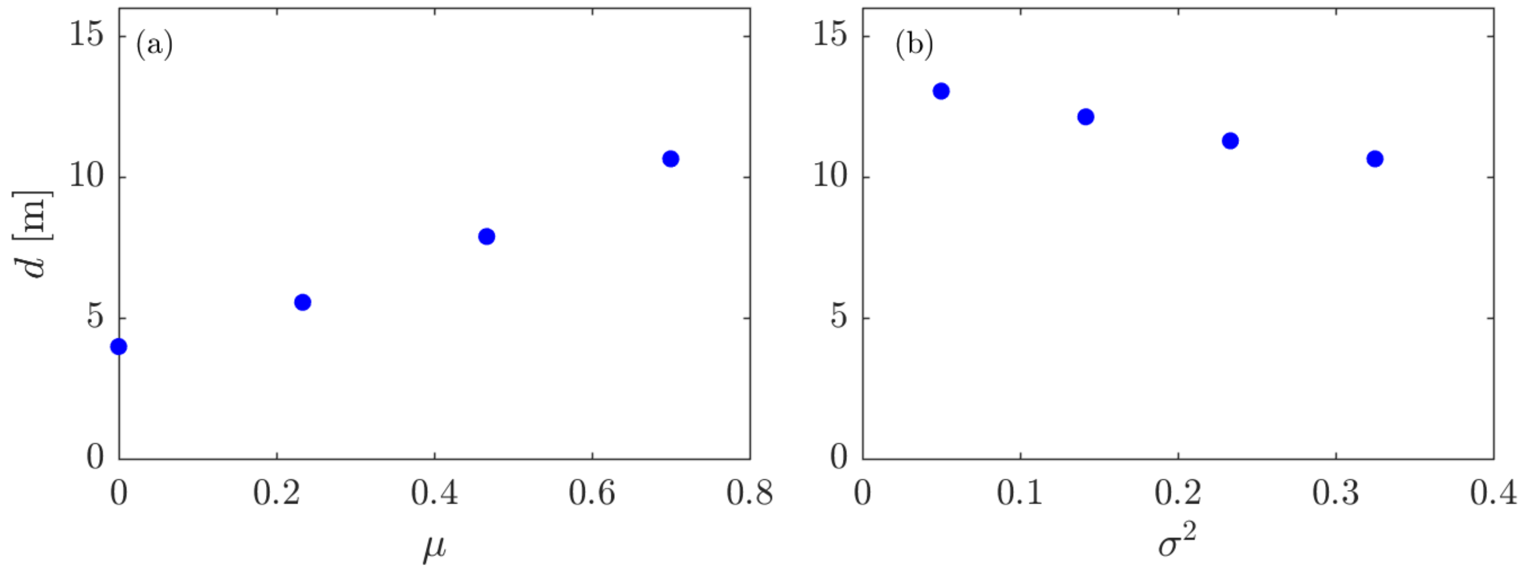
Equivalent roughness length



z_0 roughness length variation with (a) μ, and (b) σ^2
(all of these are realistic)

Results

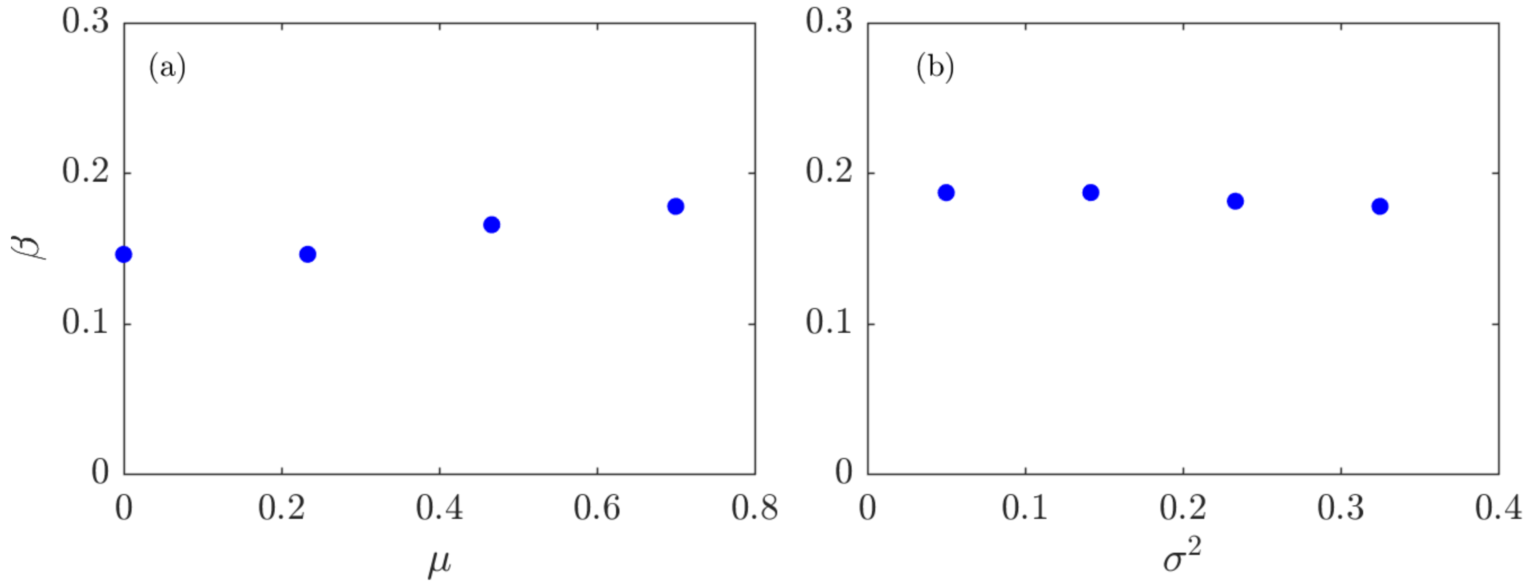
Displacement length



d displacement length variation with (a) μ, and (b) σ^2
(all of these are realistic)

Results

β-parameter



β parameter variation with (a) μ, and (b) σ^2
(somewhat lower than observed)

Sub canopy modelling: Inoue 1963

$$\frac{\partial}{\partial z} l^2 \frac{\partial}{\partial z} u + c_d LAI\, u^2 = 0\,,$$

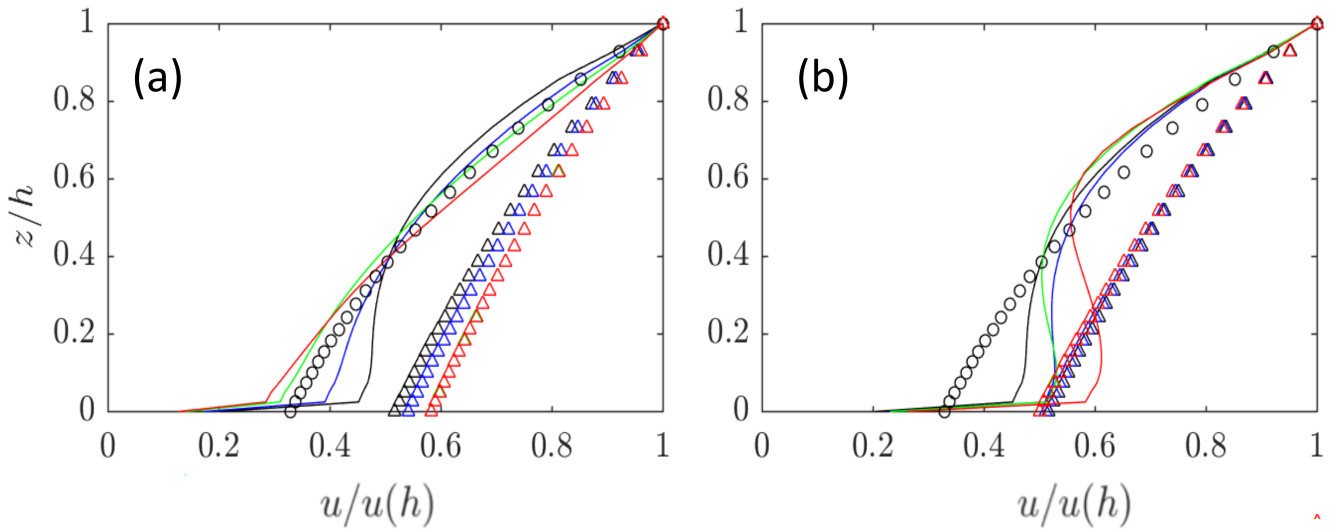
$$l = 2\beta^3 / c_d LAI$$

$$LAI = \int_0^h \alpha dz = \alpha h$$

$$u = U_h \exp \frac{\beta(z-h)}{l}\,,$$

Results

Sub canopy modelling



Modelled and simulated sub-canopy u –velocity profiles. (a and b) contain the modelled profiles using the simulated β(triangle symbols) and the observed β (circle symbol) of Harman and Finnigan (2007) and a constant mixing length based on LAI.

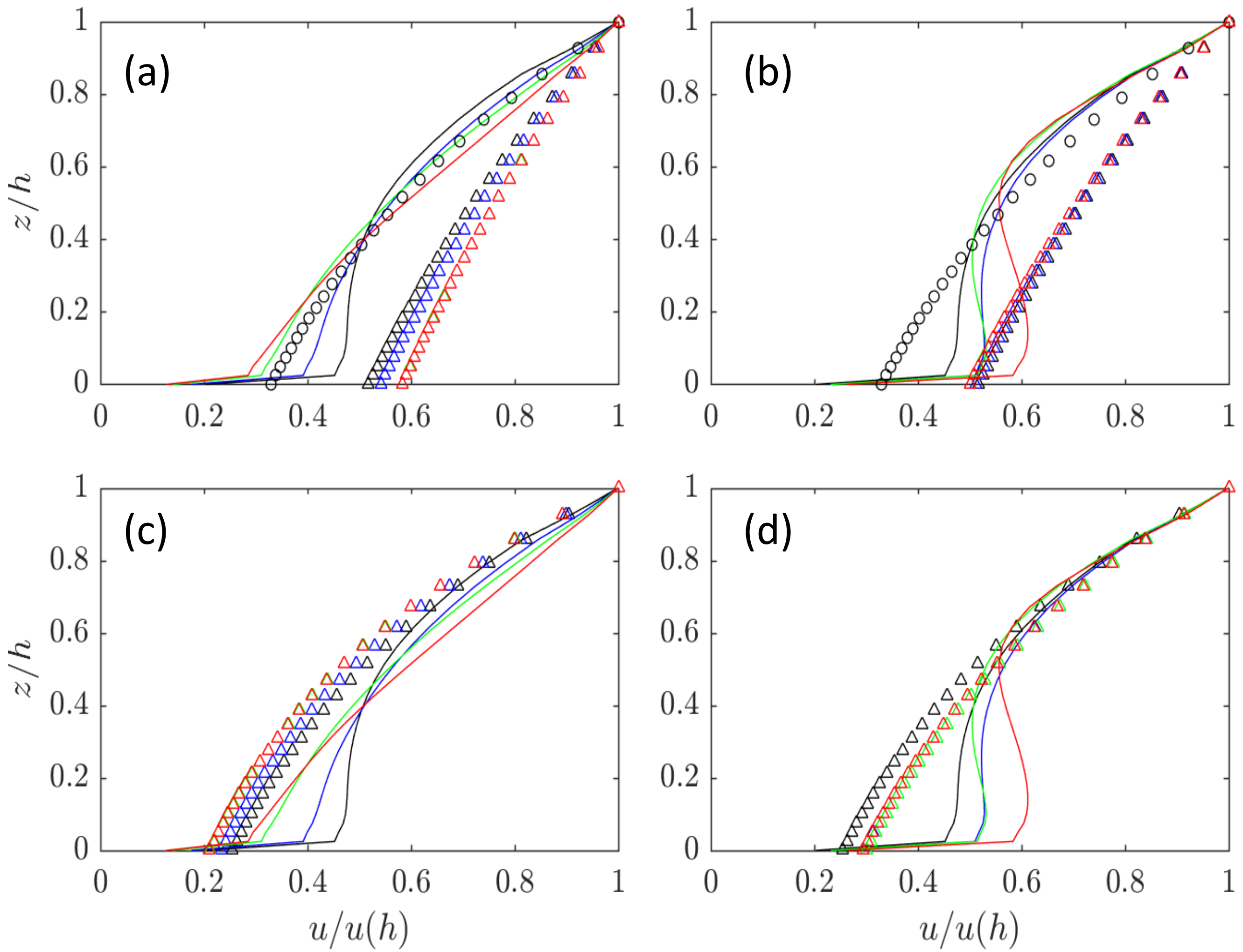
Modelling: modification

$$LAI = \int_0^h A \exp\left(-\frac{(z-\mu)^2}{\sigma^2}\right) + B\, dz\,,$$

$$dLAI = \int_0^d A \exp\left(-\frac{(z-\mu)^2}{\sigma^2}\right) + B\, dz\,,$$

Results

Improved sub canopy modelling



Modelled and simulated sub-canopy u −velocity profiles. (a and b) contain the modelled profiles using the simulated β(triangle symbols) and the observed β (circle symbol) of Harman and Finnigan [2007] and a constant mixing length based on LAI. The modelled profiles in (c and d) use the simulated β and $dLAI$.

Summary

- The effect of LAD distribution on flow over a tree canopy was investigated using LES.
- The sub-canopy mean flow profile was found to be sensitive to both μ and σ^2
- β, z_0, and d were found to be largely independent of σ^2.
- β exhibits a dependence on μ but z_0 appears to be independent of both μ and σ^2.
- d exhibits strong linear dependence μ and a weaker linear dependence on σ^2.
- The sub-canopy u-velocity model of Inoue (1963) was improved by including the displacement length

Simulations

		σ^2		
1.000	0.700	0.050	0.104	0.100
1.000	0.700	0.142	0.075	0.100
1.000	0.700	0.233	0.065	0.100
1.000	0.000	0.325	0.084	0.100
1.000	0.233	0.325	0.064	0.100
1.000	0.467	0.325	0.057	0.100
1.000	0.700	0.325	0.061	0.100