LARGE-EDDY SIMULATION OF NEUTRAL ATMOSPHERIC SURFACE LAYER FLOW OVER HETEROGENEOUS TREE CANOPIES

Or: what happens to the wind profile over forests of different types?

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BACKGROUND

1) u_{10} is an input to (eg.) McArthur Forest meter [1967]
2) Wind reduction factors are used to account for differences in forest type, essentially attempting to model u_2
3) Estimating WRF a priori from the data available to fire behaviour analysts such as forest type, prevailing wind speed, and canopy height is difficult [Heemstra, 2015]
4) Sub-canopy flow behaviour
5) Above-canopy parameterisation

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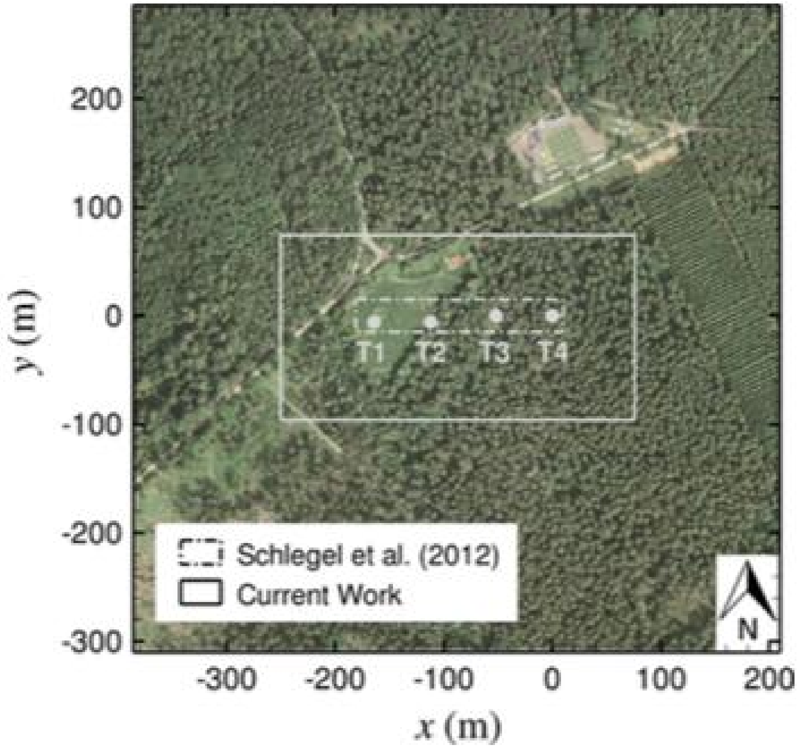
MOTIVATION

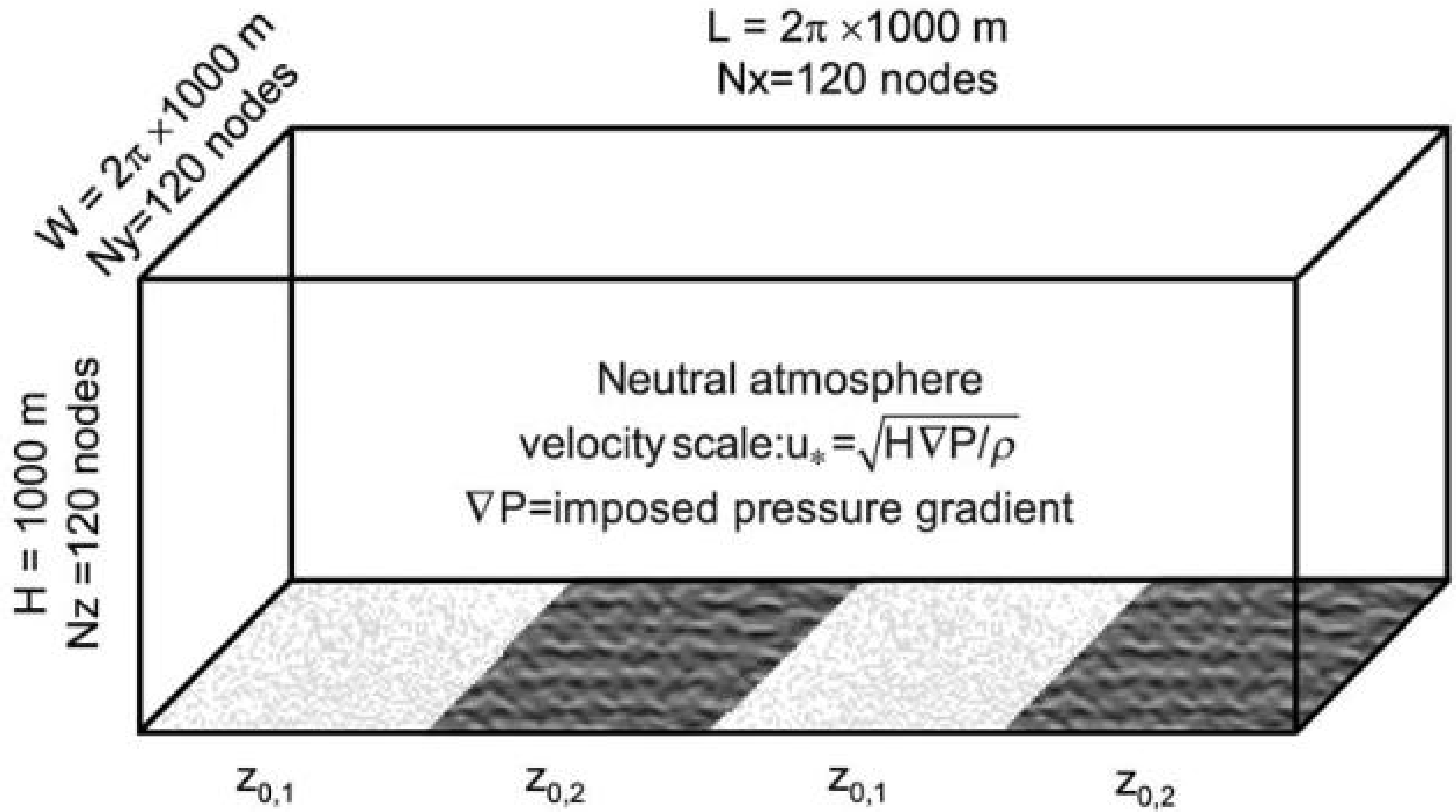
Heterogeneous forests are common, and sub-canopy wind speed predictions are useful for fire fighting

PREVIOUS WORK



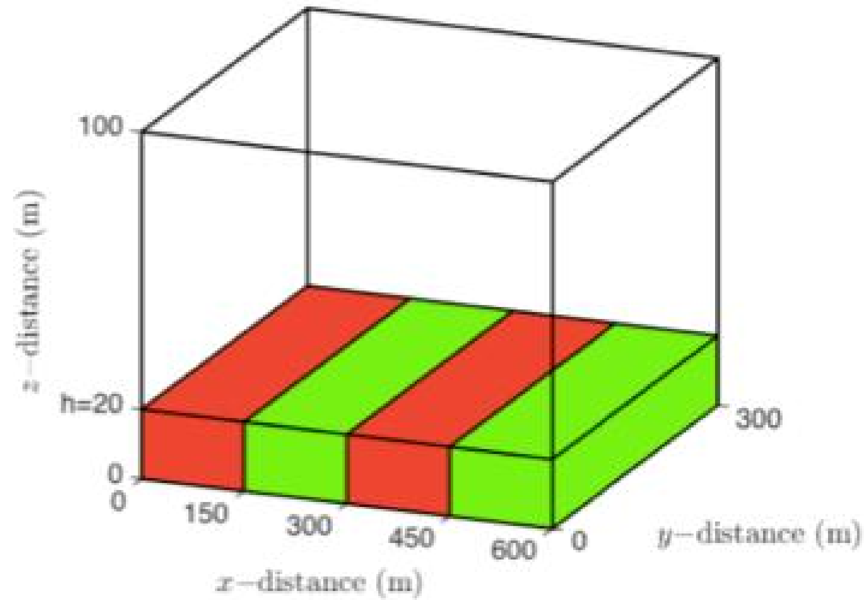
Schlegel et al. (2015), validated LES over a complicated canopy with many heterogeneities and terrain variations.

PREVIOUS WORK: IDEALISED ROUGH SURFACES



Previous work Bou-Zeid et al. (2004), LES over idealised stripes of roughness variation

OUR WORK: IDEALISED CANOPIES



Stripes of low (red) and high (green) Leaf Area Density (LAD)

BACKGROUND

1) Large eddy simulation
   a) High-resolution non-hydrostatic model
   b) Resolve the large scale motions
   c) Model small scale turbulence
2) Modelling the canopy
   a) Aerodynamic drag force
   b) Volume average of leaf area density (LAD)
3) Extensively validated

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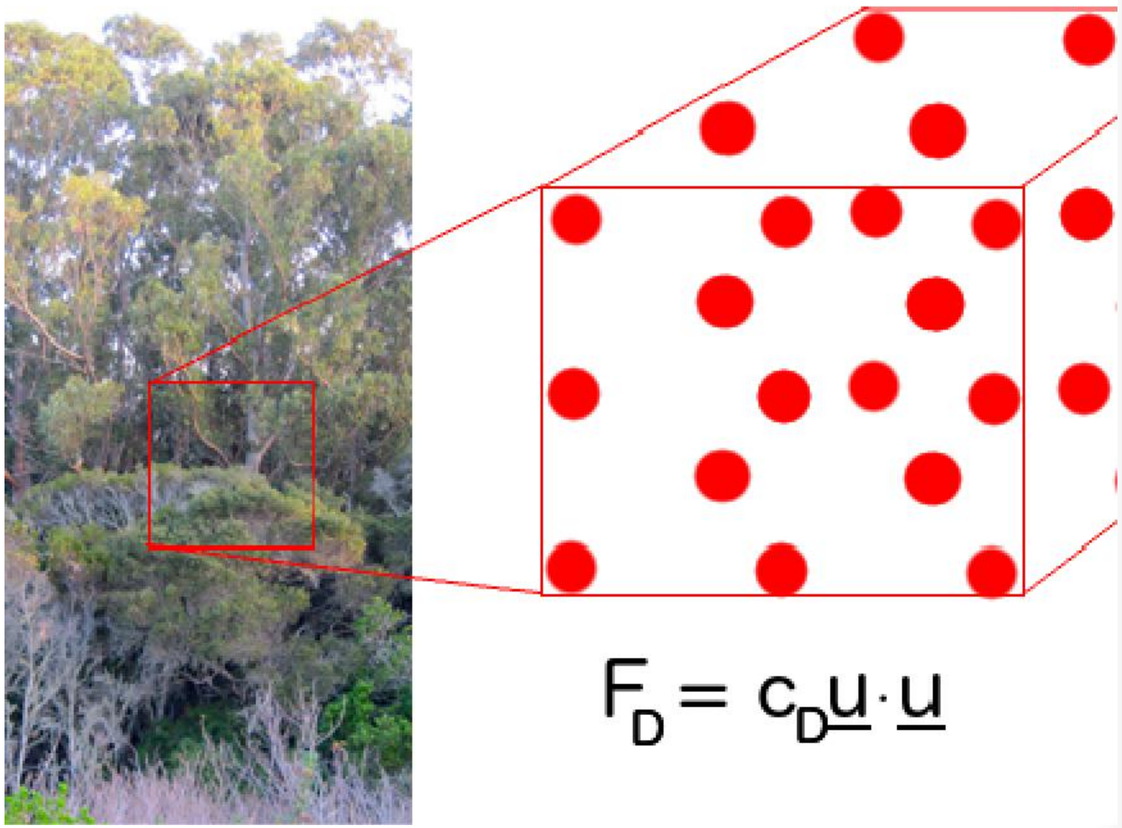

$$F_D = c_D \underline{u} \cdot \underline{u}$$

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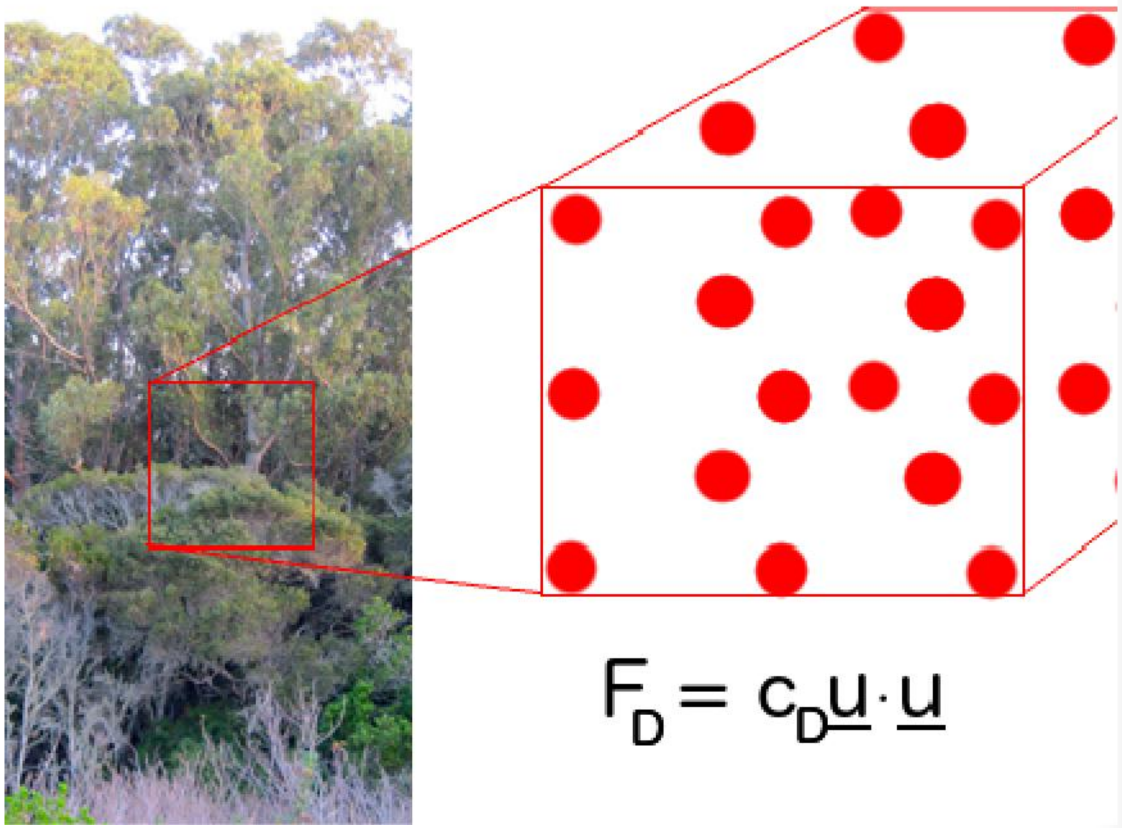

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IDEALISATIONS

1) Idea is to see the basic effects as clearly as possible
2) LAD is a step function of the streamwise direction alone
3) LAD alternates between very large and moderately small
4) Canopy length scale becomes very small
5) Constant height
6) Periodic domain, pressure-driven flow, no geostrophic effects, numerous other technical assumptions

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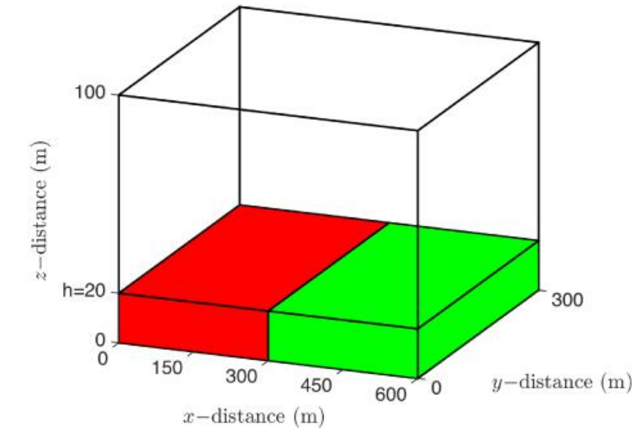
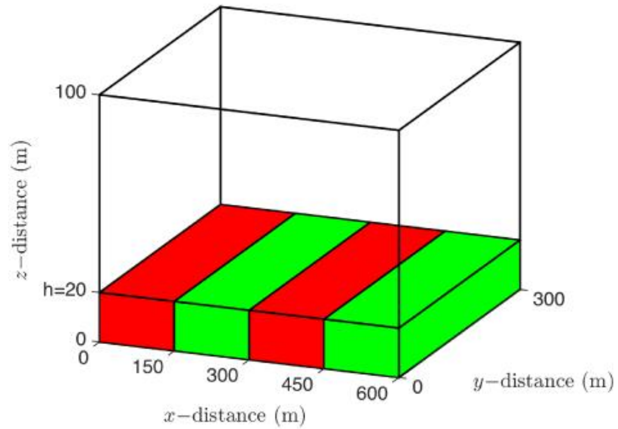
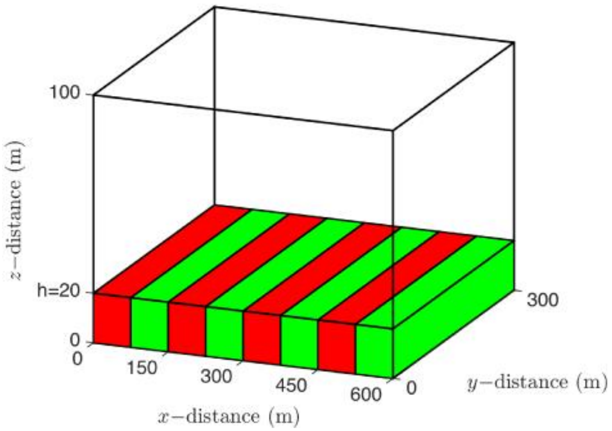
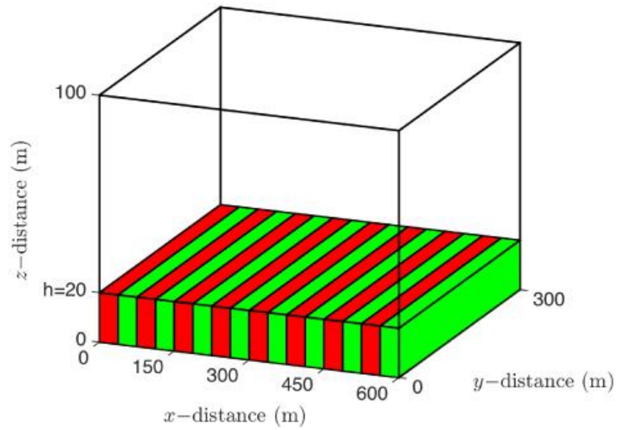
SIMULATIONS

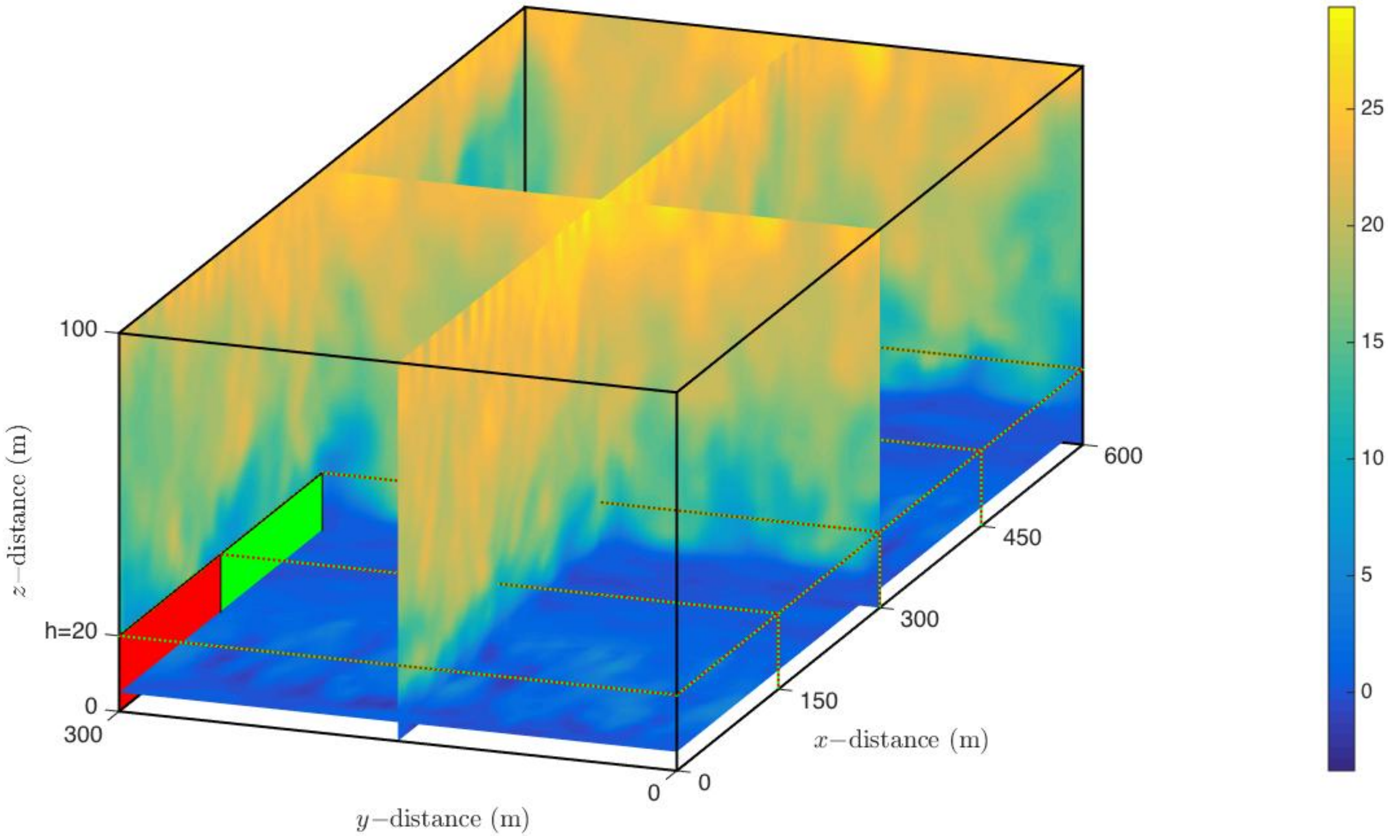




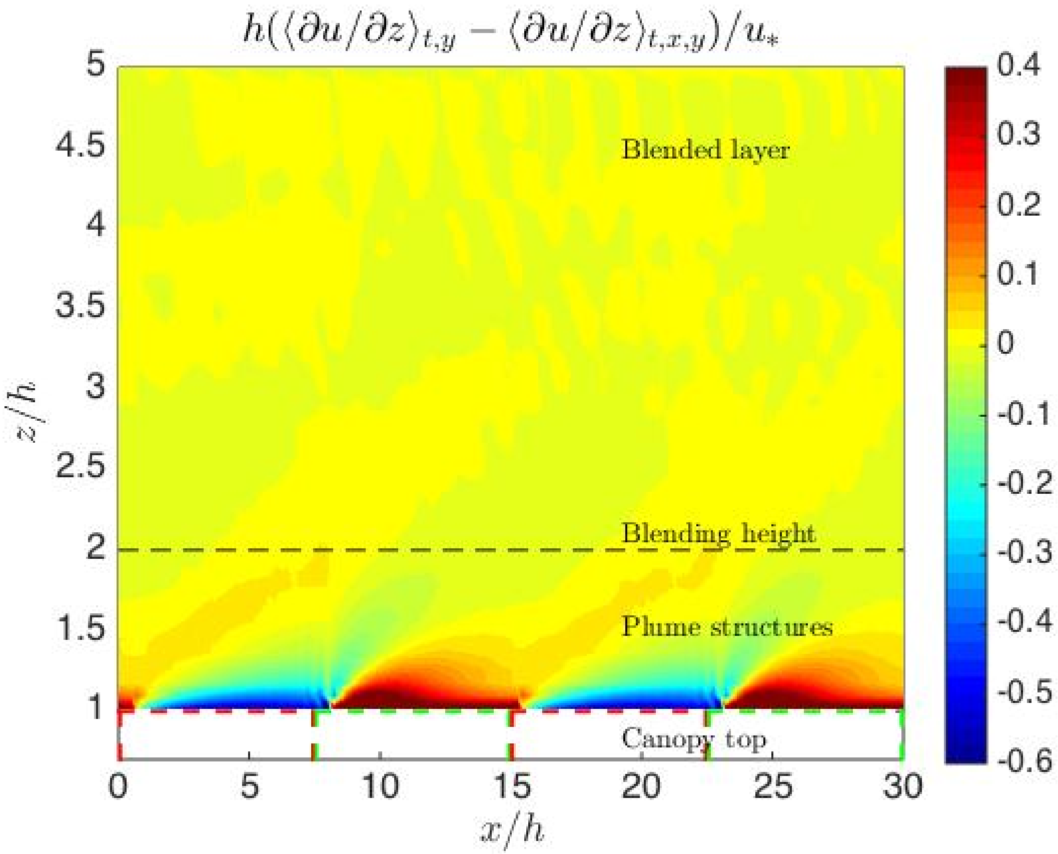




RESULTS: WHAT DOES THE FLOW LOOK LIKE?

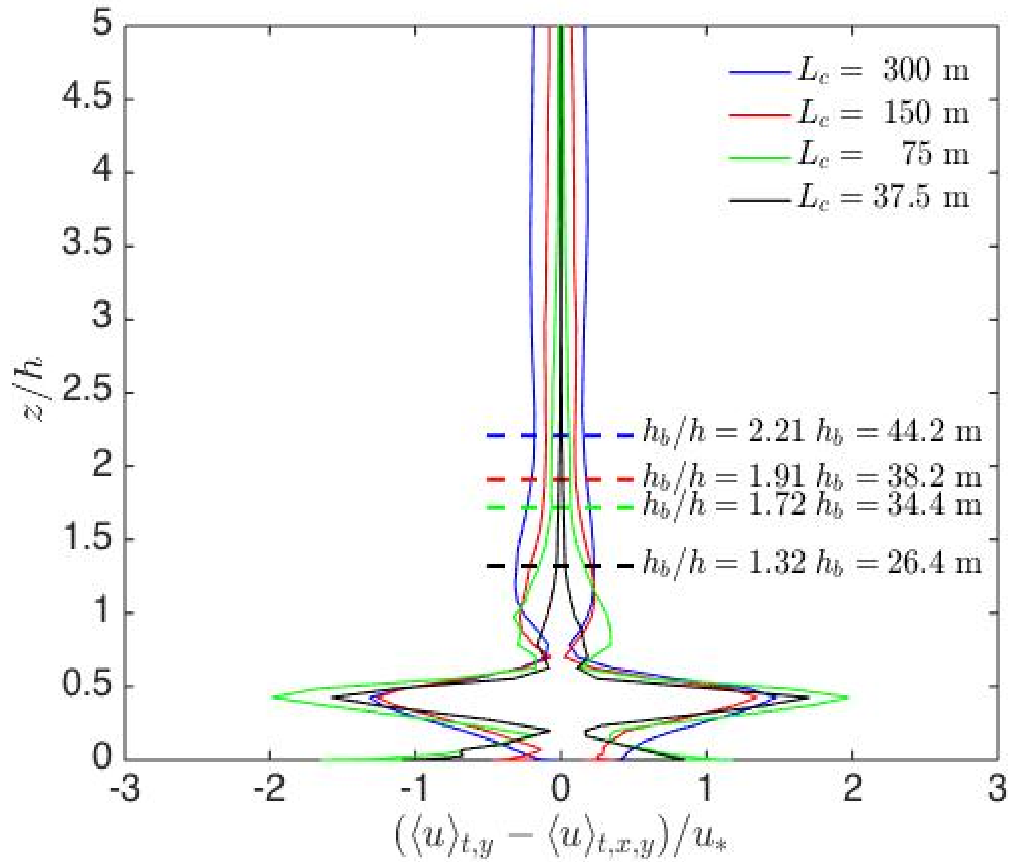


RESULTS: WHAT IS BLENDING HEIGHT?



Contours of averaged velocity gradient difference above the canopy, clearly showing the plume structure immediately above the canopy.

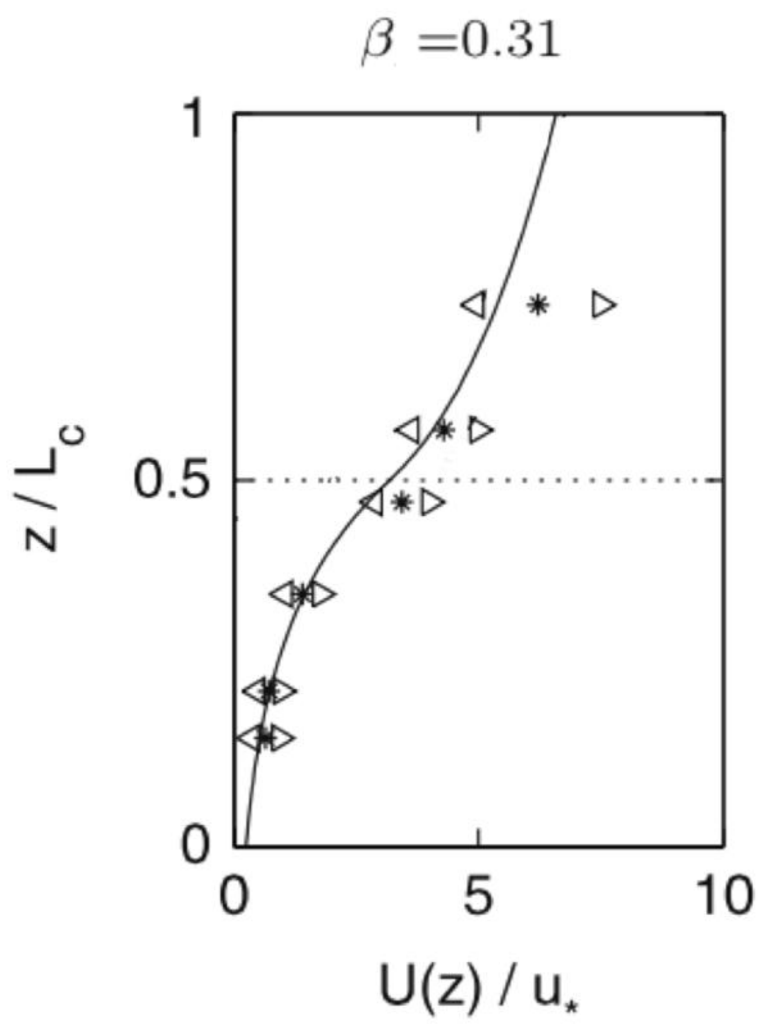
RESULTS: BLENDING HEIGHT



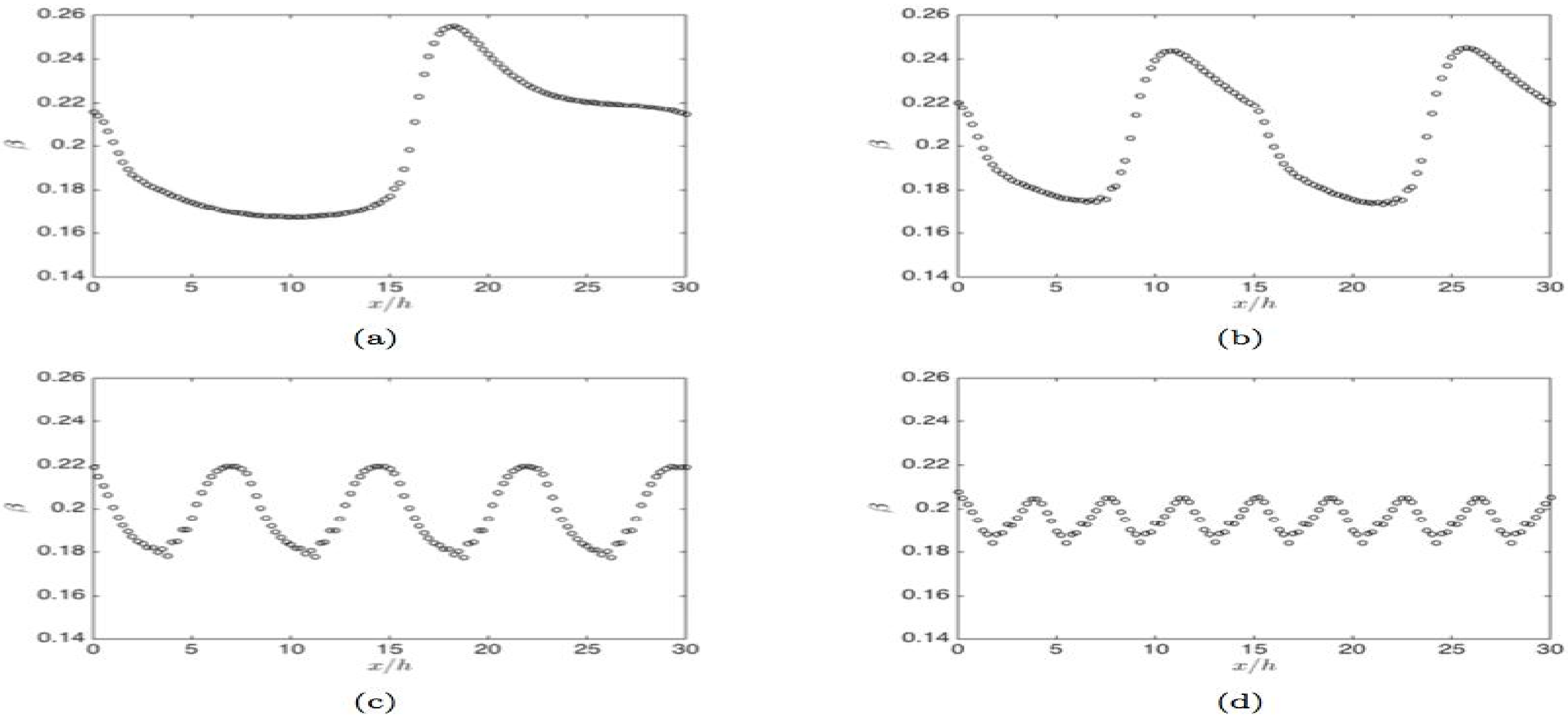
Contours of averaged velocity gradient difference above the canopy, clearly showing the plume structure immediately above the canopy.

RESULTS: WHAT IS β?

1) Parameter for sub-canopy flows
2) Harman and Finnigan *A simple unified theory for flow in the canopy and roughness sublayer* Boundary-layer Meteorol. (2007)
3) Technically: ratio of shear velocity to velocity at the top of the canopy

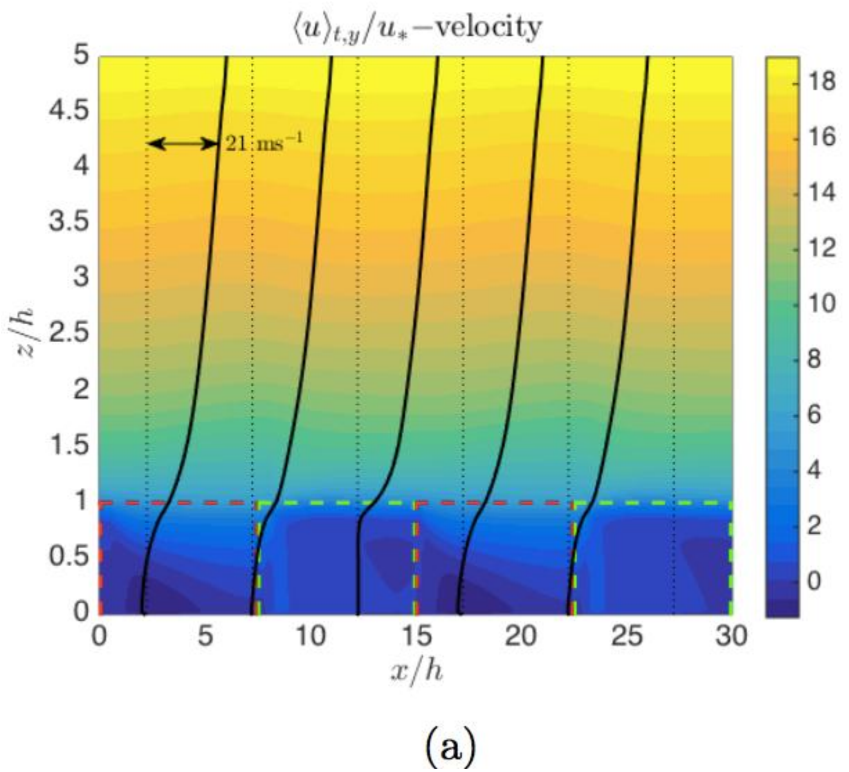


RESULTS: β

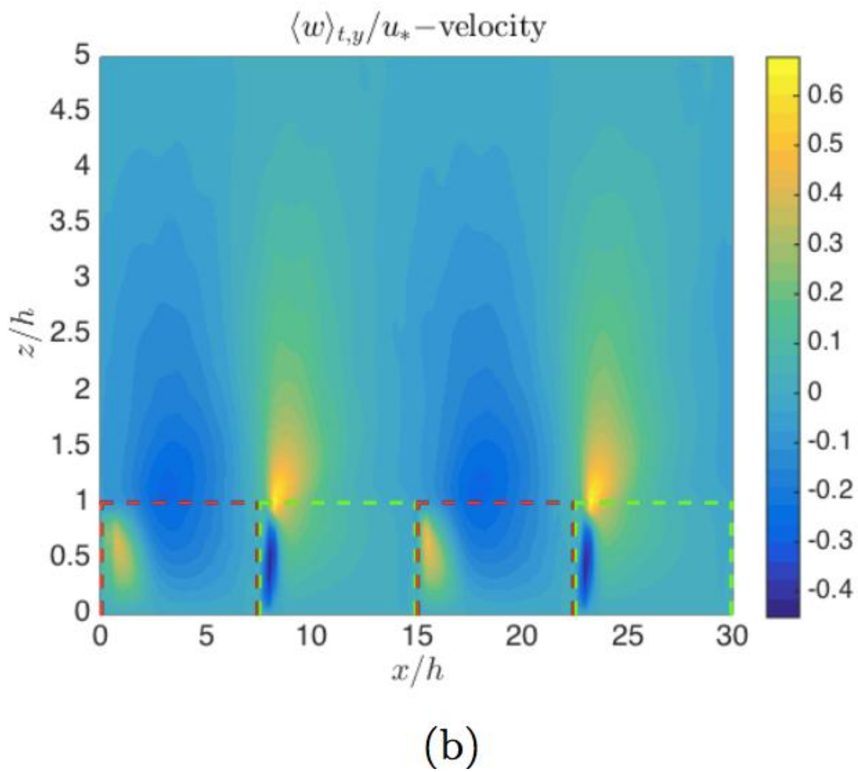


Variation of the β parameter for (a) two, (b) four, (c) eight, and (d) sixteen canopy cases. The mean value is approximately β = 0.2 in all cases.

RESULTS: CHARACTERISATION OF SUB-CANOPY WINDS



(a)

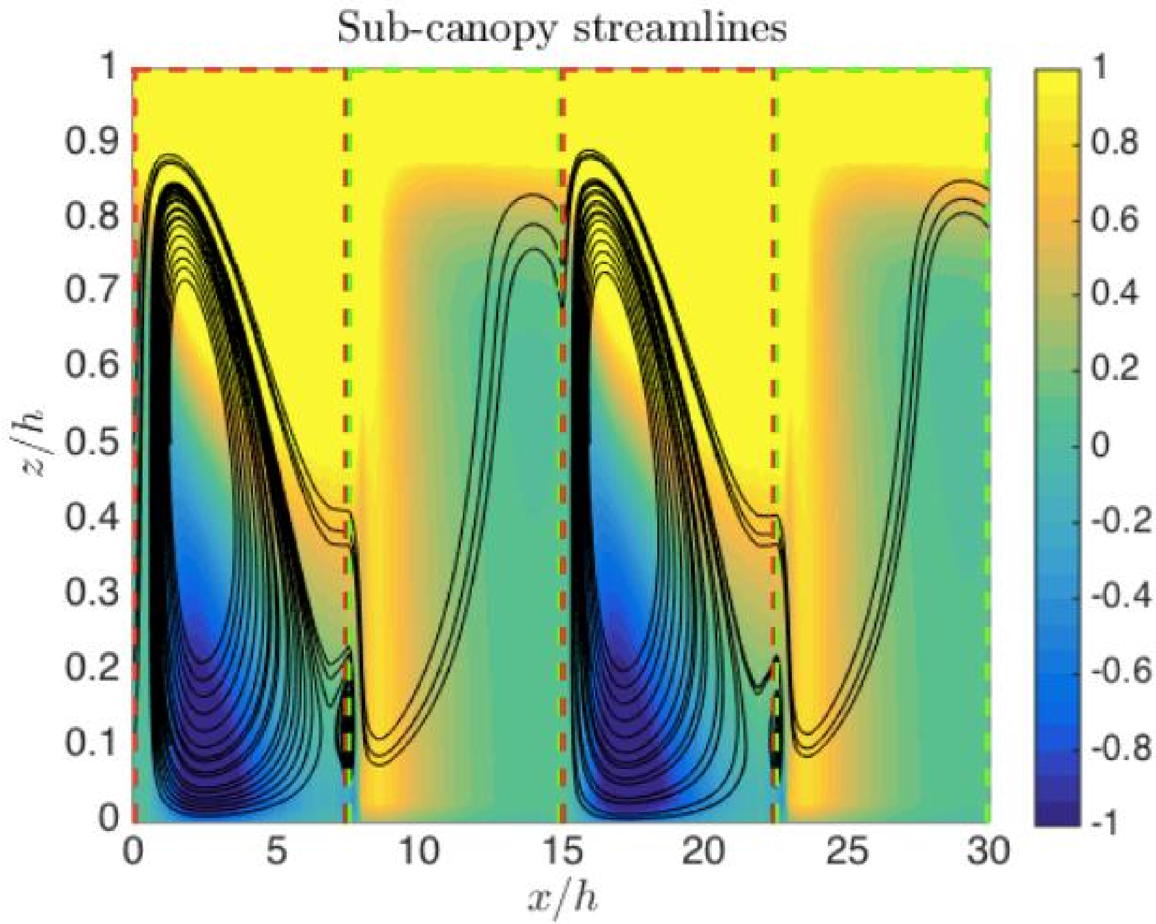


(b)

(a) Contours of nondimensional average u−velocity with superimposed profiles of average u−velocity

(b) (b) Vertical velocity showing the strong up- (yellow) and down-drafts (blue) above and within the canopies.

RESULTS: CHARACTERISATION OF SUB-CANOPY WINDS



Streamlines highlighting two recirculation vortices within the canopy superimposed on the nondimensional average u−velocity.

IMPLICATIONS FOR FIRE SPREAD

1) How the fire is driven by the spatially varying sub-canopy wind speed is unclear
2) Unlikely that the recirculation regions will persist in the presence of a large buoyant fire plume
3) Smoke, firebrand transport, and spotfire ignition to be influenced by the strong updrafts and recirculation regions which occur at canopy boundaries

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FURTHER WORK: RICH PROBLEM

1) Test the of effect of canopies on fire spread
   a) Rate-of-spread, in progress – see poster submission
   b) Simulate ignition of a spotfire at canopy boundaries
   c) Test firebrand landing distribution
2) Determine boundary-layer parameterization over stripe forest
   a) Need to increase the LAD space
3) Multiple direction of heterogeneity
   a) Vertical, longitudinal stripes, etc
4) Canopy height and terrain

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CONCLUSIONS

1) Flow over idealised heterogeneous canopies has been simulated
2) Systematic trends in h_b, periodic β with lower mean observed
3) Prominent recirculation regions are observed
4) The vertical velocity exhibits up- and down-drafts corresponding to the dense and sparse canopies respectively

QUESTIONS AND REFERENCES

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