Large-eddy simulation of wind flow around a small forest

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Background

- Forests are becoming increasingly fragmented. For example, 70% of the world's forest area is now less than one kilometre from the nearest edge.
- Eddy covariance, the current standard technique for assessing forest-atmosphere interactions, deals badly with fragmented landscapes, such as those containing forest edges.
- This is because these features can cause fluid dynamical effects that affect how forests exchange gases with the atmosphere.
- Here we used large-eddy simulation (**LES**) to study flow dynamics around the Birmingham Institute of Forest Research free-air carbon dioxide enrichment facility (**BIFoR FACE**).

Fig 1: deforestation in the Amazon, showing increasing fragmentation as well as loss of forest area. Image © NASA (MODIS Rapid Response)

Method

- We modified the LES mode of the Weather Research and Forecasting Model (v3.6.1) for forest simulations.
- We represented the forest by adding a drag term to the filtered momentum and continuity equations:

$$F_{ui} = a(z)C_d U u_i$$

where ***a(z)*** is the vertical profile of forest density; C_d the isotropic drag coefficient; ***U*** absolute wind speed; and u_i the velocity component in each direction.

- We approximated the vertical profile (i.e. shape of the trees *a(z)*) for the BIFoR FACE site in two ways: (i) **Case 1** - dense canopy and sparse understorey; and (ii) **Case 2** - extensive understorey (**Fig 3**)

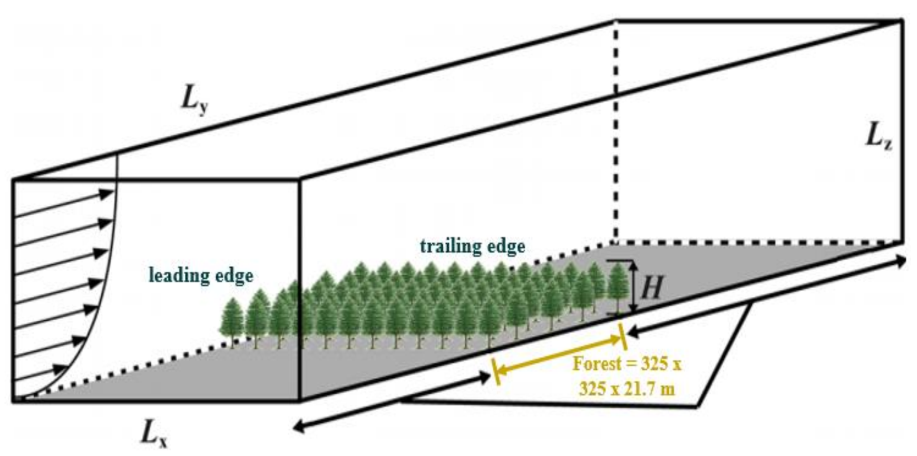
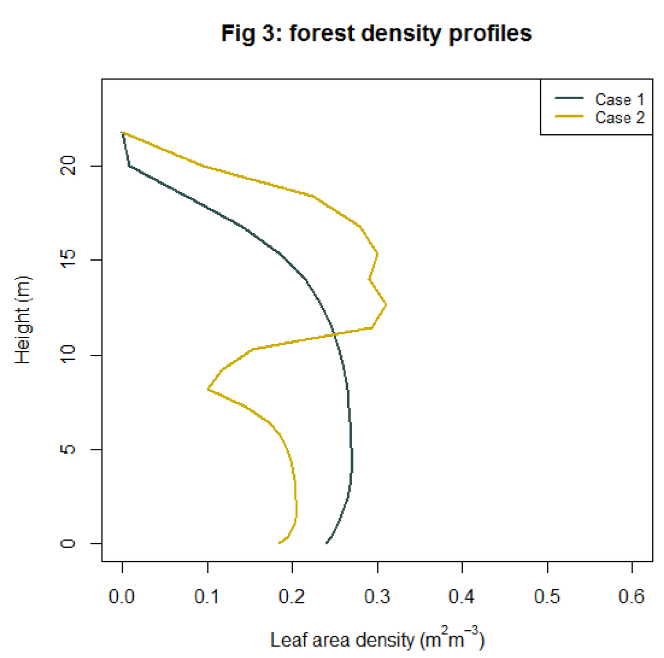


Fig 2 (left): Simulated domain 635 x 325 x 968m. Figure adapted from Kanani-Sühring and Raasch (2015)



Results

- Case 2 simulated turbulence kinetic energy above the forest better than Case 1, when compared to BIFoR data
- We found clear patterns in flow dynamics – the wind slows and deflects upwards when it hits the trees (**Fig 4a,b**).

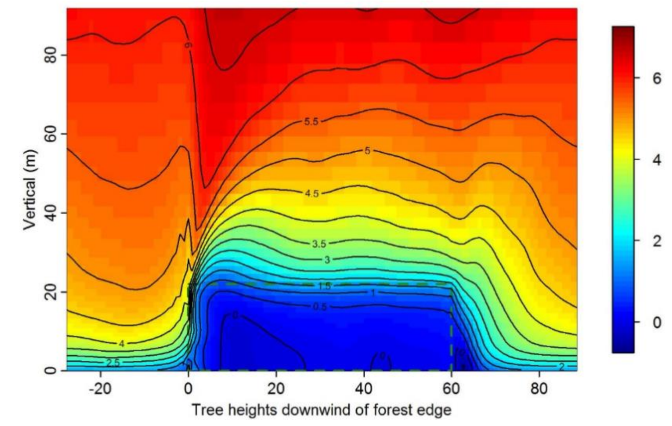
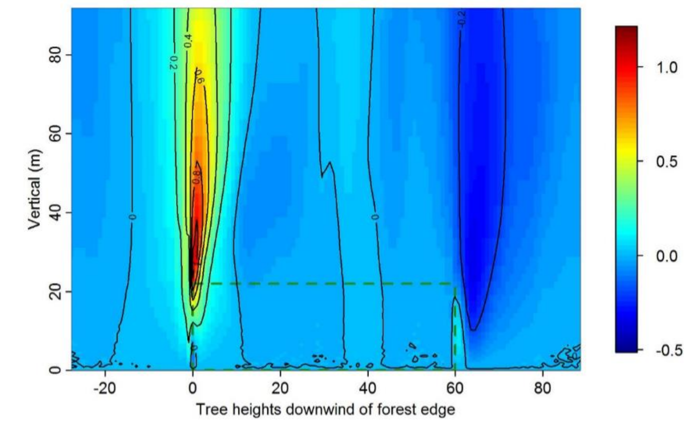


Fig 4: time and space-averaged evolutions of (**a - left**) mean streamwise velocity (x direction); and (**b – right**) mean vertical velocity



- The tops of the trees a few heights downwind of the forest edge experience very strong gusts (**Fig 5**).
- The air above and in the lee of the forest is highly turbulent (**Fig 6**).

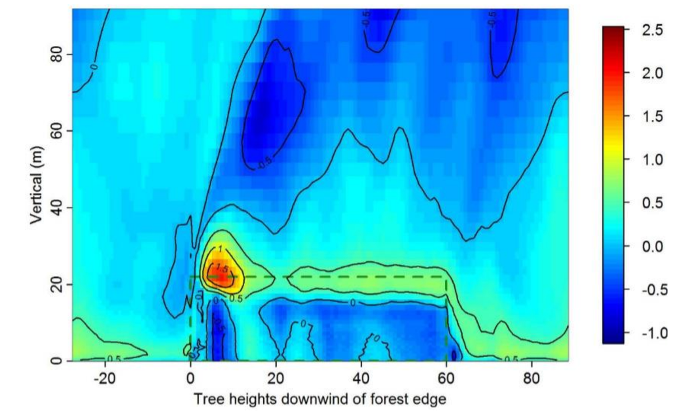
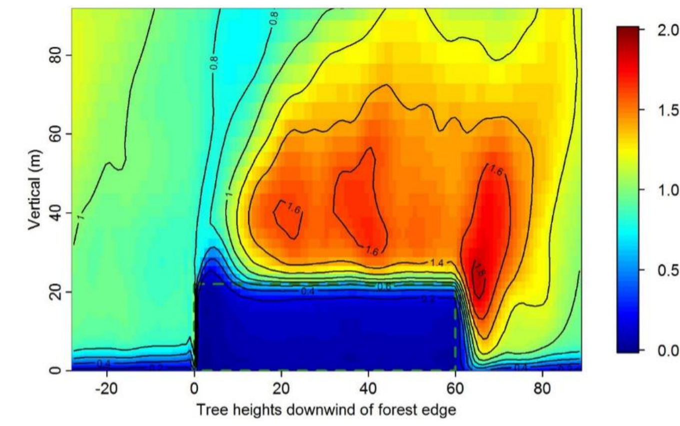


Fig 5 (left): time and space-averaged evolution of skewness of streamwise fluctuation component. High values indicate gusts

Fig 6 (right): time and space-averaged evolution of turbulent kinetic energy



Conclusions

- These results complement previous studies performed on smaller domains, with excellent quantitative agreement.
- With these results we can develop a schematic picture of typical features of flow over a small forest (**Fig 7**).

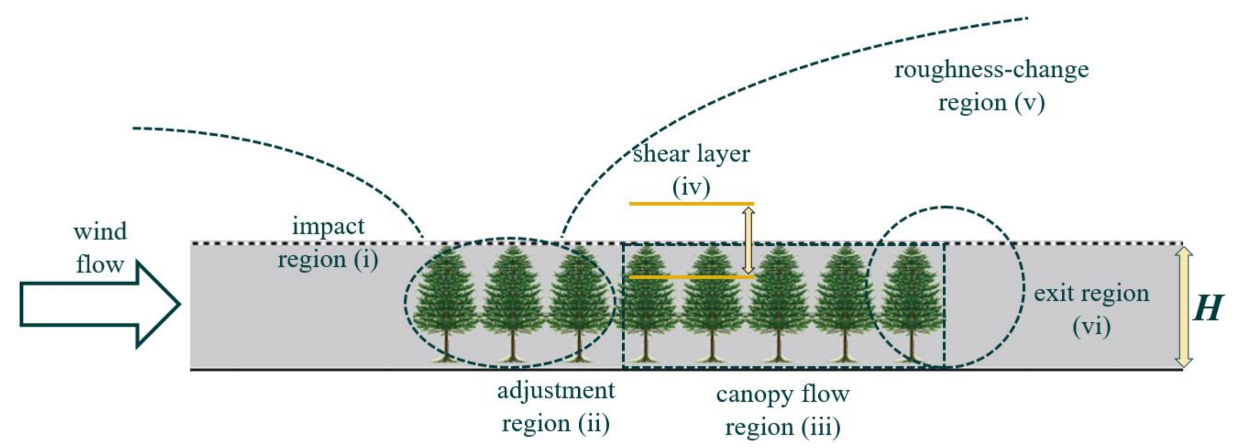


Fig 7: schematic picture of flow across a small forest. After Belcher, S.E. *et al* (2003)

i. Impact region - the forest induces a pressure gradient.

ii. Adjustment region - the flow adjusts to the drag created by the trees. The wind deflects upwards. The tree crowns experience strong gusts.

iii. Canopy flow region – here the flow is approximately in equilibrium.

iv. Canopy shear layer – energy and mass exchange between the forest and the atmosphere happens here.

v. Roughness-change region - an internal boundary layer develops above the canopy

vi. Exit region - the flow accelerates.

Next Steps

- Refine our LES model using high-resolution 3D wind data from BIFoR FACE
- Use meteorological data from BIFoR FACE to investigate how flow transports CO_2 and heat.

Sponsors

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*References

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