Wind flow in fragmented forests and its affect on CO_2 uptake

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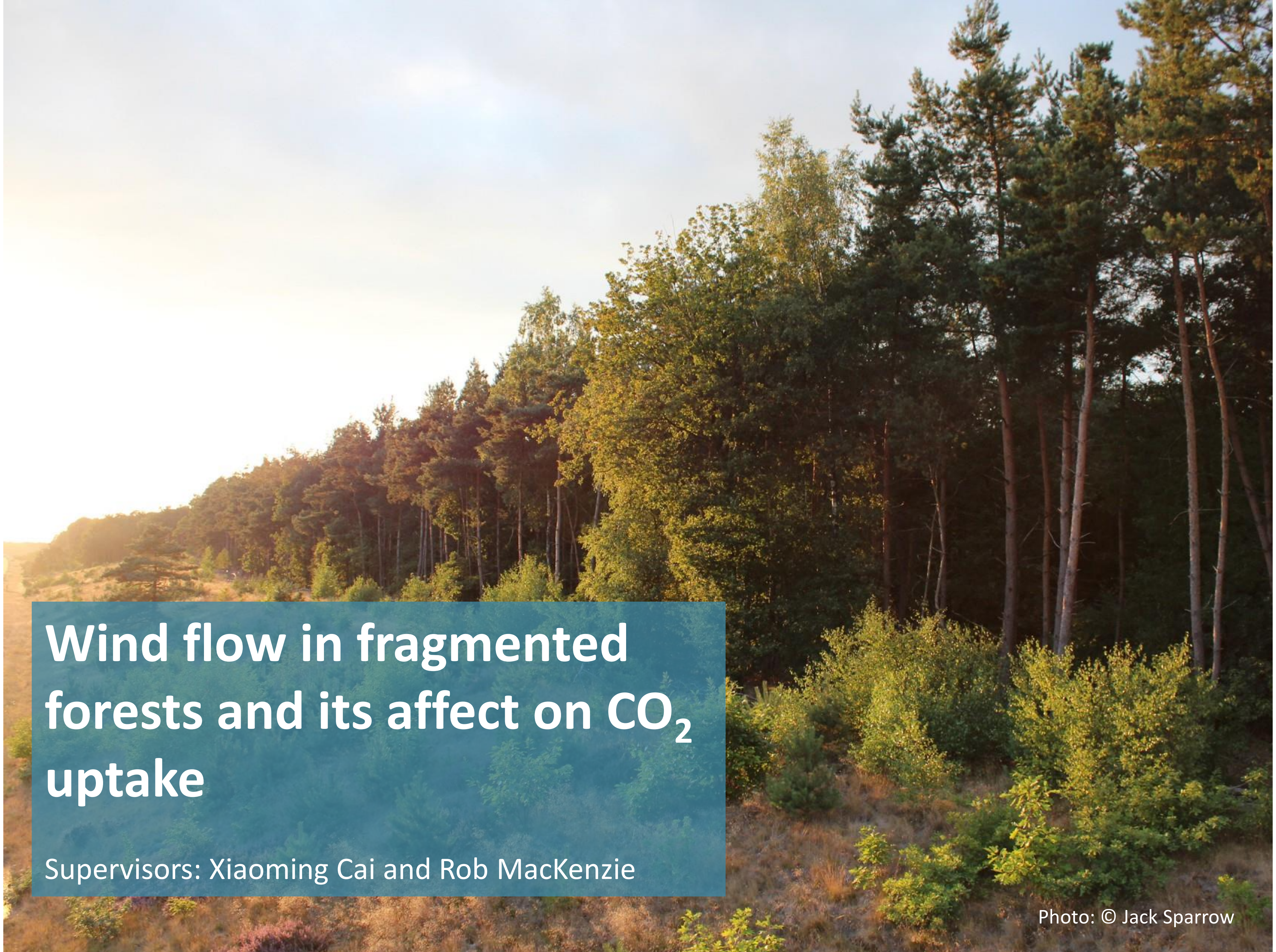


Photo: © Jack Sparrow

1. Motivation

Forests are becoming increasingly fragmented – e.g. in Borneo

Morgans, C.L. *et al* (2018) Evaluating the effectiveness of palm oil certification in delivering multiple sustainability objectives, *Environ. Res. Lett.* 13 064032

…and closer to home. This is an aerial view of the Birmingham Institute of Forest Research

Photo: Google Maps

2. A couple of comments on wind

This is how wind flow is presented for day-to-day use

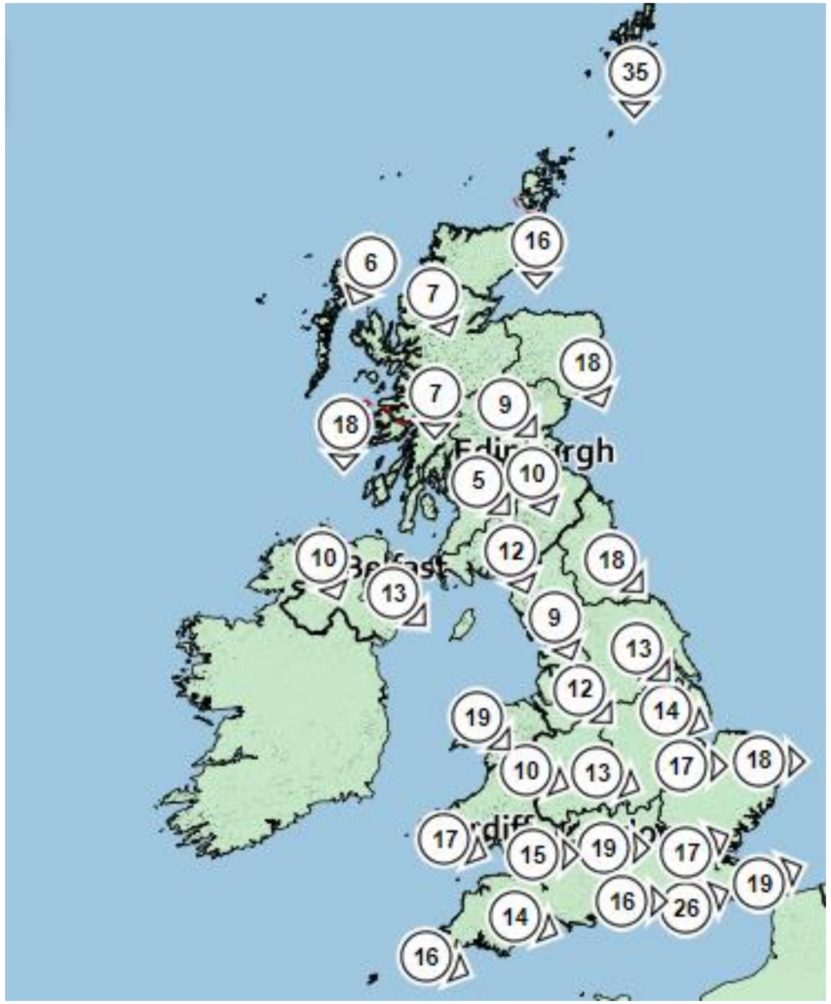
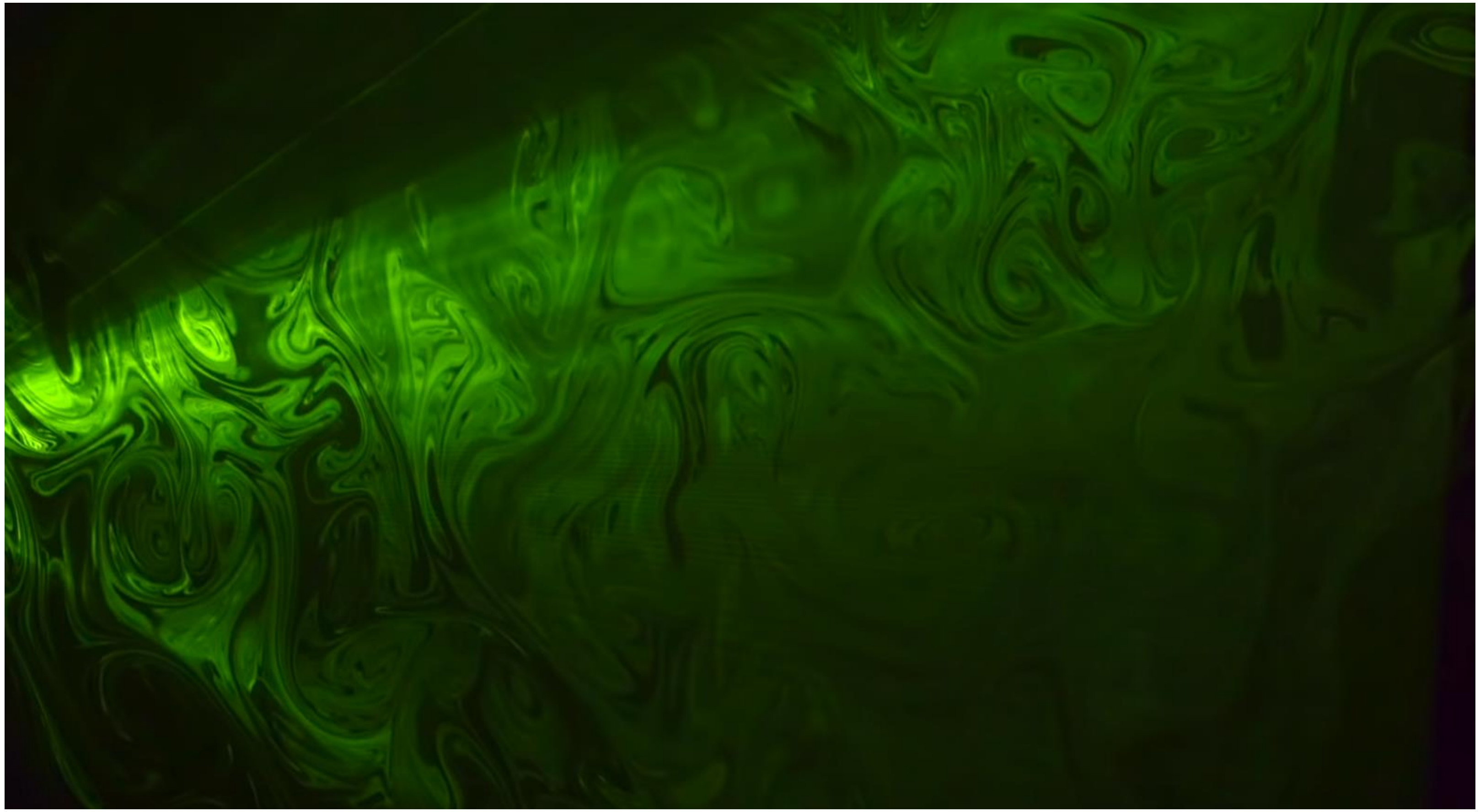


Photo: Met Office

But air is fluid – its shape changes constantly in the turbulent planetary boundary layer

Here’s a visualisation of turbulence – these eddies affect concentration gradients around the stomata of tree leaves



3. How can we study air flow at forest scales?
(i.e. method)

How does large-eddy simulation work?

(**F** = m**a** applied to a fluid)

$$\frac{\partial \boldsymbol{U}_i}{\partial t} + \boldsymbol{U}_j \frac{\partial \boldsymbol{U}_i}{\partial \boldsymbol{x}_j} = -\delta_{i3}\boldsymbol{g} + f_c \epsilon_{ij3} \boldsymbol{U}_j - \frac{1}{\rho}\frac{\partial p}{\partial \boldsymbol{x}_i} + \nu \frac{\partial^2 \boldsymbol{U}_i}{\partial \boldsymbol{x}_j^2}$$

$$\frac{\partial \overline{\boldsymbol{u}}_i}{\partial t} + \overline{\boldsymbol{u}}_j \frac{\partial (\overline{\boldsymbol{u}}_i)}{\partial \boldsymbol{x}_j} = -\frac{1}{\bar{\rho}}\frac{\partial \bar{p}}{\partial \boldsymbol{x}_i} - \frac{1}{\bar{\rho}}\frac{\partial \overline{p^*}}{\partial \boldsymbol{x}_i} - \frac{\partial \boldsymbol{\tau}_{ij}}{\partial \boldsymbol{x}_j} - \boldsymbol{F}_{ui}$$

The extra friction term is a rough parametrisation of aerodynamic drag, based on the density of the forest

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

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

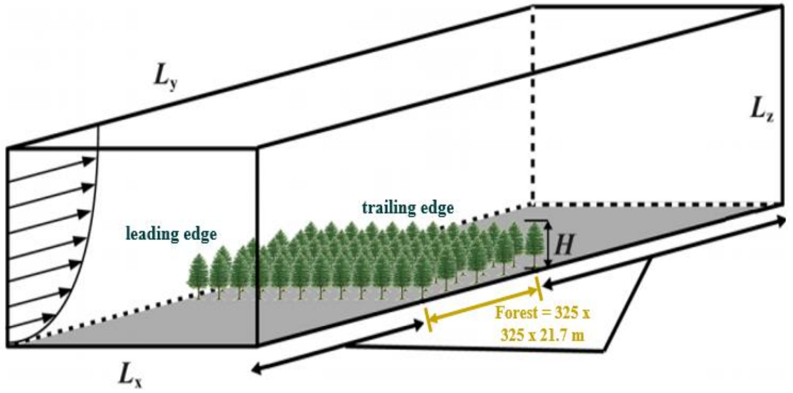
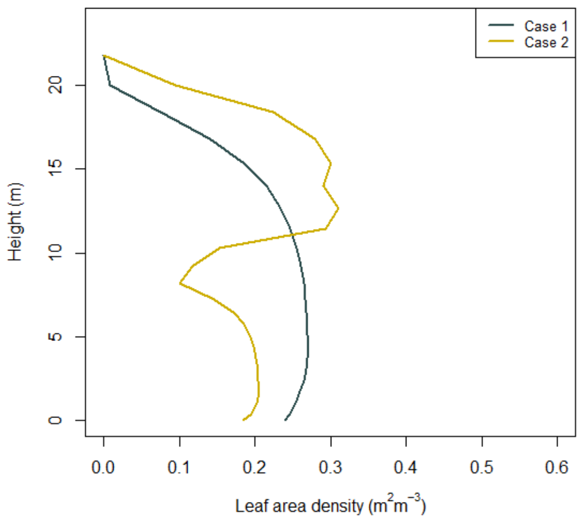


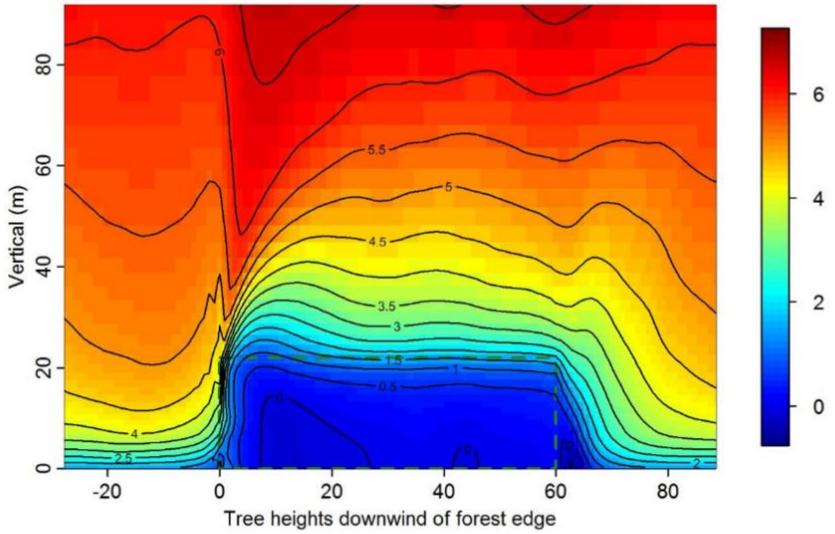
Figure adapted from Kanani-Sühring and Raasch (2015)

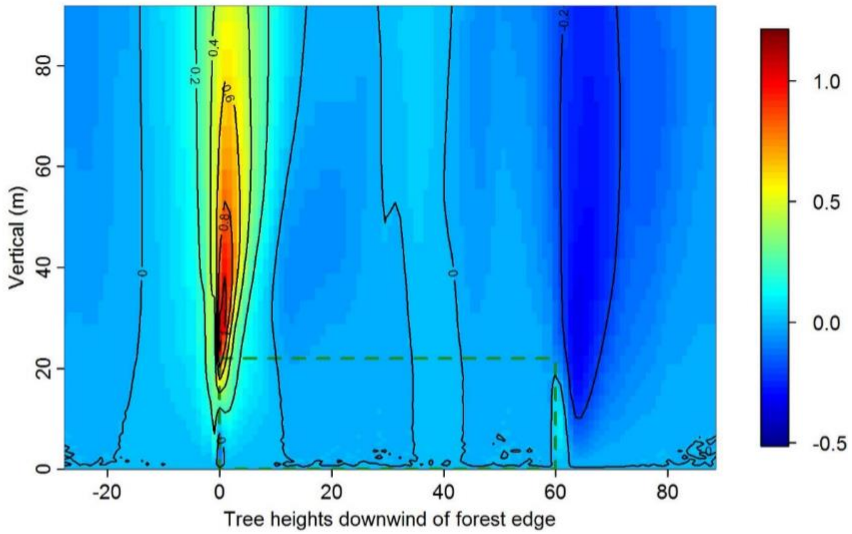
Fig 3: forest density profiles



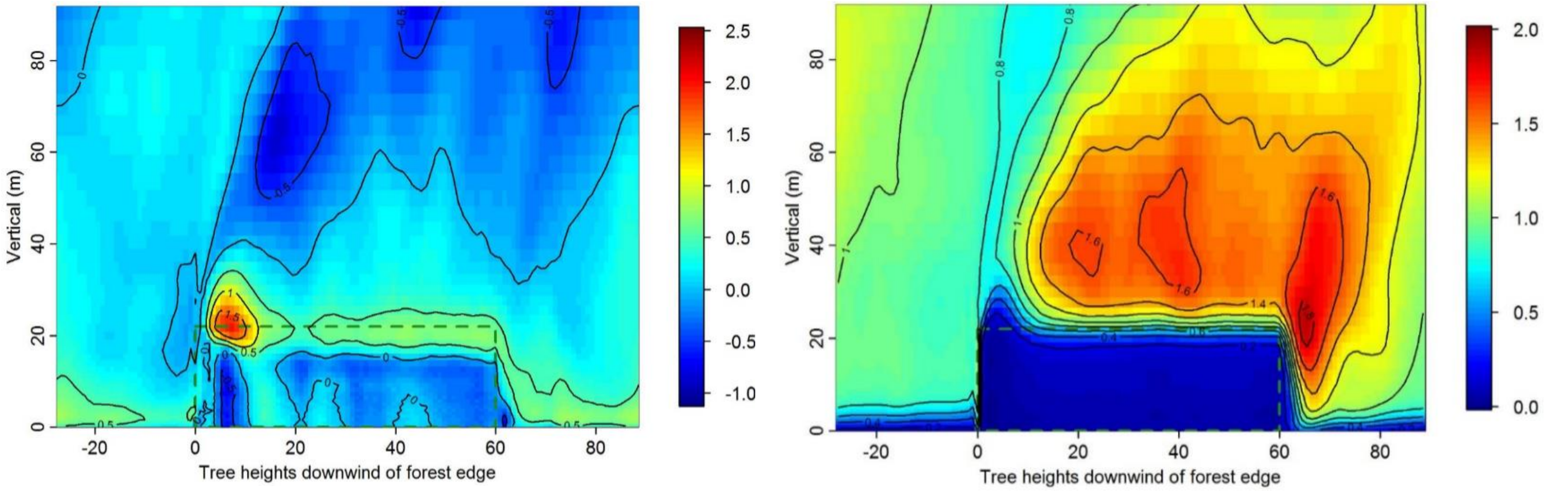
4. Results

We see clear patterns in flow dynamics – here are the streamwise and vertical components of the flow

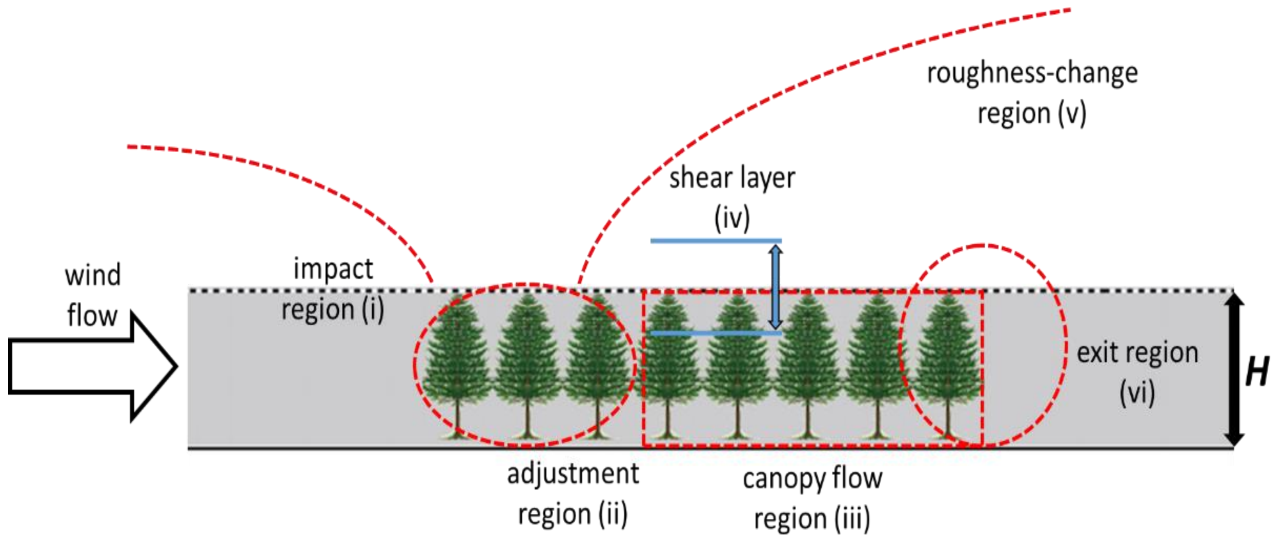




Gusts (left) and turbulence kinetic energy (right)



Here is a summary of the key dynamical features you can expect to see around a small forest



After: Belcher, S.E. *et al* (2003) Adjustment of a turbulent boundary layer to a canopy of roughness elements. *Journal of Fluid Mechanics*, **488**, 369-398

5. Discussion and next steps

Limitations

1. All we are doing at the moment is adding drag
2. The forest structure is highly idealised
3. Very little comparison of simulations and real data from forests

To sum up

1. Forests are becoming increasingly fragmented
2. This fragmentation may affect carbon uptake
   i. most of what we know about forests is from point measurements in homogeneous landscapes
   ii. fragmentation increases turbulence in forests
   iii. this changes concentration gradients around the leaves, affecting uptake
3. Nonetheless, initial results suggest there are clear patterns in wind flow around forests
4. We want to look at:
   i. flow structures for realistic forests
   ii. how scalar fields follow the flow

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For further information and references:

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