

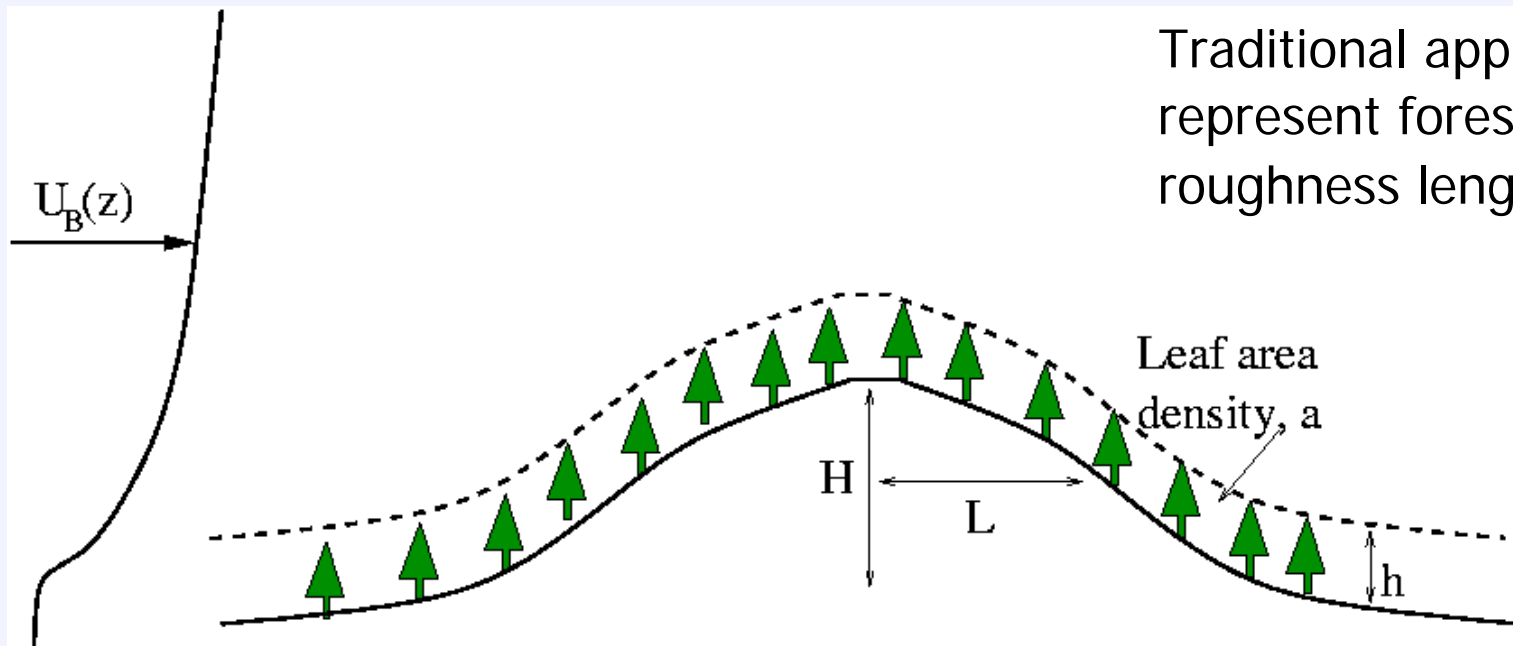
# Large-eddy simulations of atmosphere-canopy interactions over hills



# Motivation

- Important applications for
  - Flux calculations and global carbon budget
  - Orographic form drag
  - Predicting and preventing tree damage
  - Locating wind farms
- Motivated by recent theoretical results of Finnigan and Belcher (2004)

# An example hill



Traditional approach - represent forest by a roughness length,  $z_0$

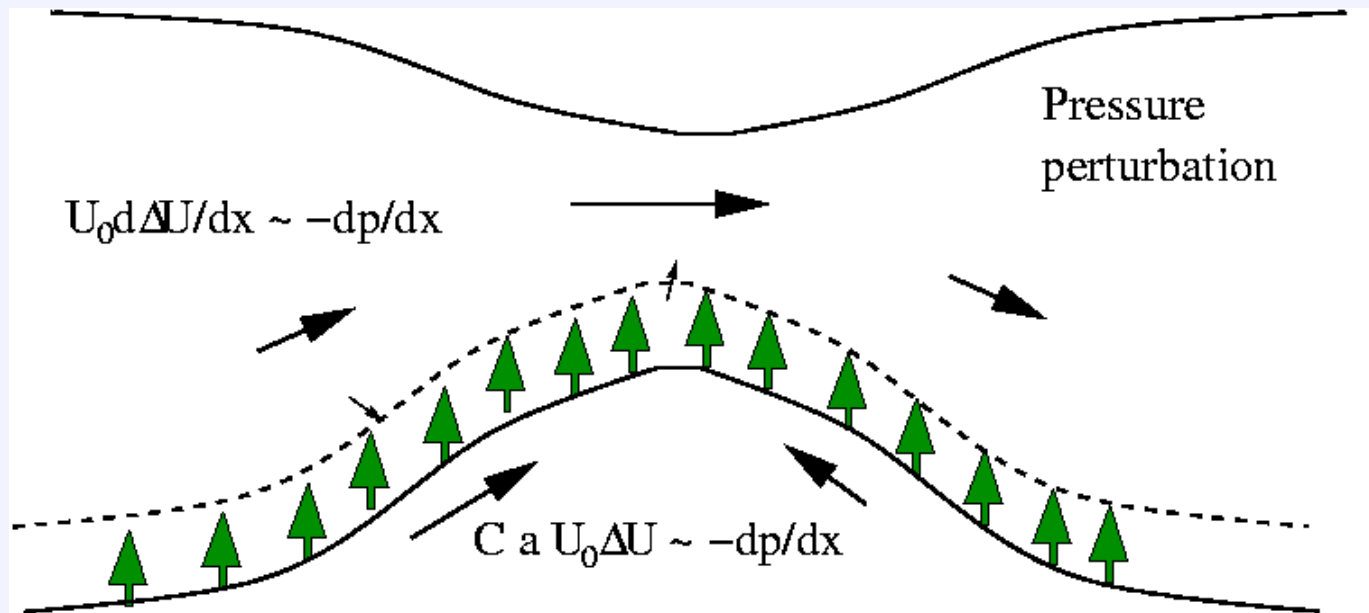
Here we explicitly model flow with the forest canopy.

$$L = 100 \text{ m}, H = 10 \text{ m}, \\ h = 20 \text{ m}, a = 0.25 \text{ m}^{-1}$$

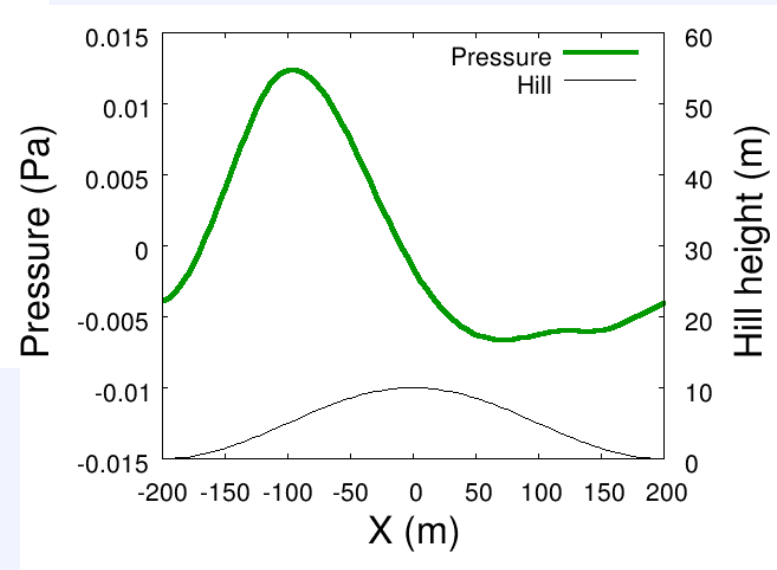
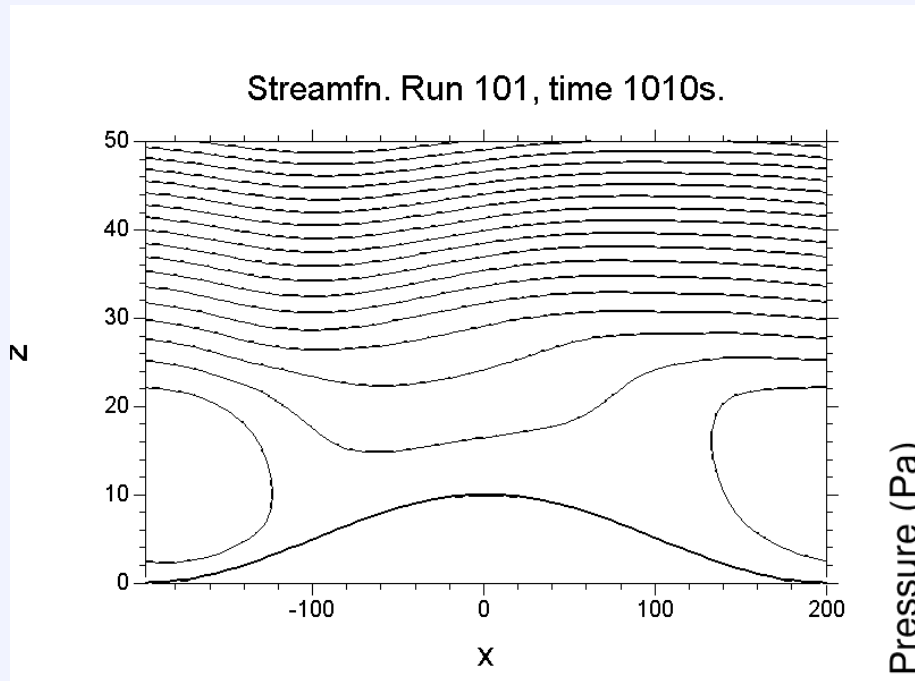
# 1 1/2 order closure model

- Using BLASIUS model from UK Met Office
- 1 1/2 order turbulence closure scheme
- Fixed mixing length in canopy
- Additional canopy drag term in momentum equation,  $-C a U |U|$
- Additional dissipation in canopy

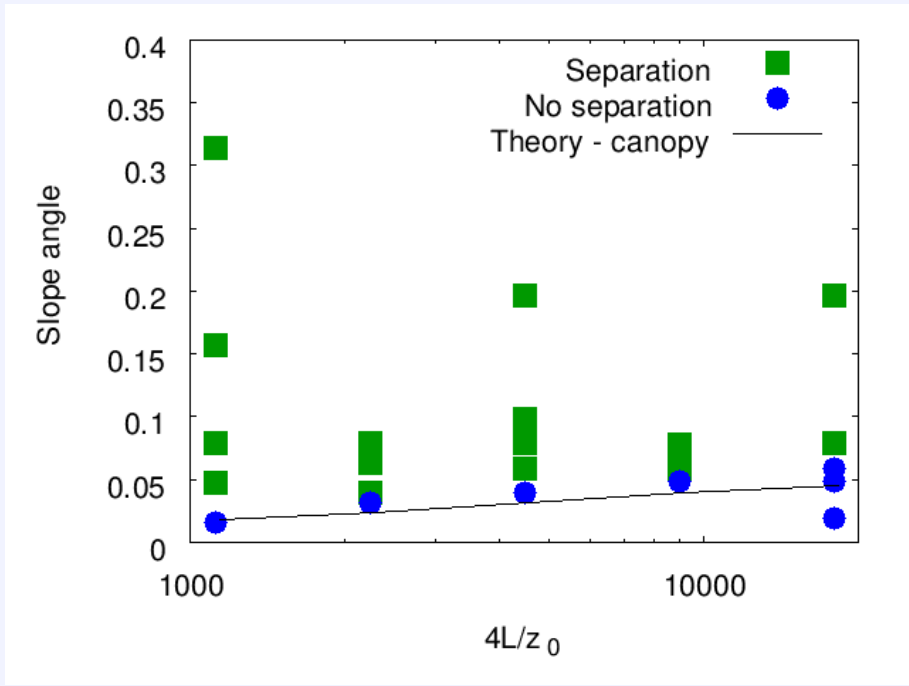
# Induced flow



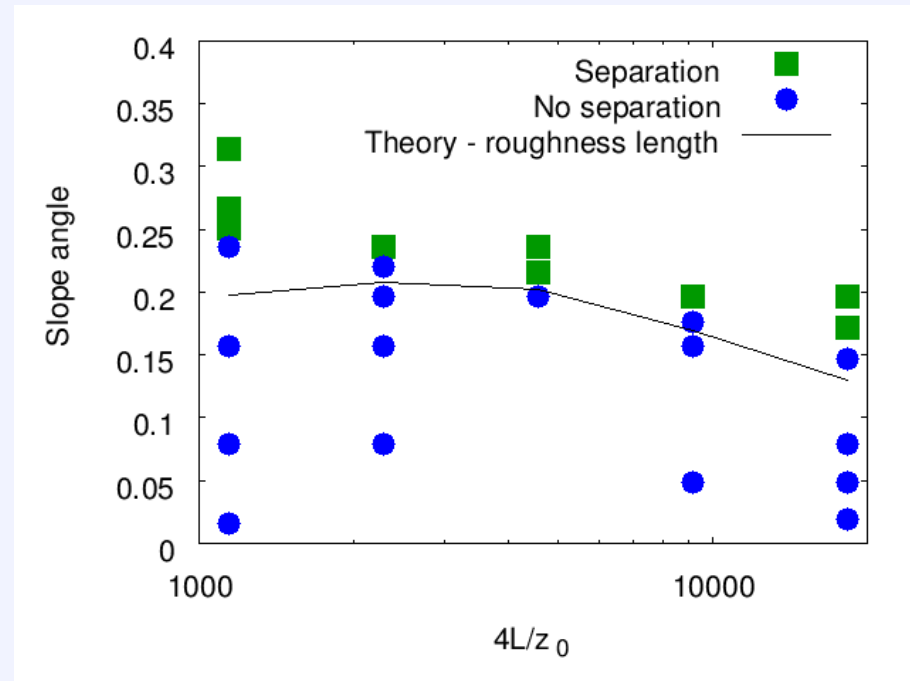
# Model Results



# Flow separation

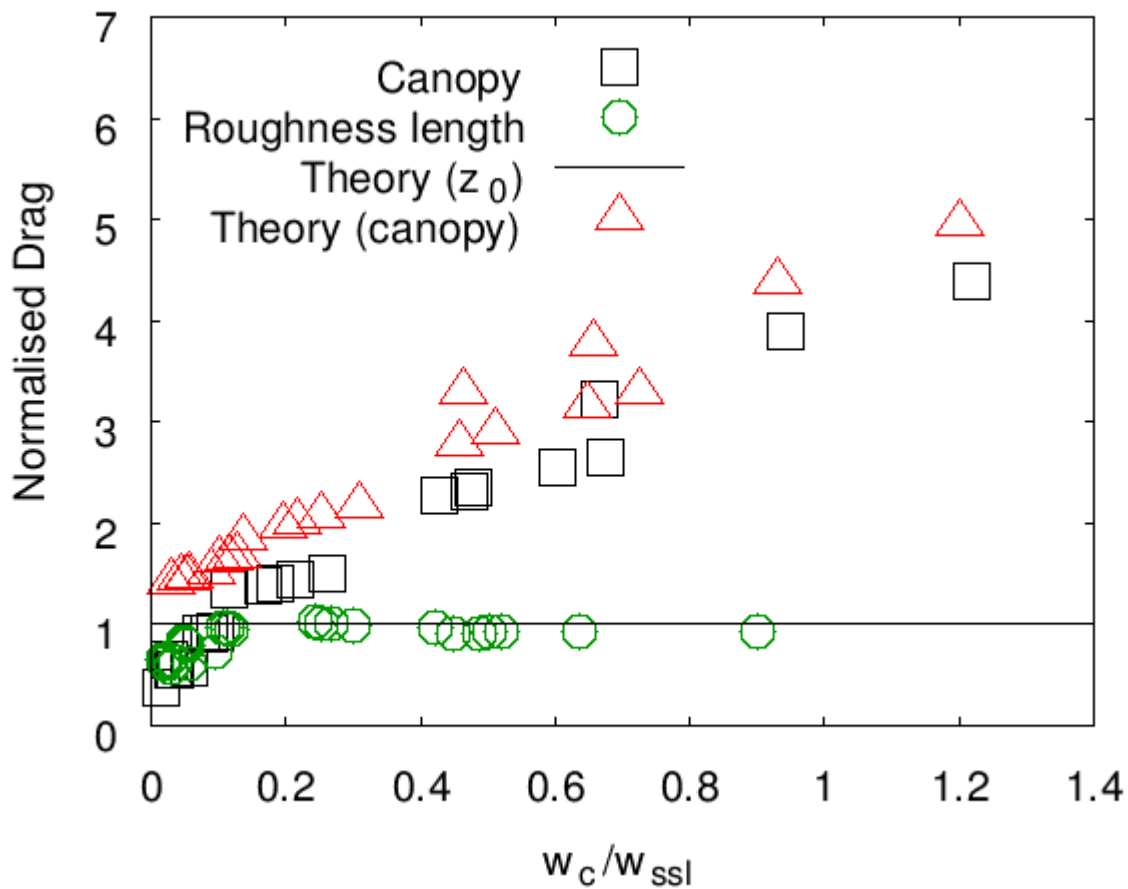


Canopy



Roughness length

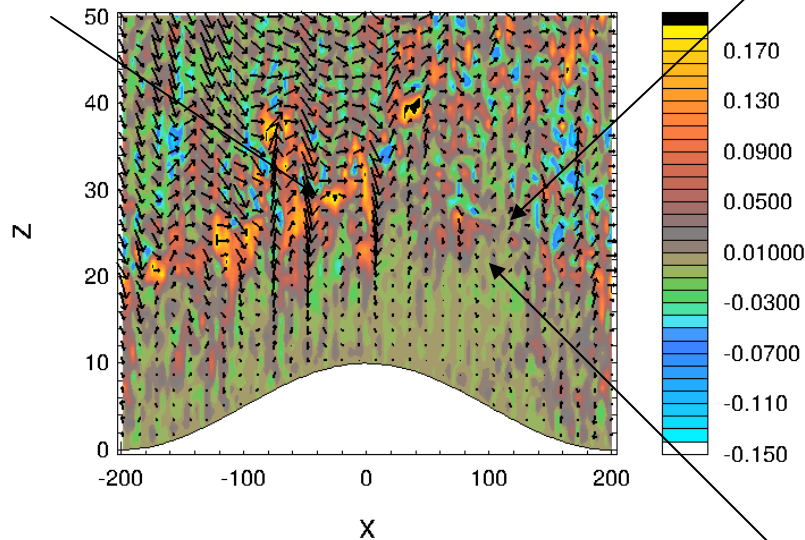
# Drag



# LES over a hill

Enhanced  
shear

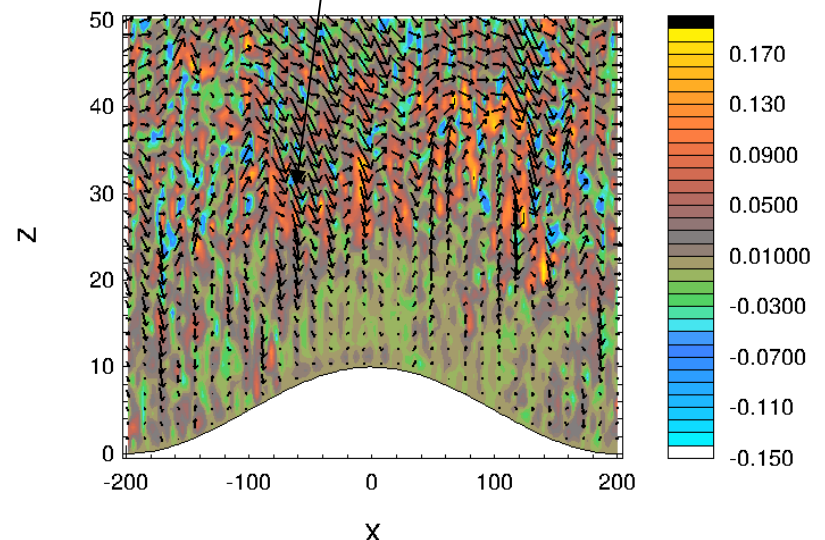
VORTY. Run 101, time 5000s.



Reduced  
shear

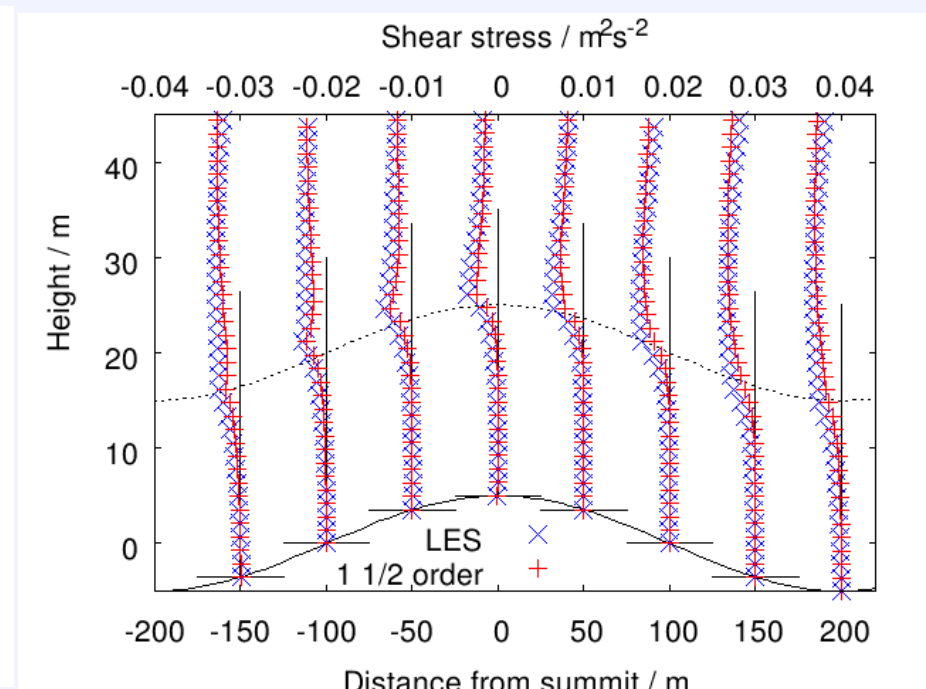
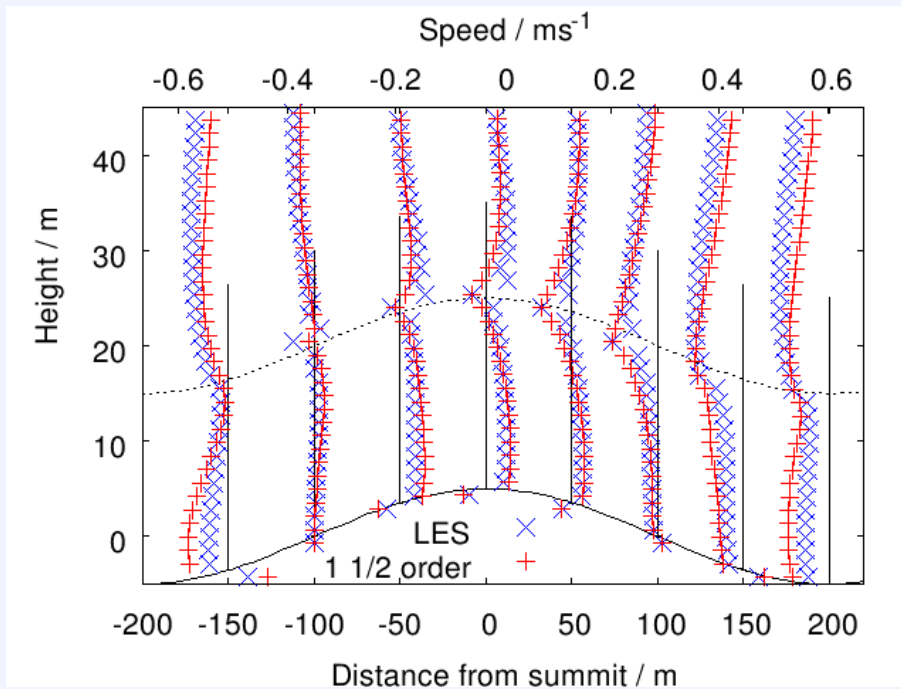
Large scale descent

VORTY. Run 101, time 6002s.



Separation

# Profiles of wind perturbation and $u'w'$



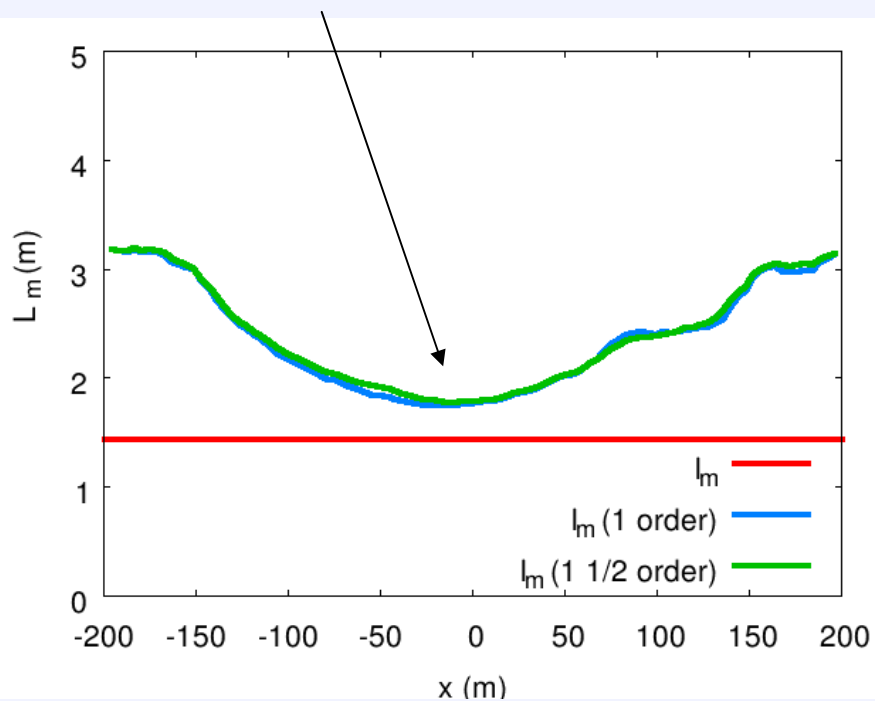
# Comparison of closure schemes

- In the 1 1/2 order closure scheme we assume a Smagorinsky closure  $\tau_{ij} = -\rho u_i u_j = S_{ij} \nu$ , where
  - $\nu = l_m (\Lambda_0 k)^{1/2}$  (1 1/2 order closure)
  - $S_{ij} = \partial u_i / \partial x_j + \partial u_j / \partial x_i$
- In the 1 1/2 order closure scheme we **prescribe** the mixing length  $l_m$  as constant in the canopy, and increasing with height above.
- In the LES we can **diagnose** the mixing length and use this to test the closure assumptions.

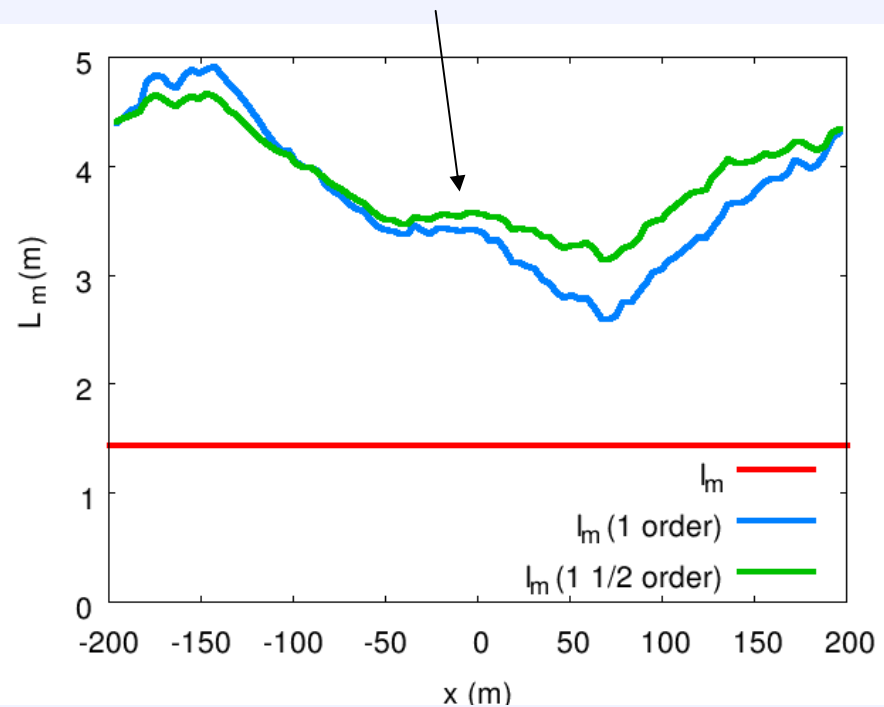
# Comparison of mixing length

Reduction in  $l_m$  over hill. Also observed in the Furry Hill wind tunnel expts of Wilson et al (1998).

Larger  $l_m$  within canopy. Not obvious in Furry Hill expts.



Canopy top (20m)

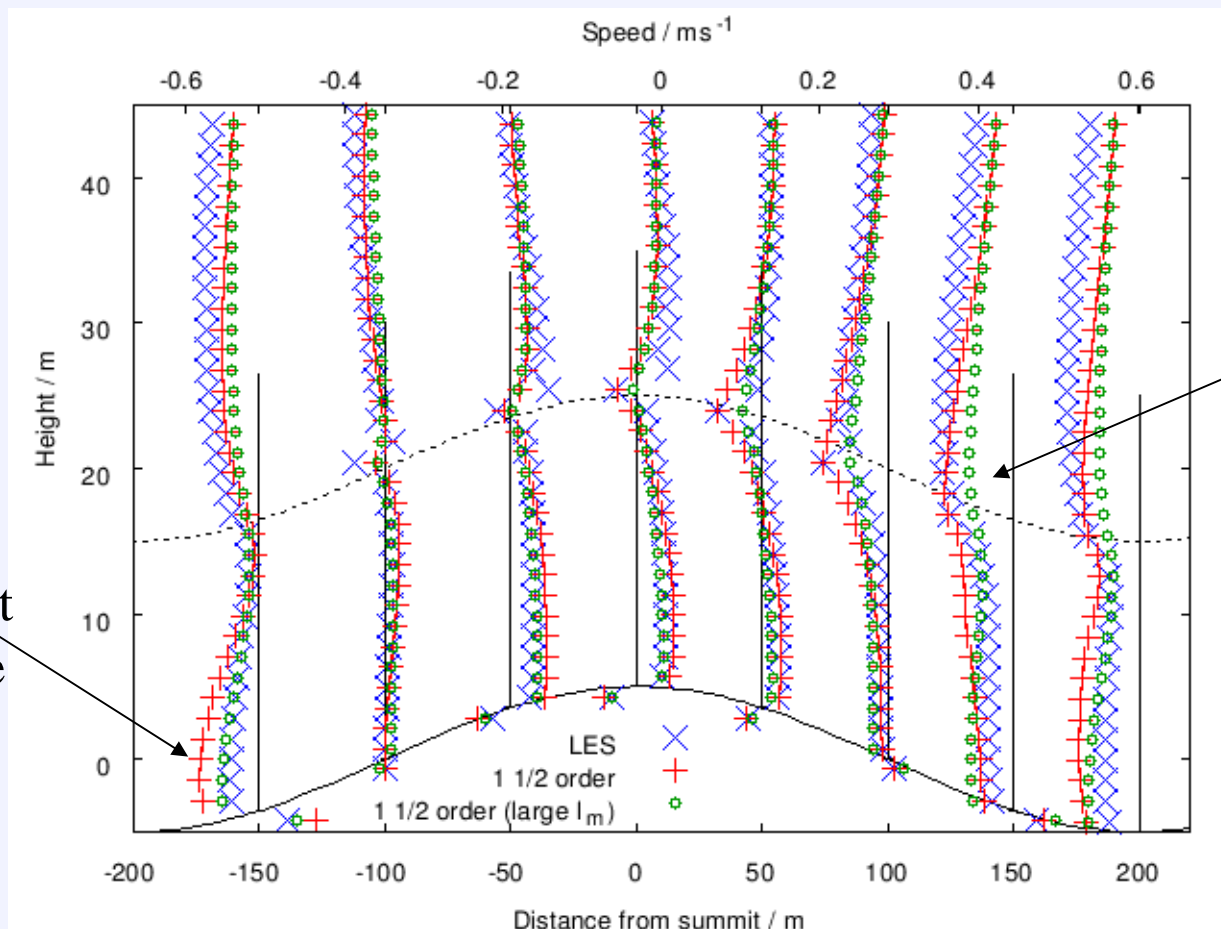


Mid canopy (16m)

# Simulations with a larger mixing length

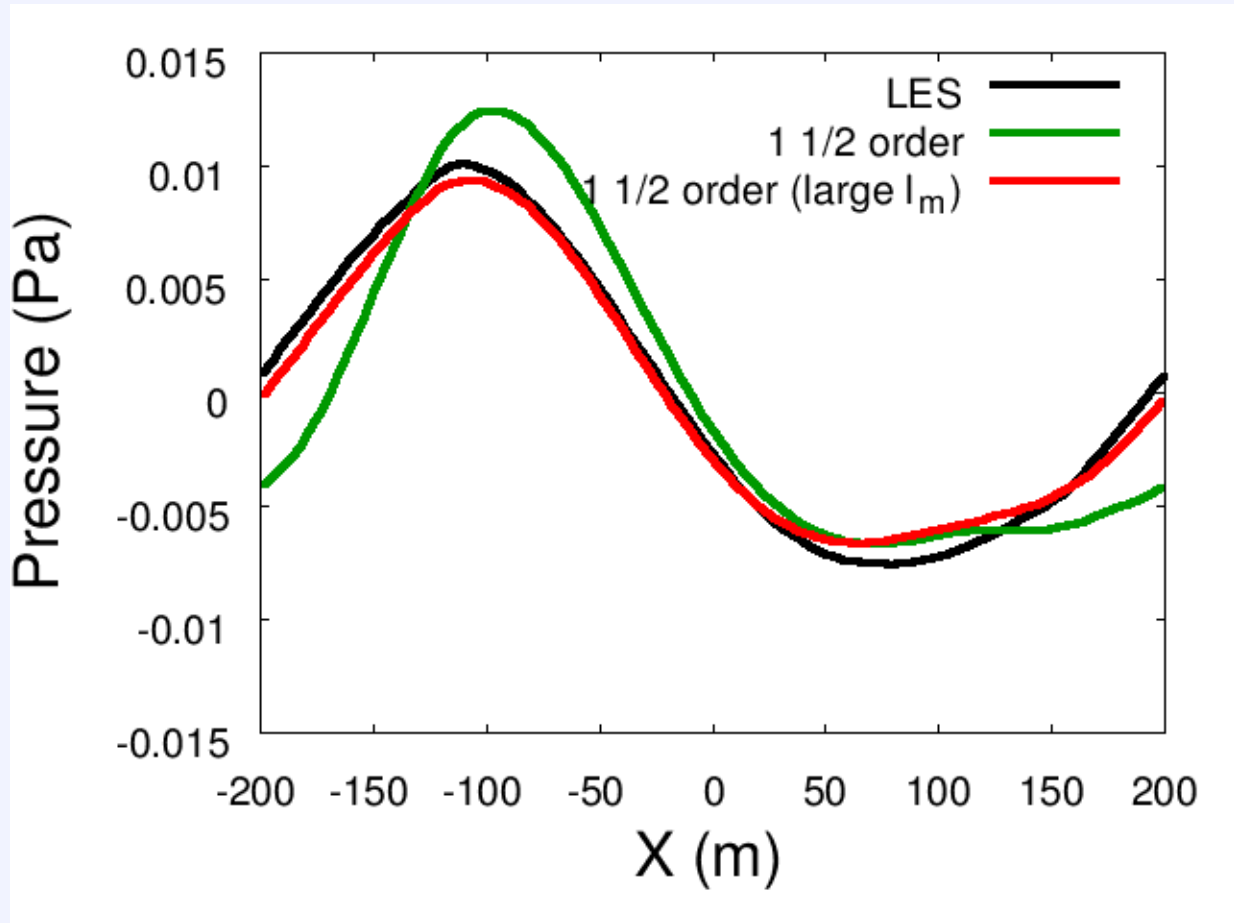
$l_m = 2.5\text{m}$   
within the  
canopy

Better  
agreement  
within the  
canopy



Still some  
problems in  
the lee of the  
hill

# Simulations with a larger mixing length



# Conclusions

- The presence of a forest canopy can significantly alter the near-surface flow over a hill. Inclusion of the dynamics of the canopy is important to properly model this. Inclusion of the canopy can lead to
  - Increased drag
  - Enhanced separation
  - Lower wind speeds

# Conclusions

- LES simulations provide a useful way of gaining more detailed information on the turbulence within and above the canopy.
- Based on these LES simulations there is some evidence that the mixing length used in the first order closure schemes may be too small.

# Future work

- Better closure schemes for inhomogenous canopies.
- Partially forested hills (a more practical problem in many locations).
- Extension of work to non-neutral flow, particularly for night-time drainage flows.
- Field measurements over forested hills