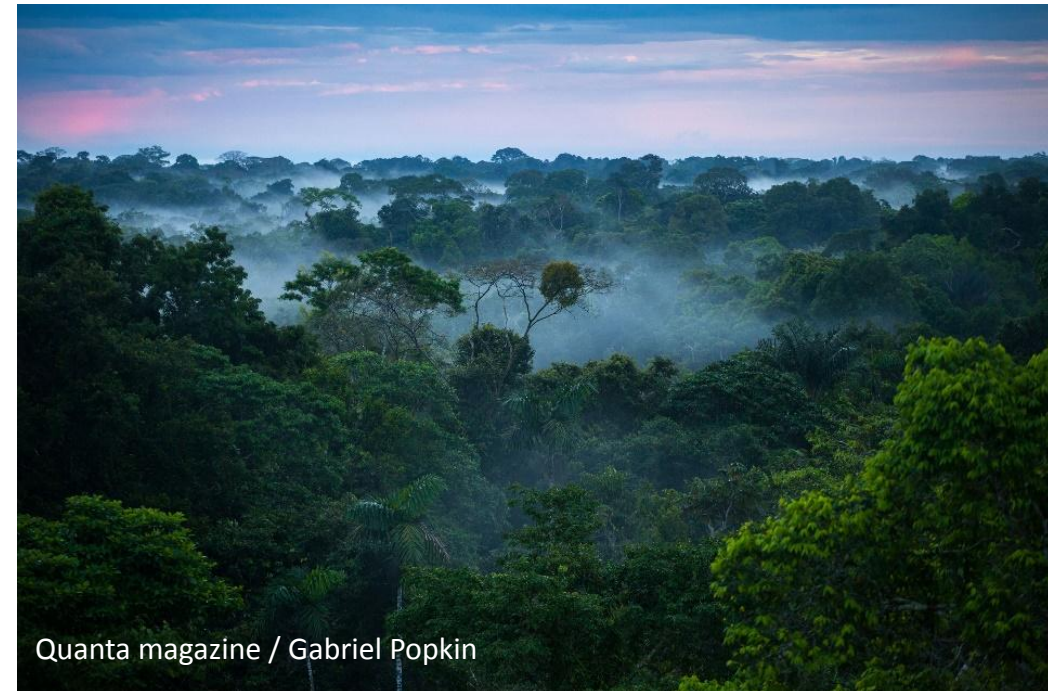


# Land-atmosphere flux exchanges and the land surface climate

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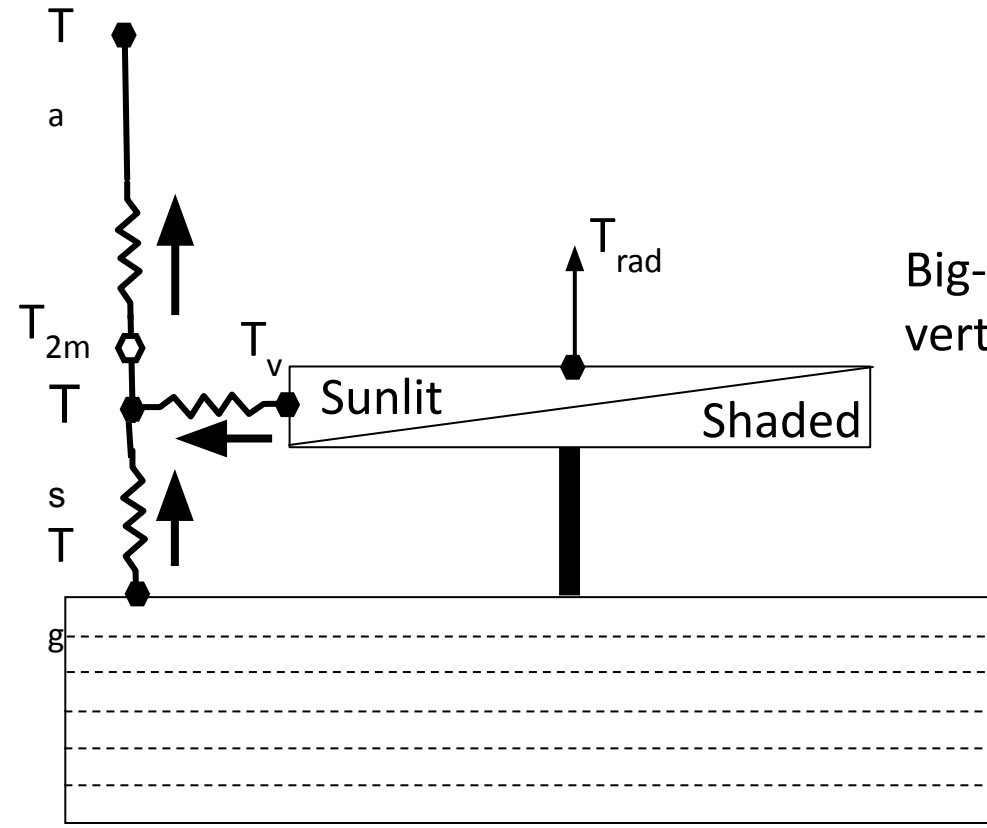
Where does the atmosphere stop and the land begin?



# CLM5 perspective of the land surface

Flux to atmosphere uses MOST

“Surface” is an imaginary height (where wind speed extrapolates to zero at  $d+z_0$ )



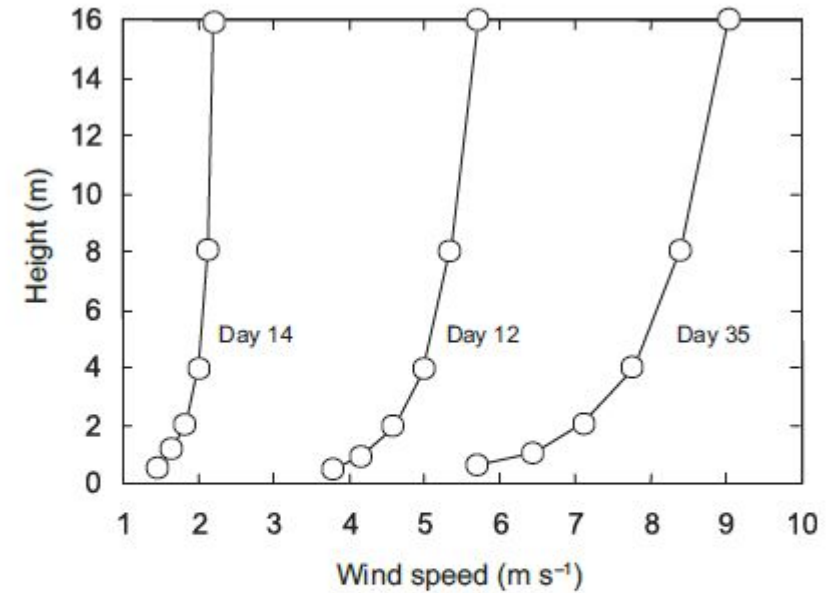
Big-leaf canopy without vertical structure

Soil/snow  
 12 snow layers  
 20 soil layers  
 5 bedrock layers  
 8.5 m deep

Deardorff (1978) JGR 83C:1889-1903  
 Dickinson et al. (1986) NCAR/TN-275+STR  
 Dickinson et al. (1993) NCAR/TN-387+STR

# Monin-Obukhov similarity theory

$$V_a = \frac{u_*}{k} \left[ \ln \left( \frac{z_{atm,m} - d}{z_{0m}} \right) - \psi_m \left( \frac{z_{atm,m} - d}{L} \right) + \psi_m \left( \frac{z_{0m}}{L} \right) \right]$$



**Figure 6.1** Wind profile above sparse grassland in southeastern Australia under near-neutral conditions measured at 1630 hours on days 12, 14, and 35 of the Wangara experiment. Data from Clarke et al. (1971) and reproduced from Bonan (2016).

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$$\theta_{atm} - \theta_s = \frac{\theta_*}{k} \left[ \ln \left( \frac{z_{atm,h} - d}{z_{0h}} \right) - \psi_h \left( \frac{z_{atm,h} - d}{L} \right) + \psi_h \left( \frac{z_{0h}}{L} \right) \right]$$

$$q_{atm} - q_s = \frac{q_*}{k} \left[ \ln \left( \frac{z_{atm,w} - d}{z_{0w}} \right) - \psi_w \left( \frac{z_{atm,w} - d}{L} \right) + \psi_w \left( \frac{z_{0w}}{L} \right) \right]$$

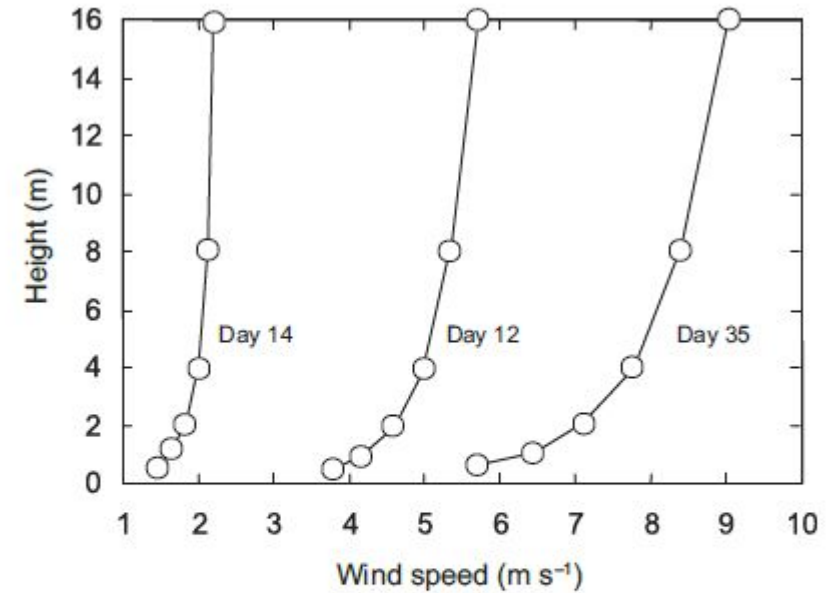
## Definitions:

$z_{atm}$  is the height corresponding to  $V_a$ ,  $\theta_{atm}$ , and  $q_{atm}$

$u(z) = 0$  at  $z_0 + d$

$\theta(z) = \theta_s$  at  $z_0 + d$

$q(z) = q_s$  at  $z_0 + d$



**Figure 6.1** Wind profile above sparse grassland in southeastern Australia under near-neutral conditions measured at 1630 hours on days 12, 14, and 35 of the Wangara experiment. Data from Clarke et al. (1971) and reproduced from Bonan (2016).

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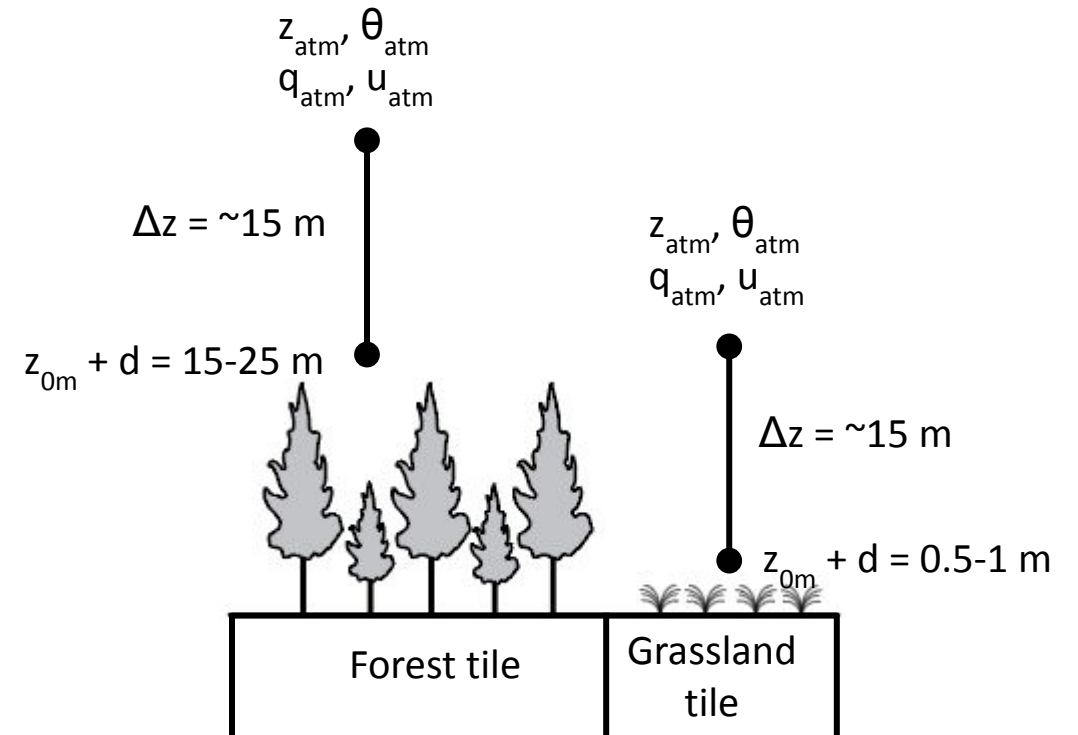
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The atmospheric reference height received from CAM  $z'_{atm}$  is assumed to be the height above the surface as defined by the roughness length  $z_0$  plus displacement height  $d$ :

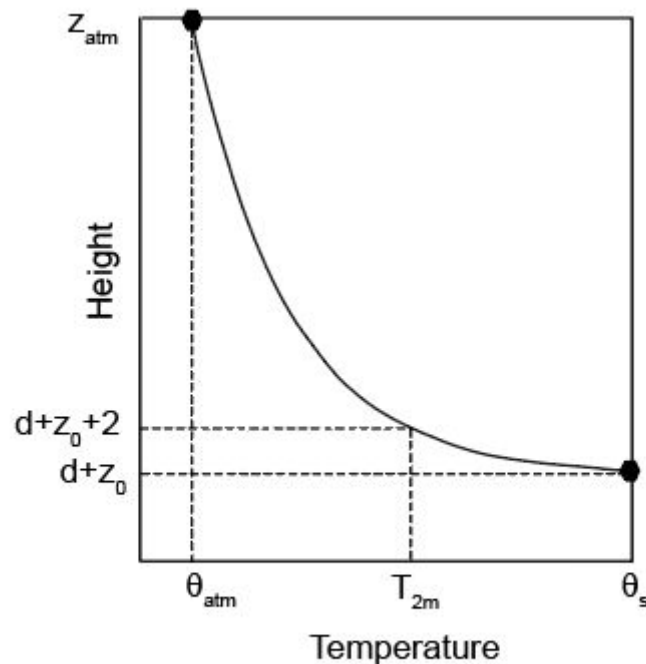
$$z_{atm} = z'_{atm} + (z_{0m} + d)$$

$z_{0m} + d$  is the theoretical height at which  $u(z)=0$



# Surface quantities

“2-m” is defined as 2 m above the apparent sink ( $z_0 + d$ ) to diagnose  $T_{2m}$  and  $q_{2m}$



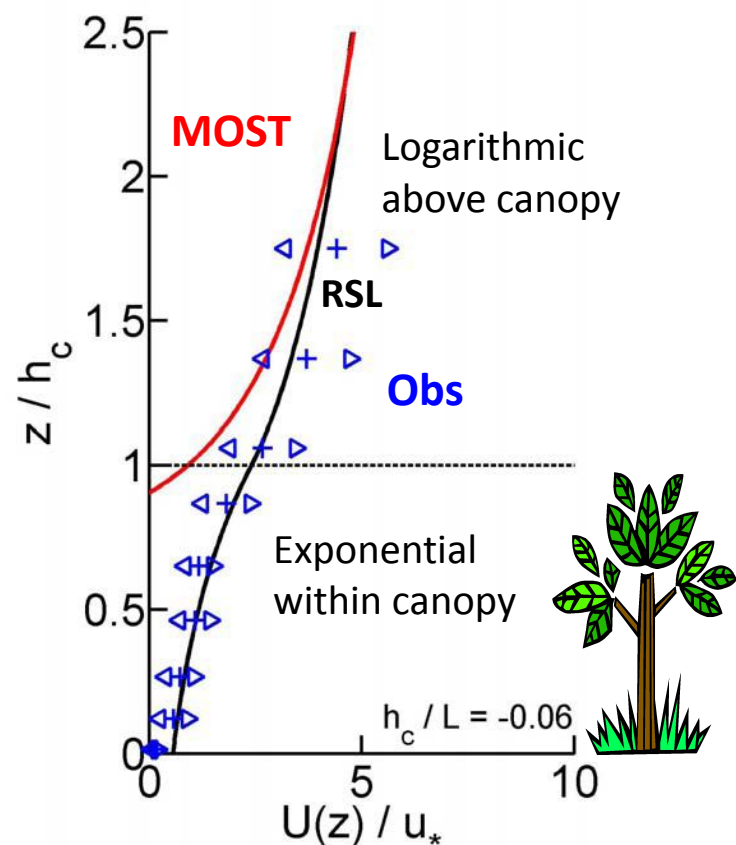
“10-m wind” is defined as 10 m above the apparent sink for momentum ( $z_0 + d$ ):

$$u_{10m} = V_a - \frac{u_*}{k} \left[ \ln \left( \frac{z_{atm, m-d}}{10+z_{0m}} \right) - \psi_m \left( \frac{z_{atm, m-d}}{L} \right) + \psi_m \left( \frac{10+z_{0m}}{L} \right) \right]$$

# Roughness sublayer theory

CLM (and most other models) use MOST, which fails above and within tall plant canopies

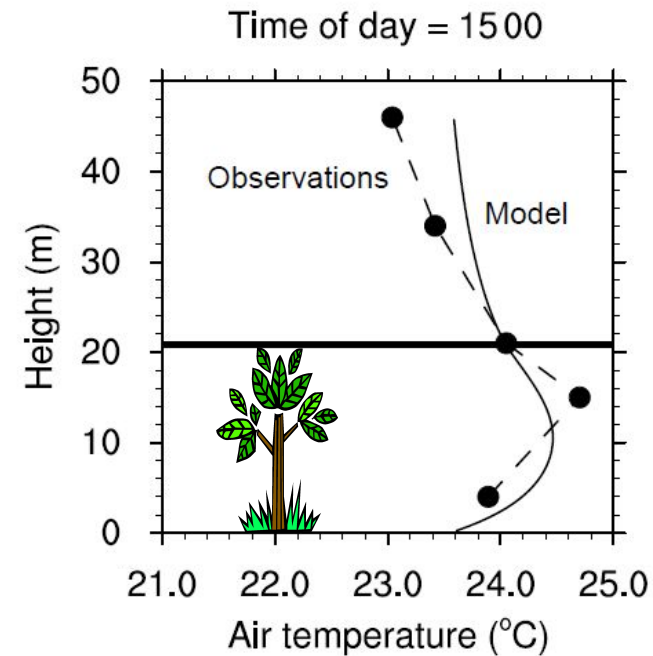
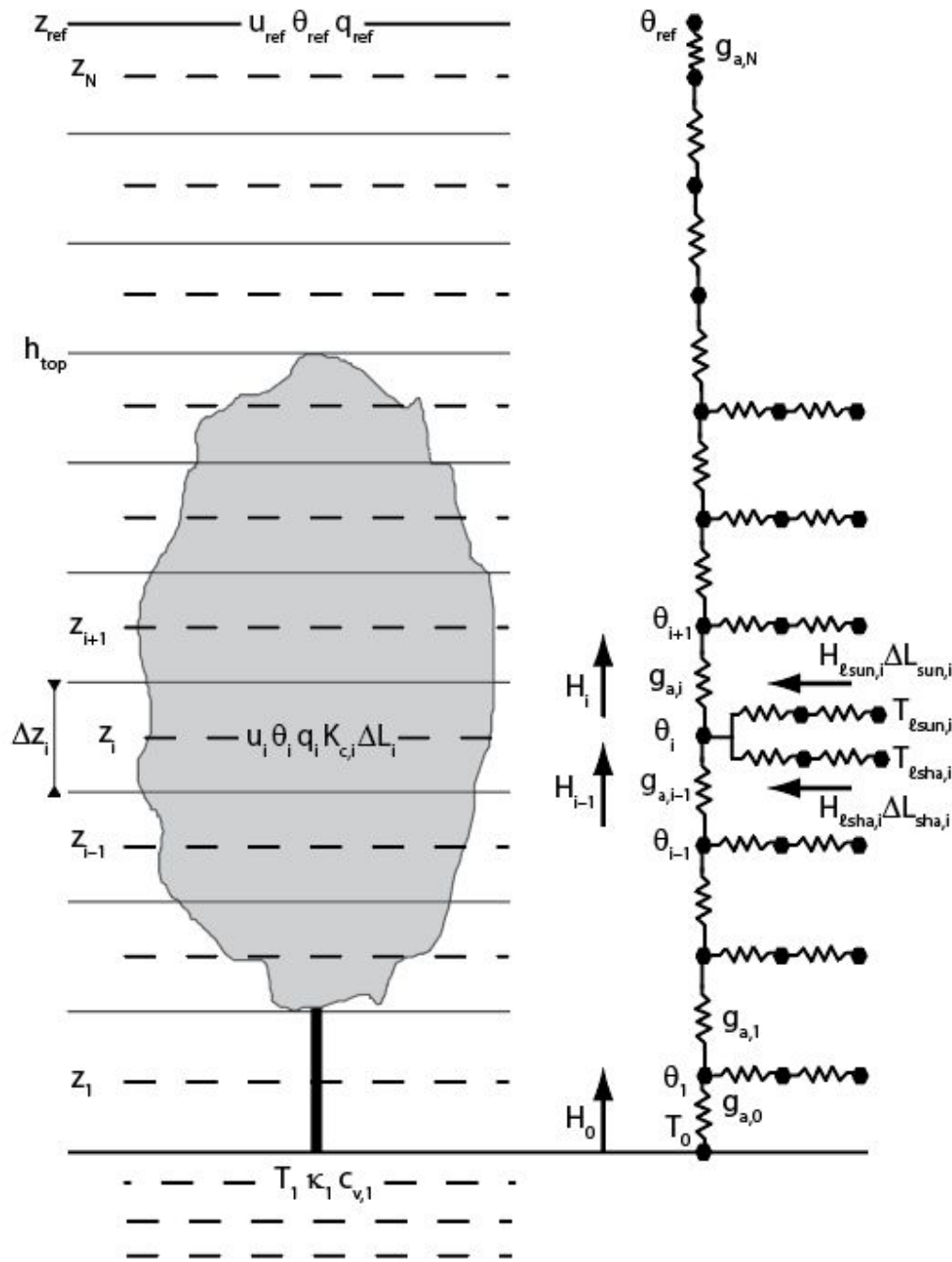
## CSIRO flux station near Tumbarumba



# Multilayer canopy

The physics and physiology of the multilayer canopy are simpler and more consistent with theory (and directly observable) than is the CLM5 big-leaf canopy (with many ad-hoc parameterizations and much technical debt), *and it also enables new science*

- Bonan, Williams et al. (2014) *Geosci. Model Dev.*, 7, 2193-2222
- Bonan, Patton, et al. (2018) *Geosci. Model Dev.*, 11, 1467-1496
- Bonan, Patton, et al. (2021) *Agric. For. Meteorol.*, 306, 108435

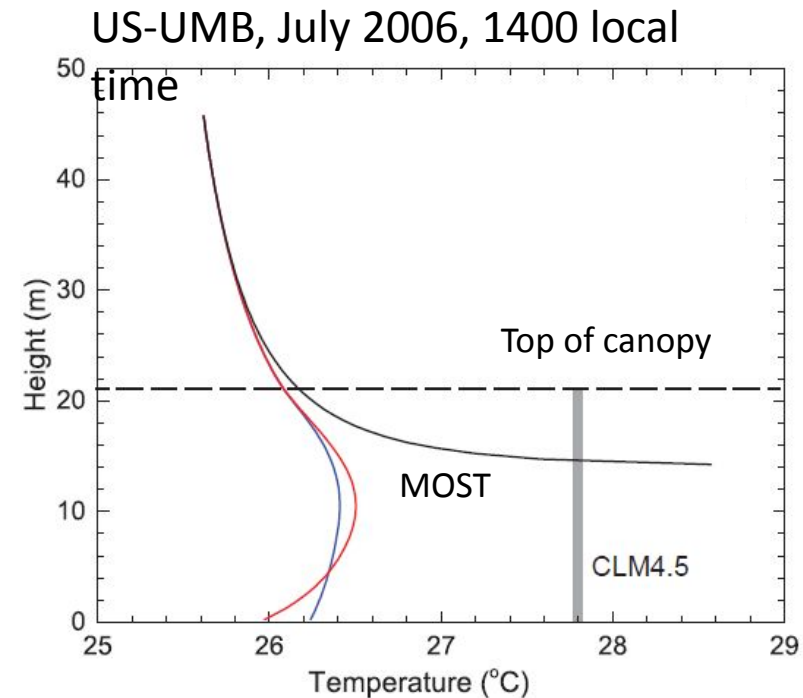
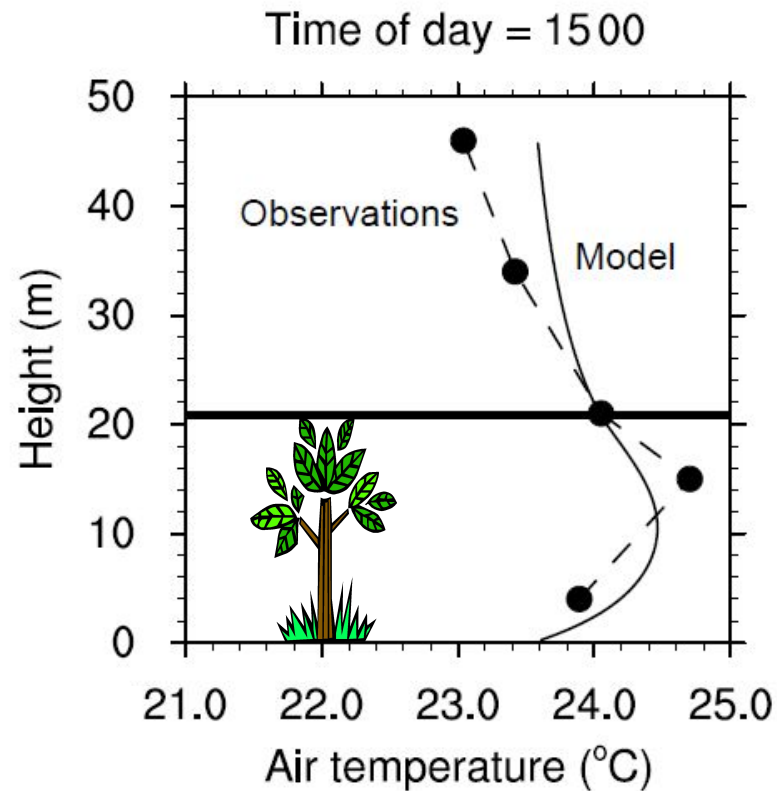


University of Michigan Biological Station

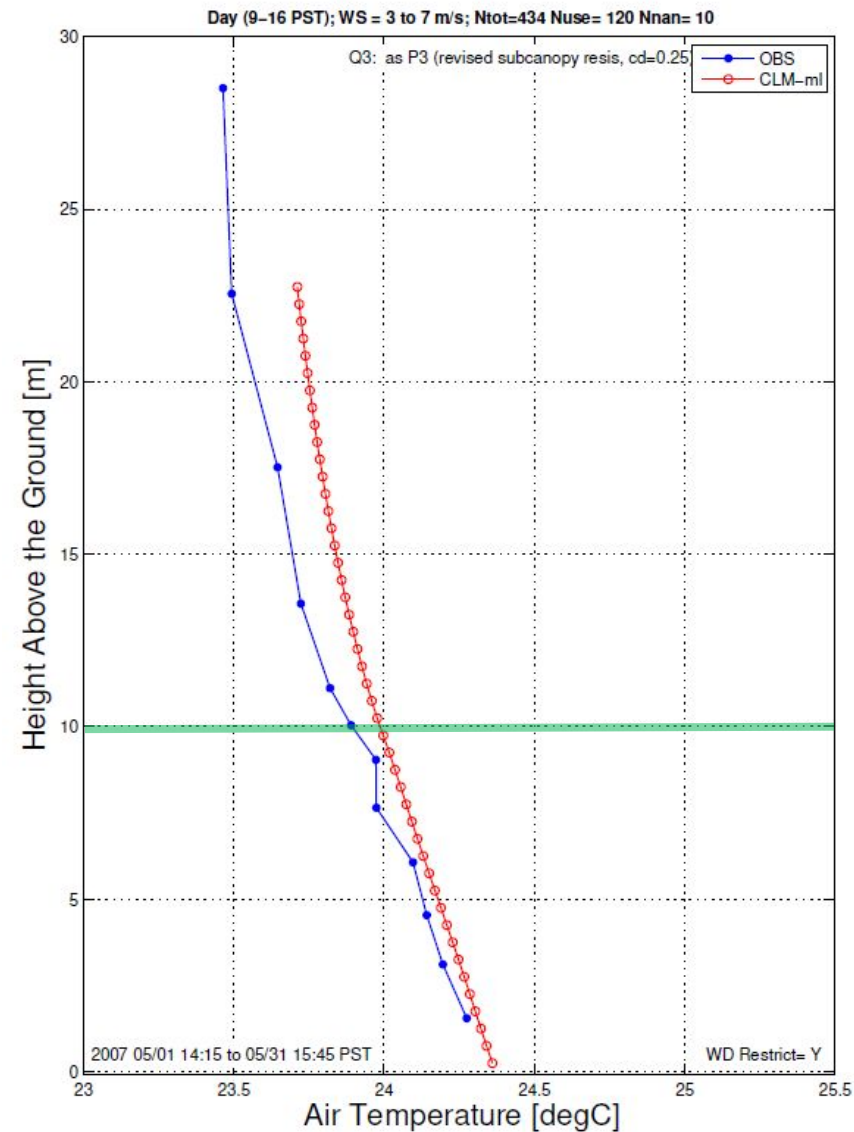
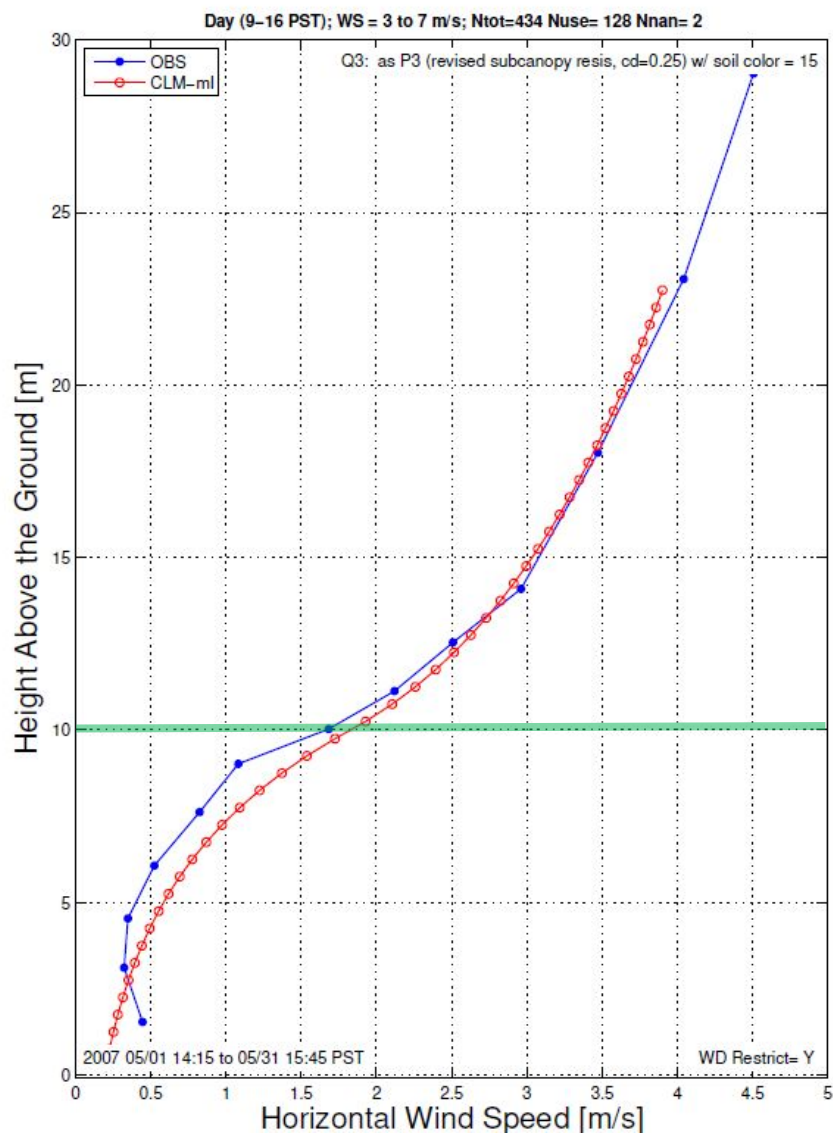


# Within canopy temperatures

US-UMB, July 2006  
(deciduous broadleaf  
forest)



# Vertical profiles within and above a walnut orchard



# Land in Earth system models



Where does the atmosphere stop and the land begin? Or, what is the “surface” in a land surface model?

