



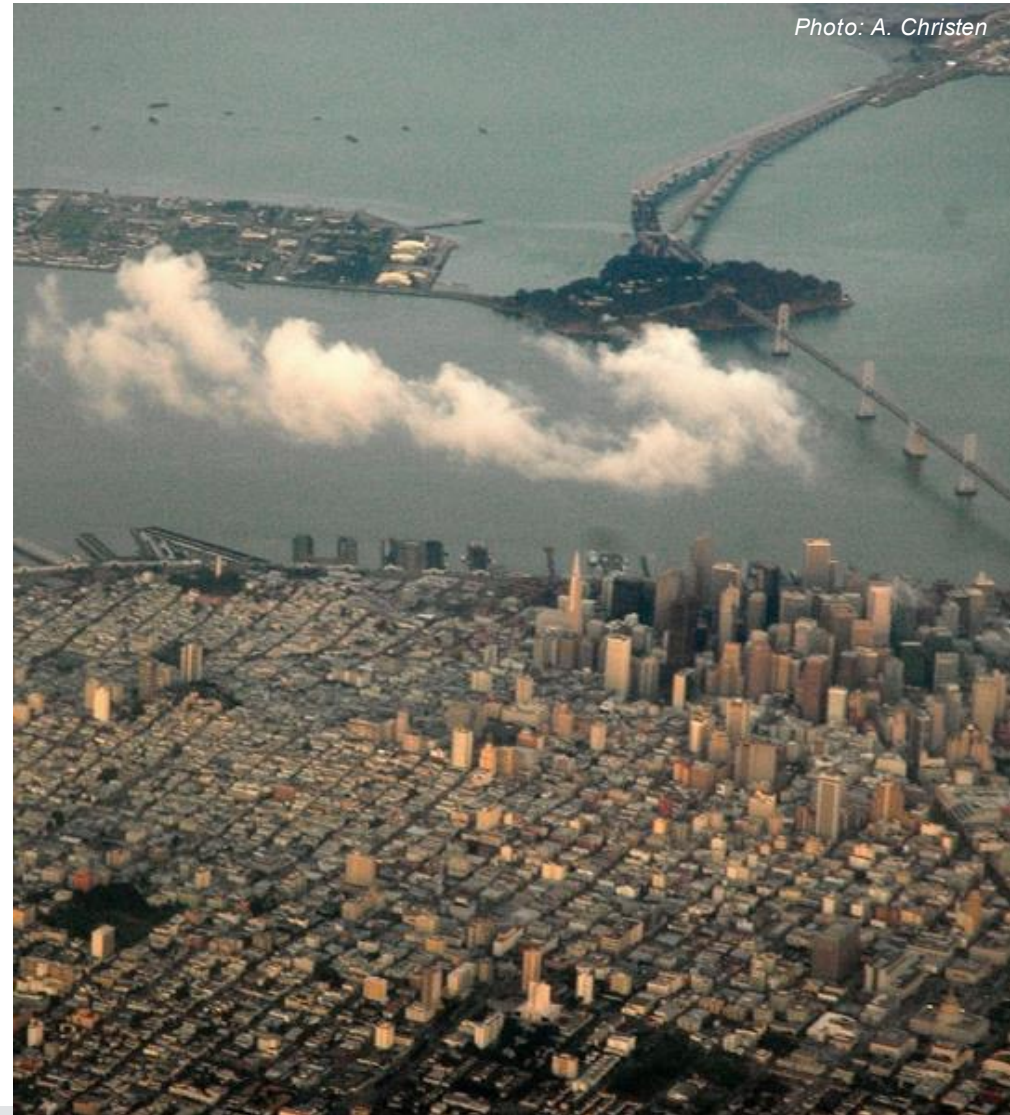
*Photo: R. Vogt, Univ. Basel*

## 27 Advection

# Today's learning objectives

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- Discuss when our 1-D assumption in micrometeorology isn't suitable.
- Explain what happens to the wind profile if we introduce horizontal changes in surface roughness.
- Describe how horizontal changes in surface properties affect the surface energy balance partitioning.

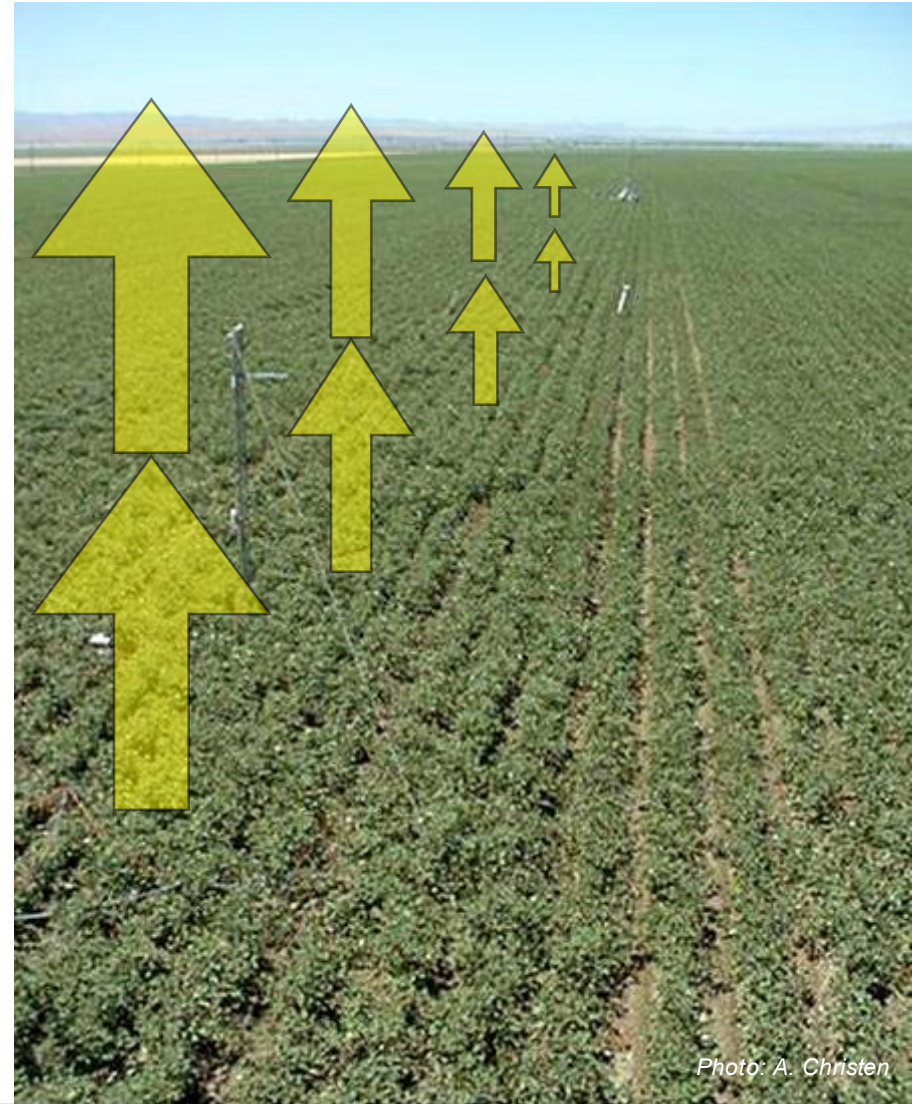


## 1-D view of surface layer.

It has been implicit in all derivations to this point that the **surface layer** of the ABL is a 'constant flux layer':

- Flux densities do not vary horizontally.
- Flux densities do not vary vertically.

This allowed us to assume that flux densities measurements made anywhere in the surface layer represented the surface value.



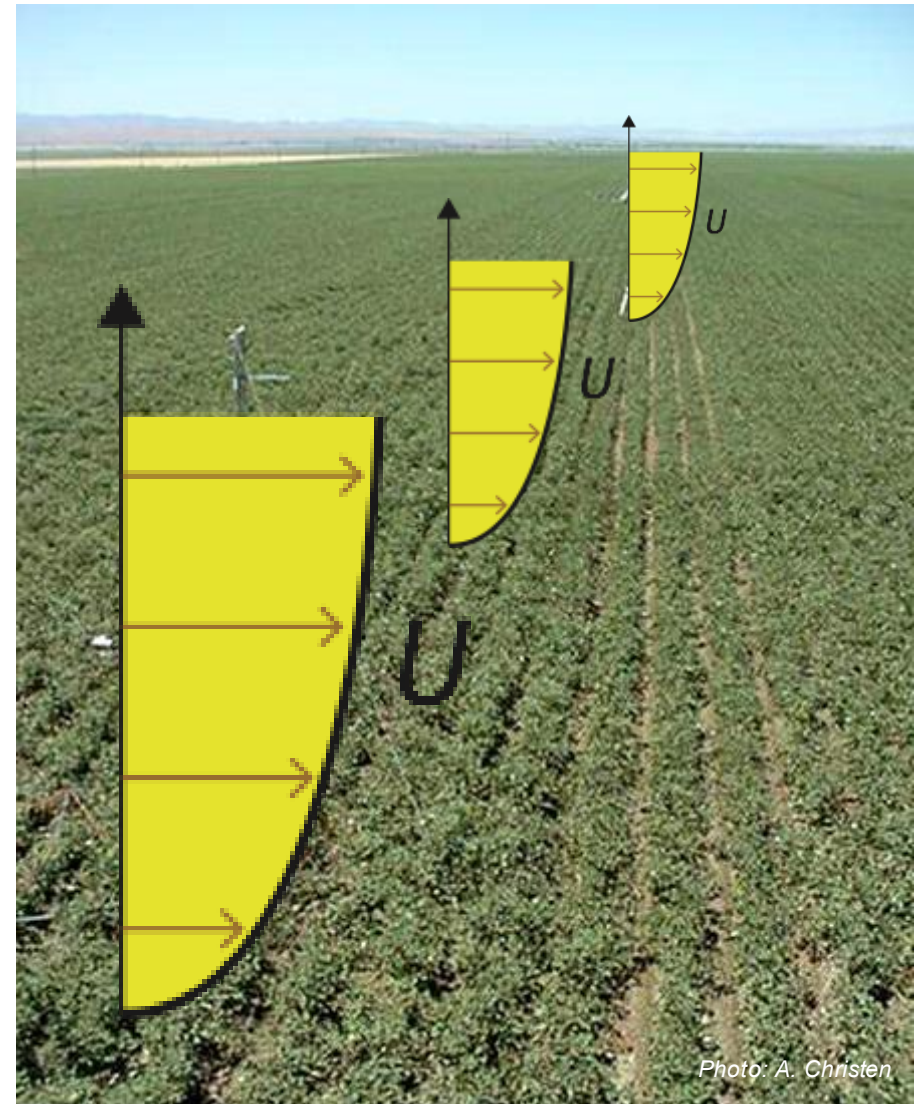
*Photo: A. Christen*

## 1-D view of surface layer.

It also allowed us to describe a one dimensional wind profile ('log-law')

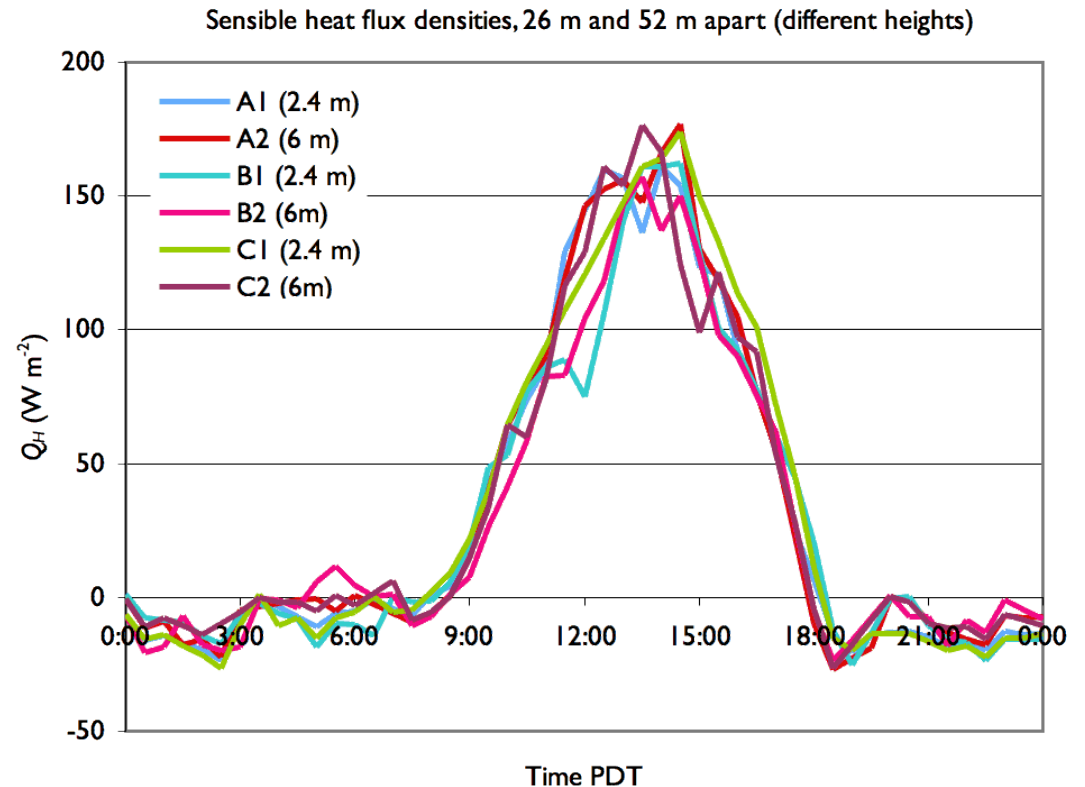
Wind is only a function of height  $z$ , it does not change with horizontal position.

Reynolds stress (expressed by  $u_*$ ) is constant with height.



## Variability in otherwise 'ideal' surface layer

Observations with eddy covariance instruments show that even over ostensibly 'ideal' flat, homogeneous and extensive sites, horizontal and vertical variability of  $\tau$ ,  $Q_H$ ,  $Q_E$  etc. is in the order of 5 to 10%.



Instruments within 50m horizontal distance (EBEX-2000)

# Inhomogeneous surfaces

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The real world is not made of 'infinite, homogeneous, plains'. It is a **patchwork** of different surfaces each with its own energy balance, roughness etc. Hence microclimates at the surface vary greatly, sometimes sharply, and often they are uneven, patchy, rolling etc.

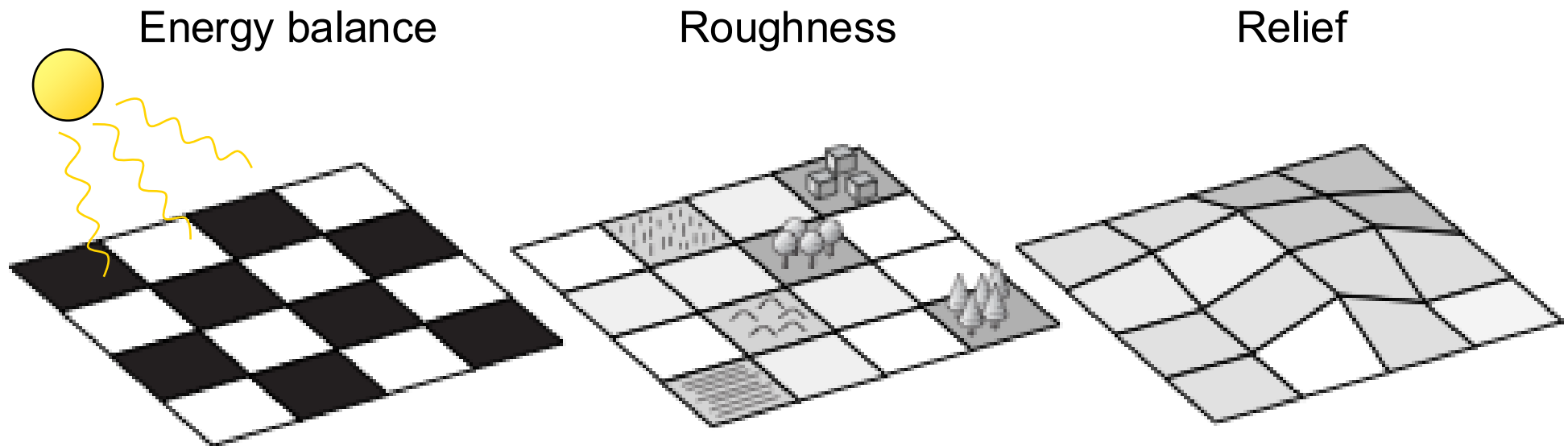




Photo: A. Christen

# The complex surface

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This is the geographical challenge of boundary layer climatology - a 3D reality.

We shall see how our idealized 1D world of micrometeorology has to be re-adjusted.

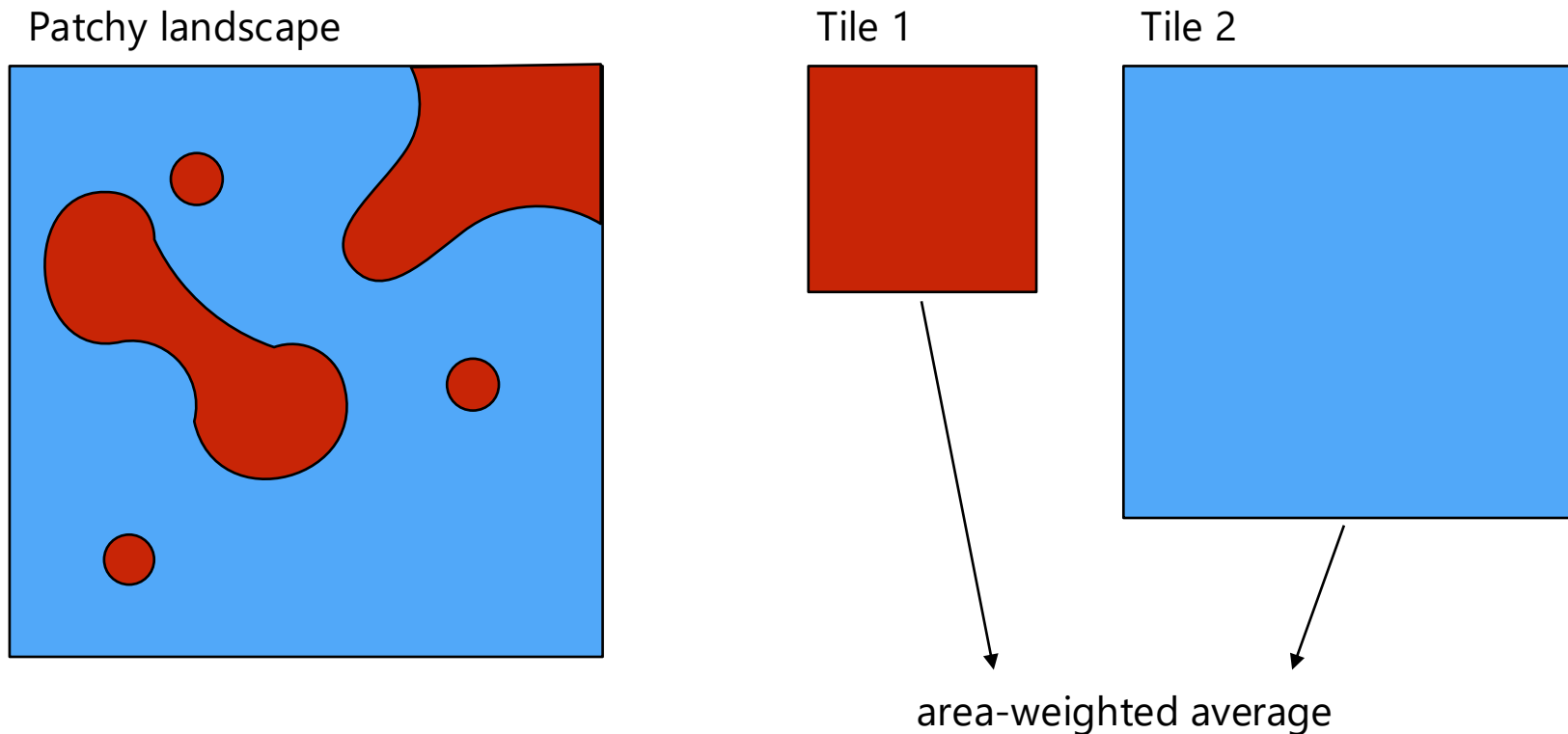
We start with the simplest 2D-steps in surface properties.



## Tile-approach used in weather forecasting

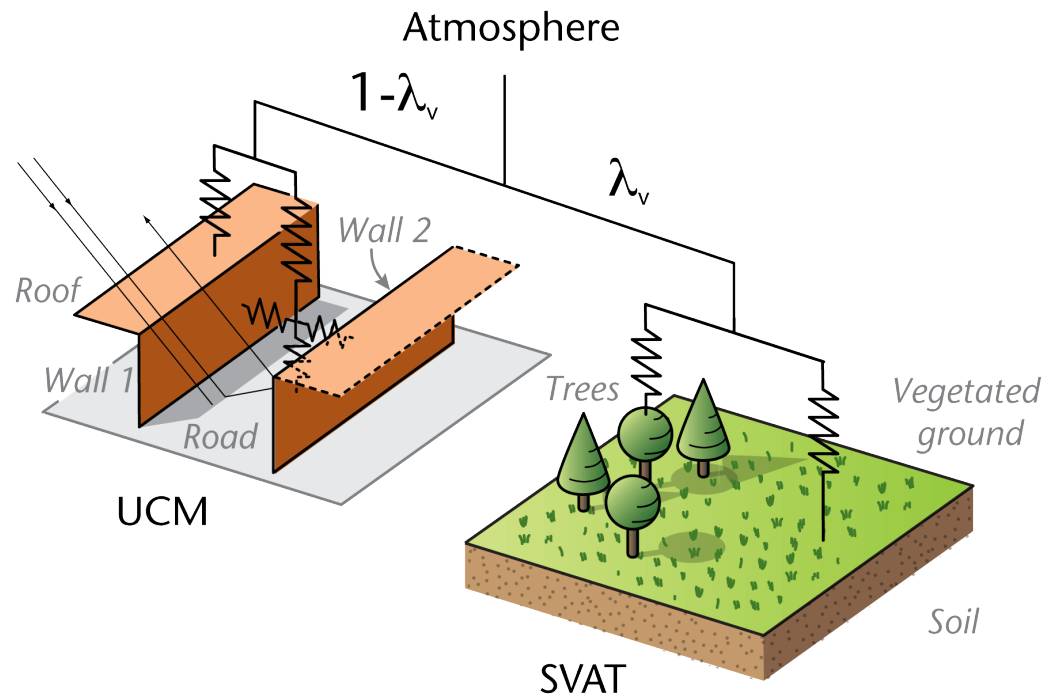
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In a 'tile approach' we calculate the exchange of different patches separately and then average them by fractional occurrence:

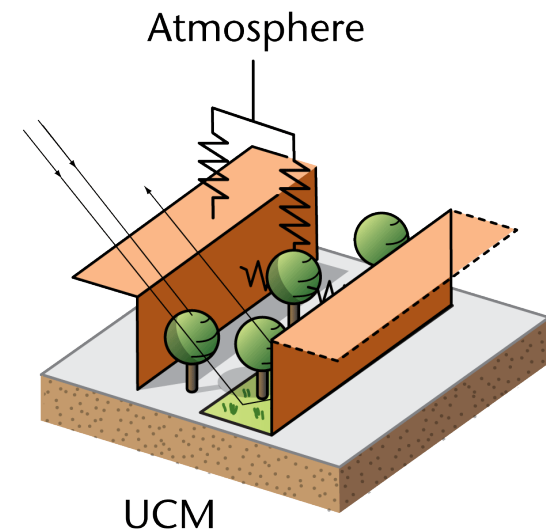


# Why the tile approach might not work

(a) 'Tile approach'



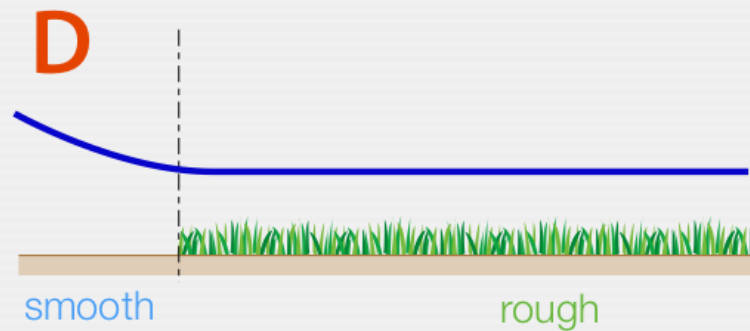
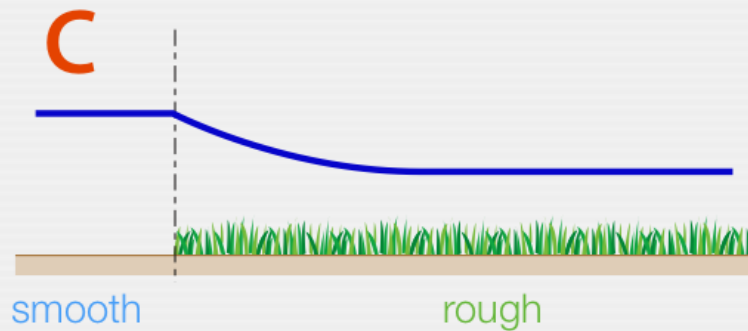
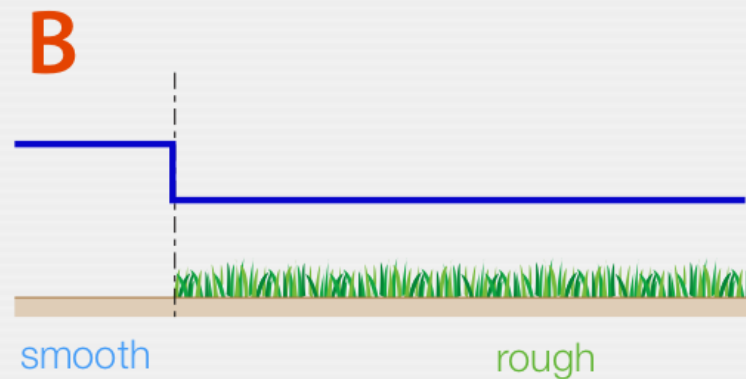
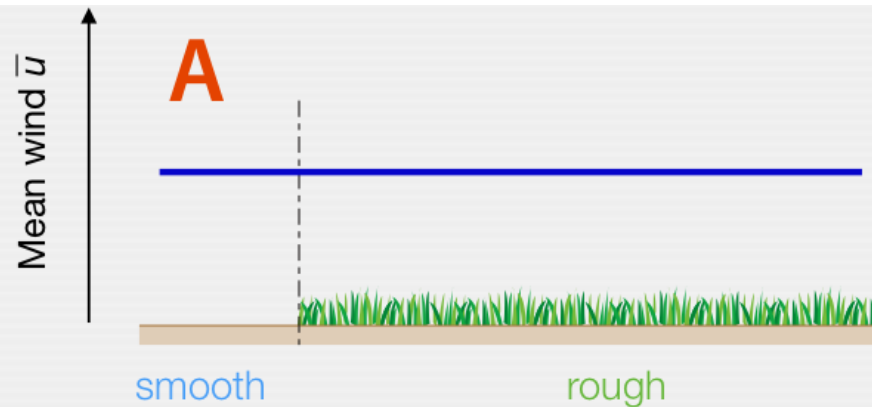
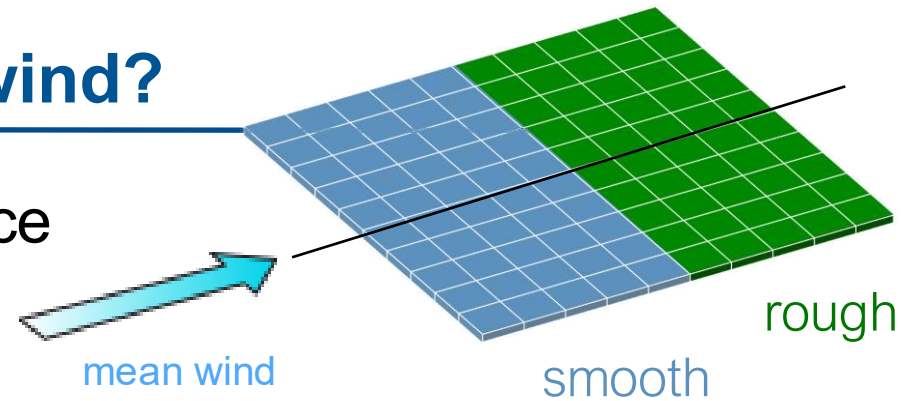
(b) Integrated vegetation



Soil-vegetation-atmosphere = SVAT  
Urban Canyon Models = UCM


# Change in roughness - effect on wind?

How does **mean wind  $\bar{u}$**  near the surface change for a transition from a smooth to a rough patch?



Join at:  
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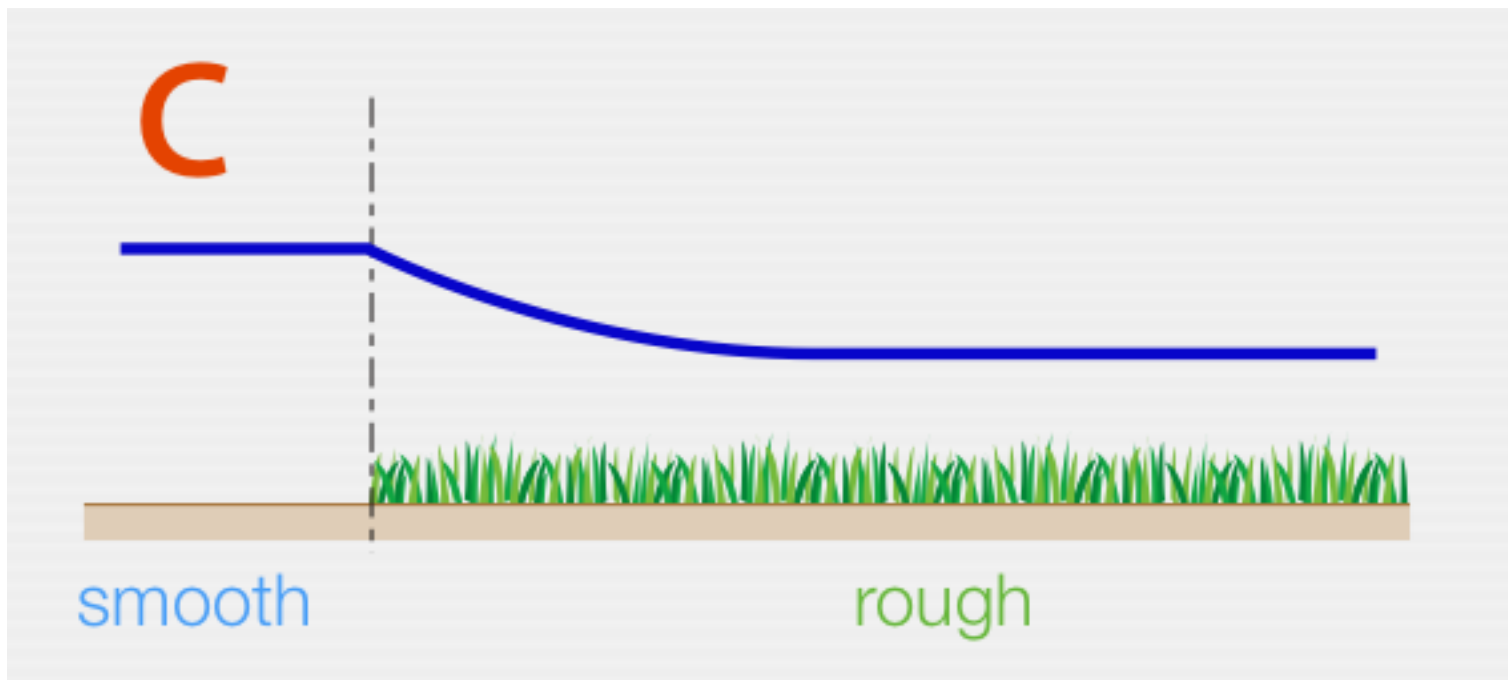
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## Mean wind is slowed.

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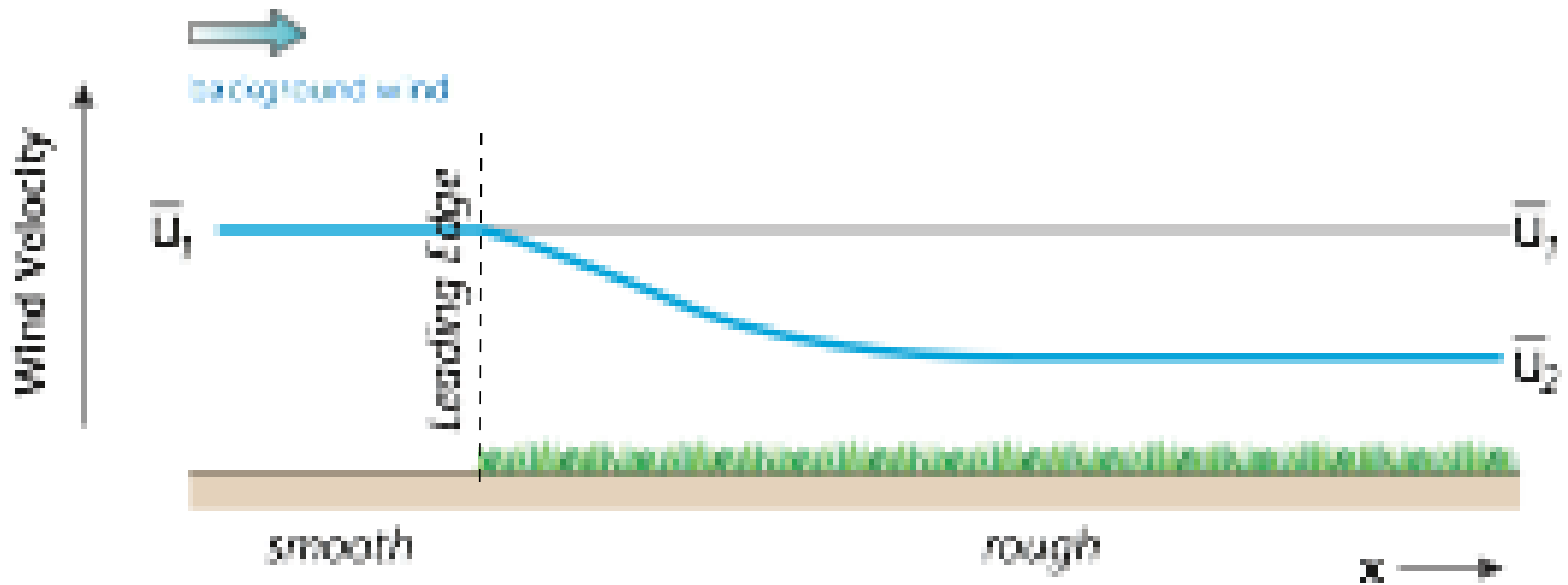
The correct answer is **C**. Mean wind will be slowed once it reaches the rough surface - but slowing does not happen immediately (inertia)



## Mean wind is slowed.

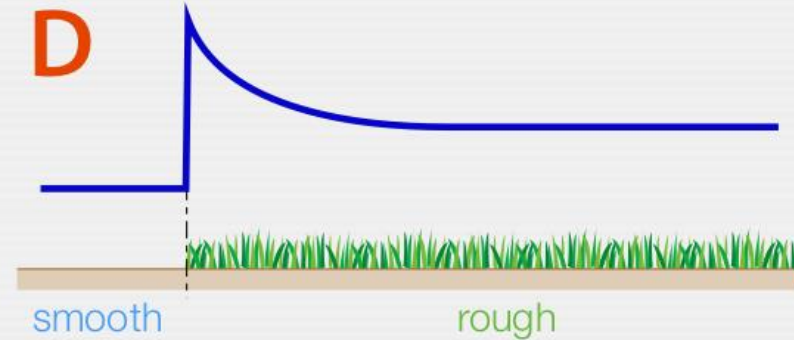
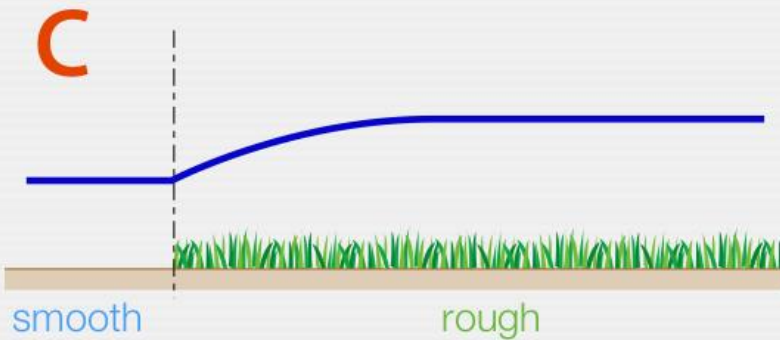
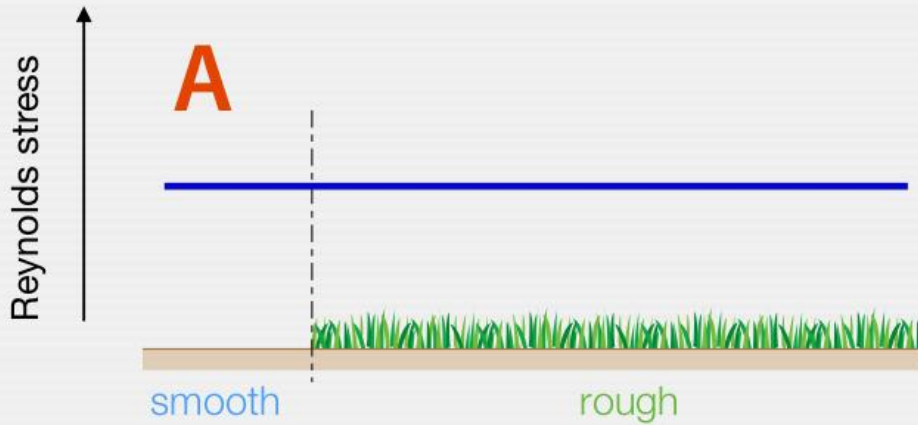
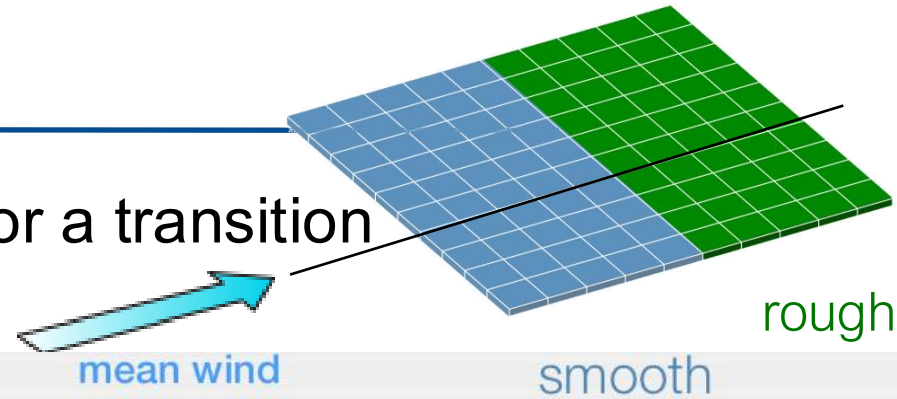
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The correct answer is **C**. Mean wind will be slowed once it reaches the rough surface - but slowing does not happen immediately (inertia)




# Change of Reynolds stress?

How does **Reynolds stress  $\tau$**  change for a transition from a smooth to a rough patch?



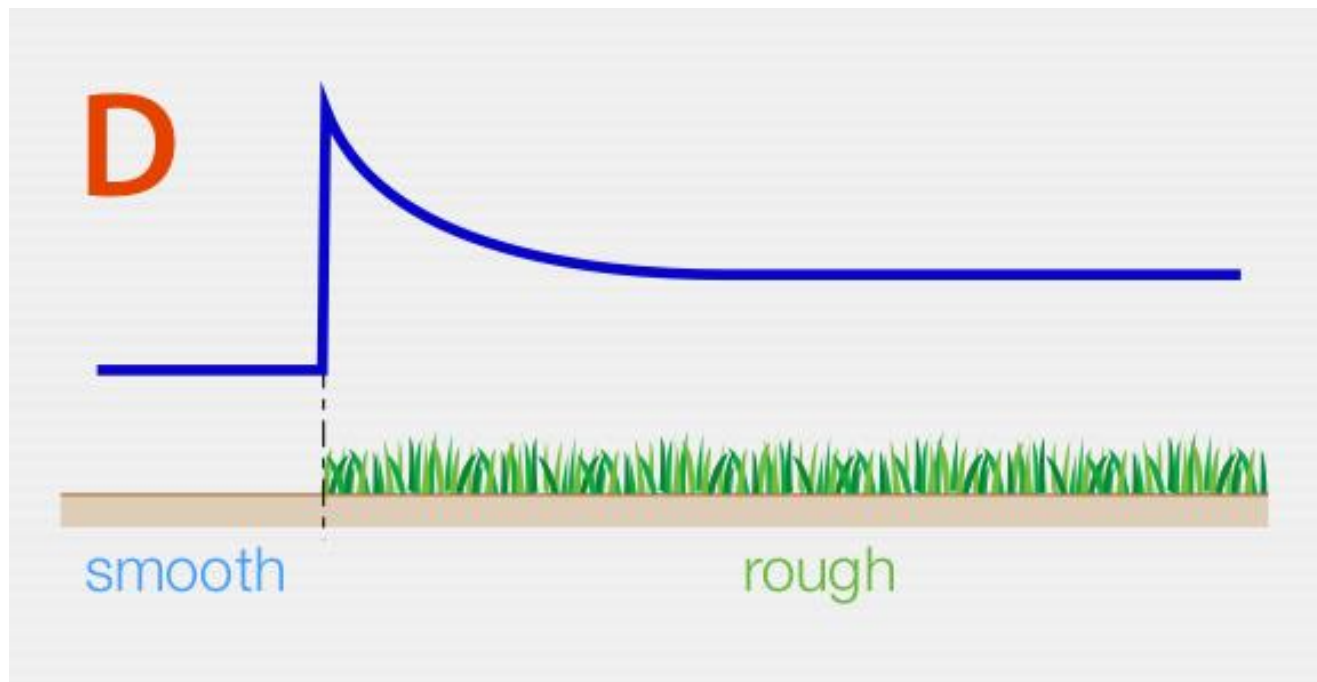
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## Reynolds stress is 'overshooting'.

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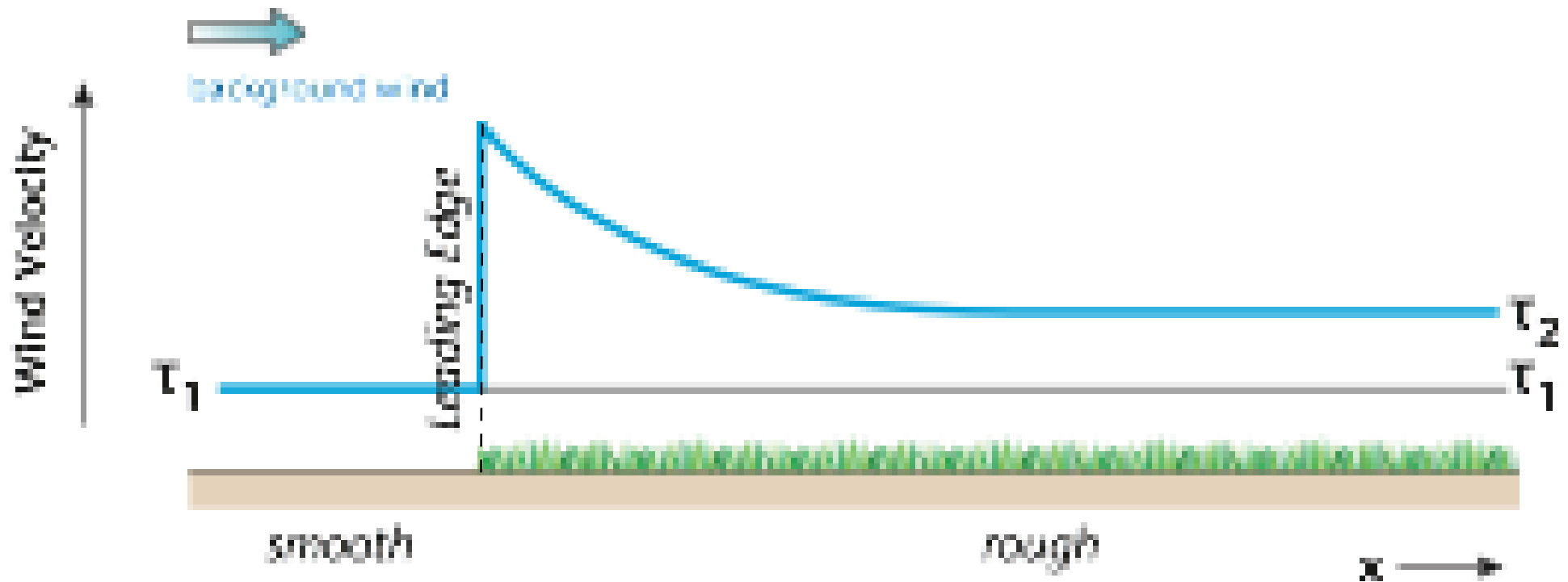
The correct answer is **D**. Reynolds stress  $\tau$  is strongest, where mean wind and roughness are high:



We conclude: Reynolds stress is '**overshooting**' and readjusts afterwards to its new value

## Reynolds stress is 'overshooting'.

The correct answer is **D**. Reynolds stress  $\tau$  is strongest, where mean wind and roughness are high:



We conclude: Reynolds stress is '**overshooting**' and readjusts afterwards to its new value  $\tau_2$ .

# Relevance of step-changes in landscapes.

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- ◀ Forest edges are generally more susceptible to damage



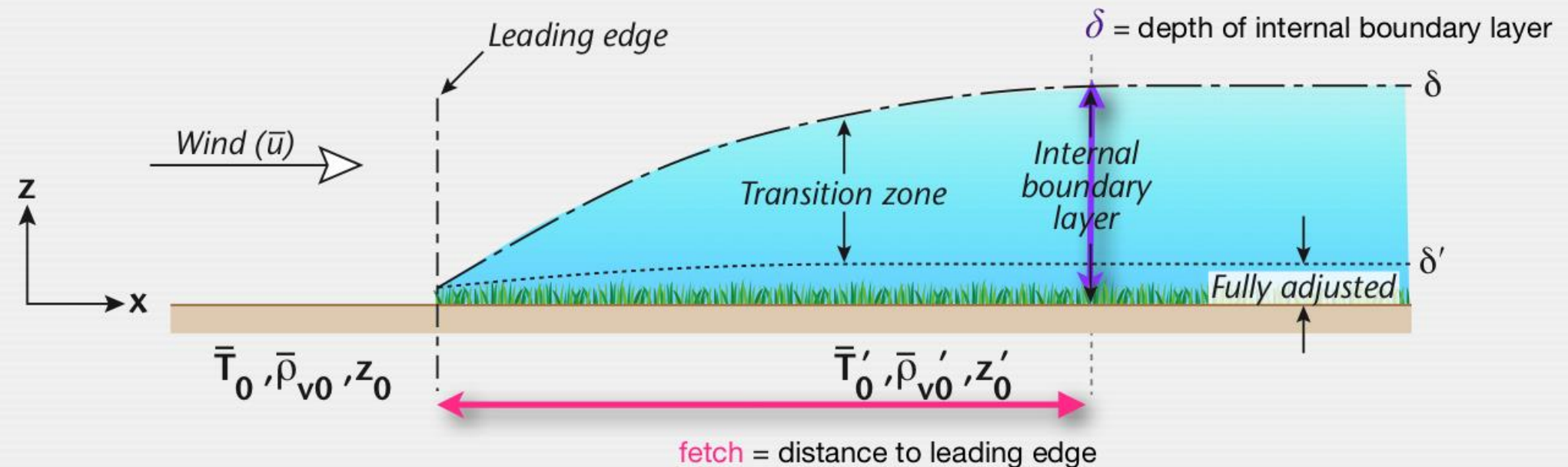
- ▲ Windbreaks protect crops from wind erosion and excessive Evapotranspiration (conserve water)

*Photos: A. Christen*

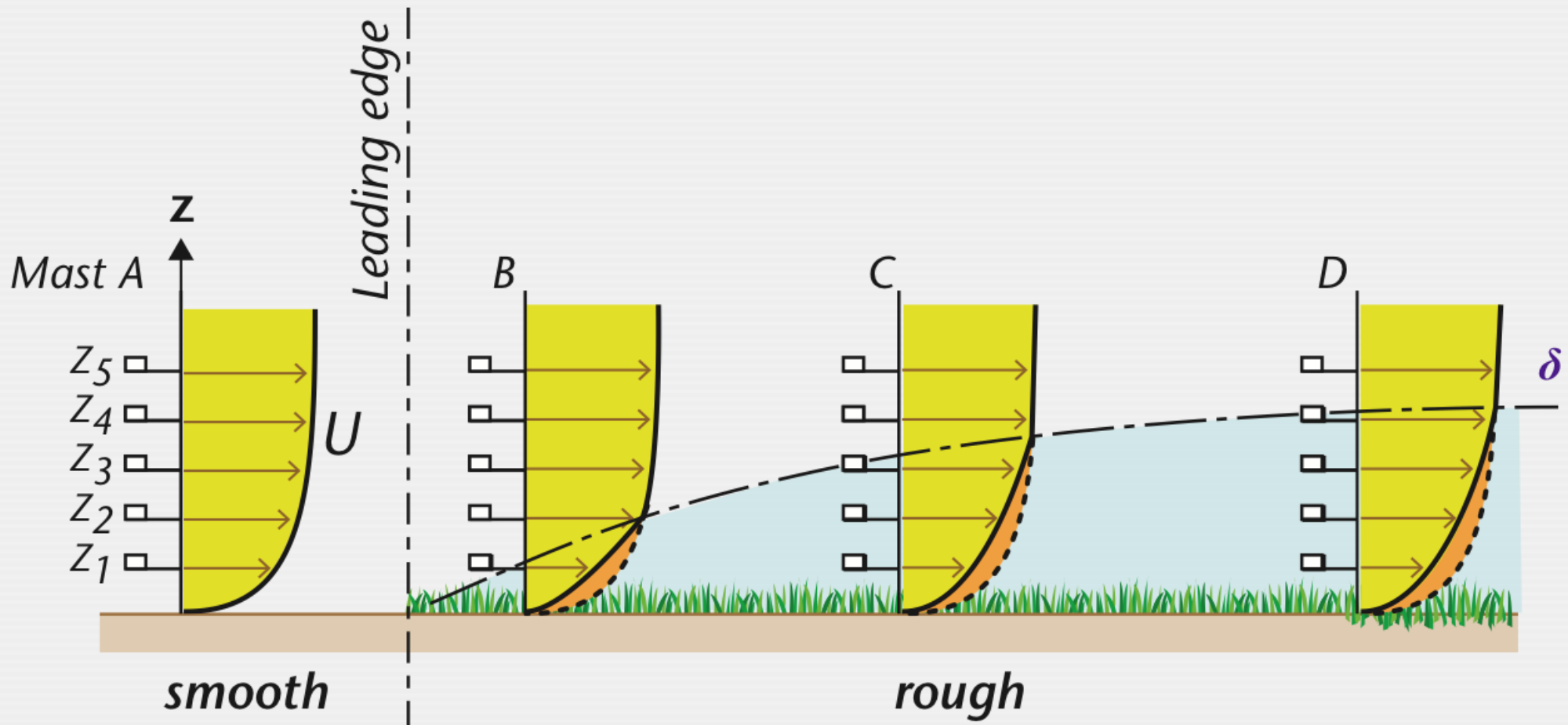
## Internal boundary layer.

As air crosses a sharp change in surface properties ( $z_0$ ,  $T_0$ ,  $\rho_{v0}$ , etc.) the air immediately above is affected (due to turbulent exchange) - the internal boundary layer.

Modification affects an even deeper layer ( $\delta$  - known as the **internal boundary layer depth**) at greater distances ( $x$  - known as **fetch**):

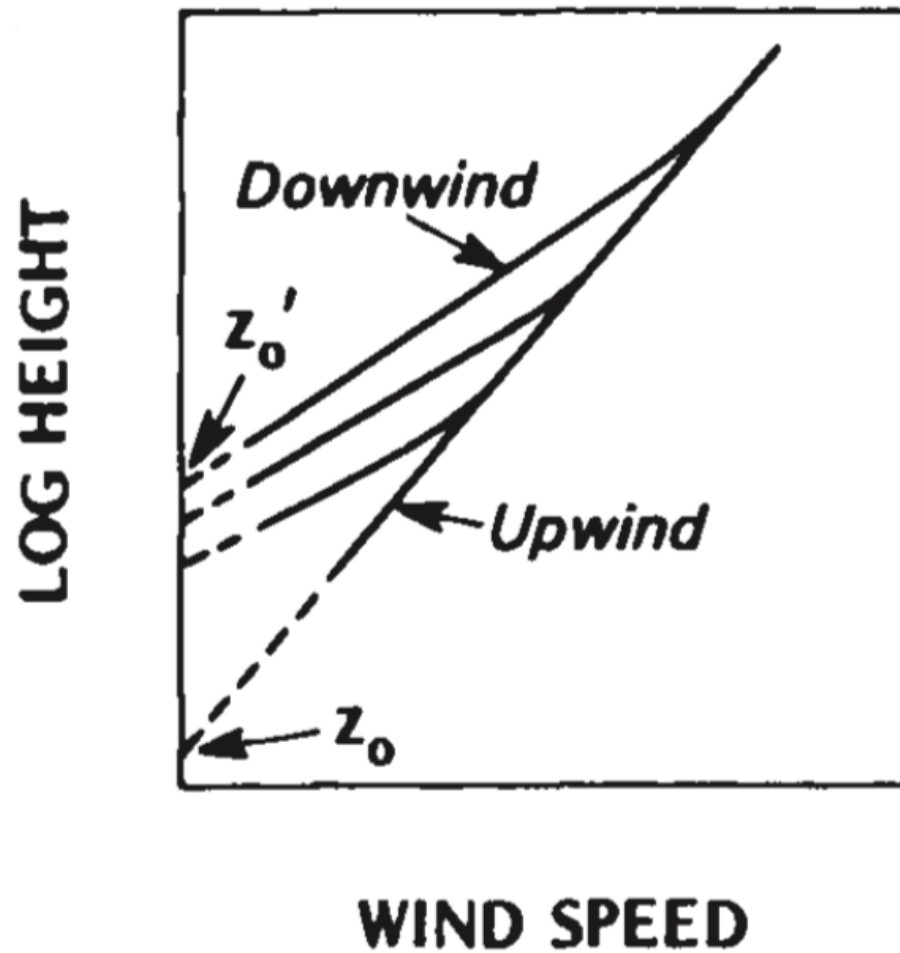


# Changes to the wind profile across a step change.

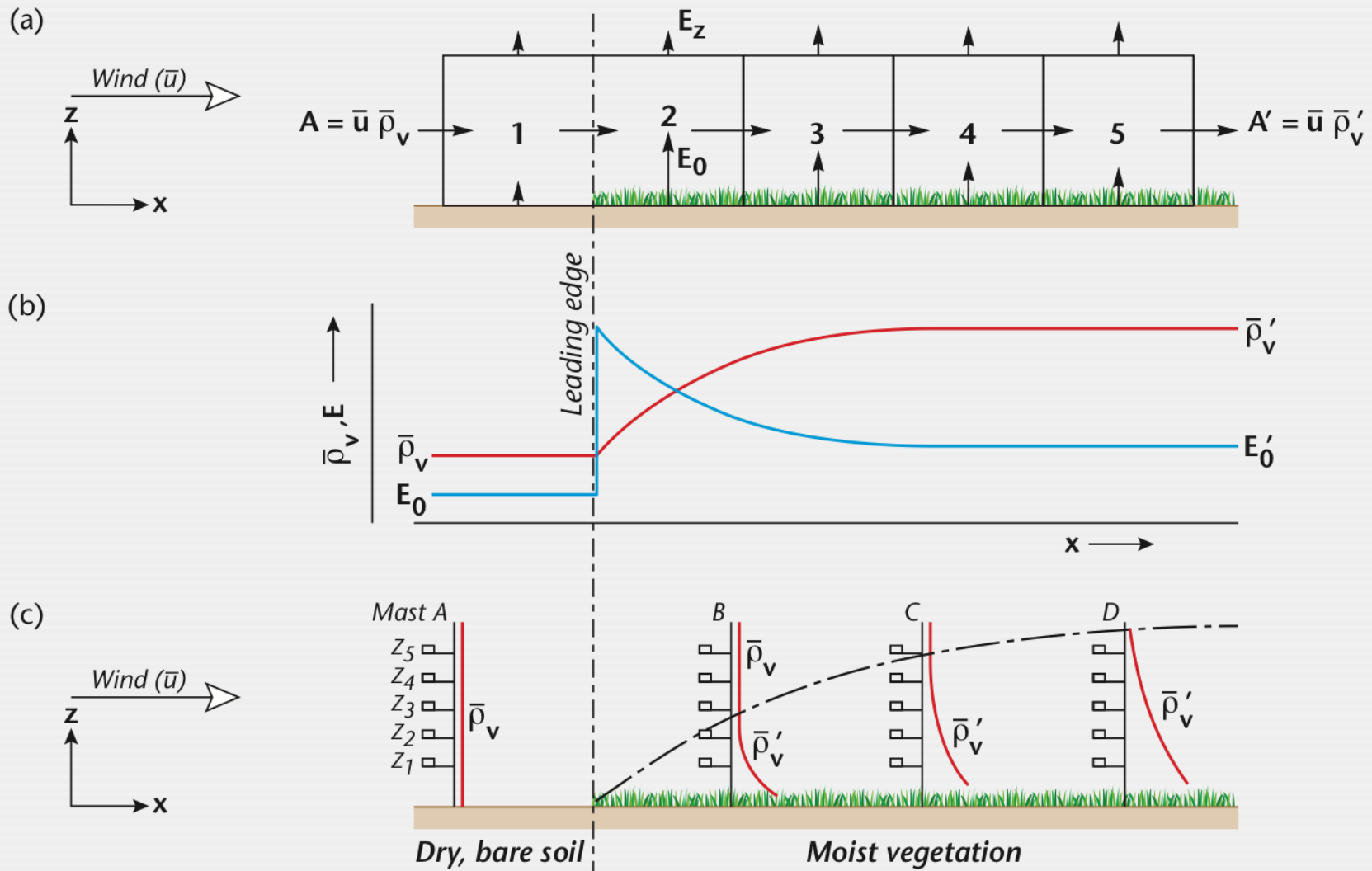


# Adjustment of wind profile

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# Changes in evaporation.



## Depth of the internal boundary layer

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Only the lowest 10% of the internal boundary layer depth  $\delta$  are fully in equilibrium with the new surface ( $\delta'$ ) and the rest ( $\delta - \delta'$ ) is in transition.

Common rule-of-thumb is that **height** to **fetch** ratio is  $\delta/x \approx 1:100$ .

A more accurate estimation is possibly by a power law:

$$\frac{\delta}{z_0(1)} = a_{IBL} \left( \frac{x}{z_0(1)} \right)^{b_{IBL}}$$

Empirical constant **a** (0.35 - 0.75)

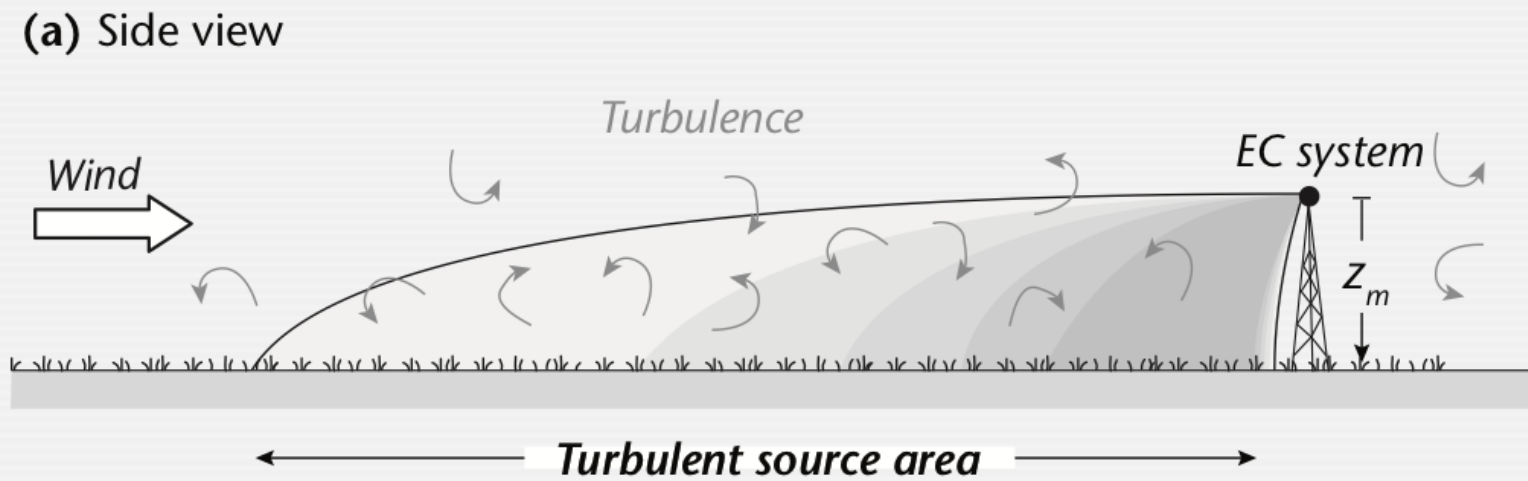
Empirical constant **b** (0.8 for neutral, and 0.6 to 0.7 for unstable)

## Depth of the internal boundary layer

The parameter  $a$  can be also framed as a function of both roughnesses:

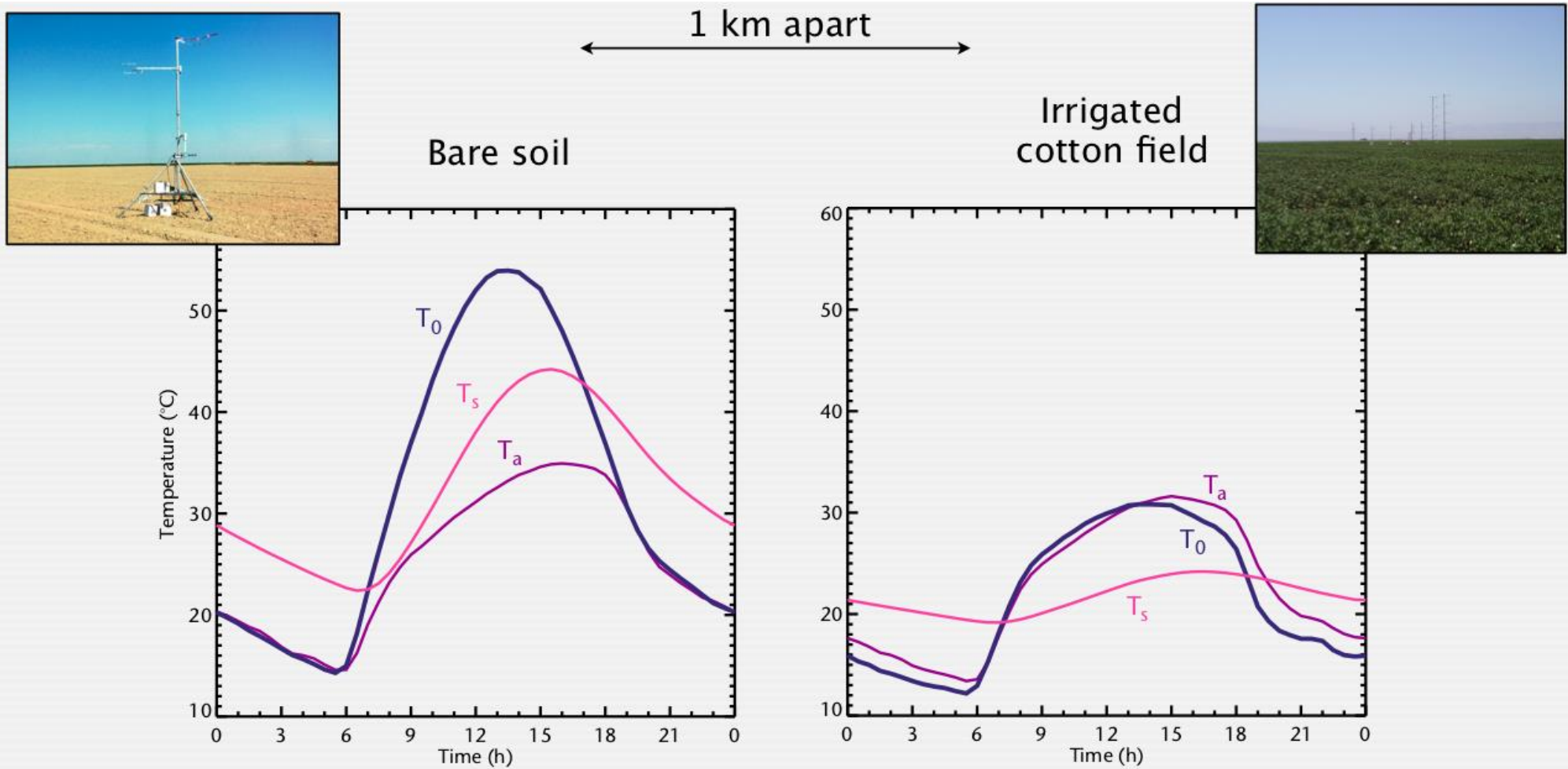
$$a_{IBL} = 0.75 + 0.03 \ln \left( \frac{z_{0(2)}}{z_{0(1)}} \right)$$

Knowledge of IBL is relevant to see what a sensor at height  $\delta$  measures:



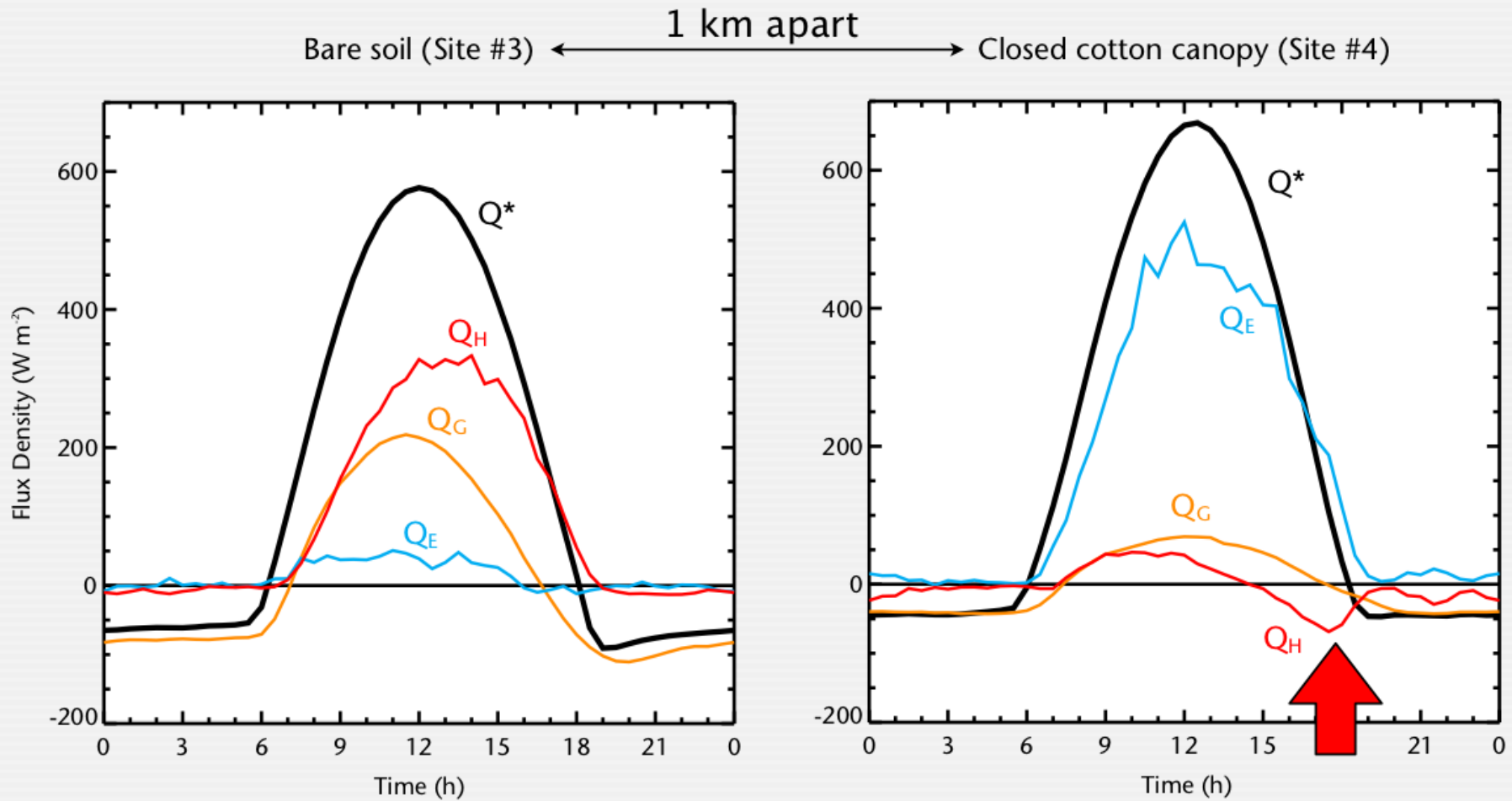


# Changes in the surface energy balance



Data from the National Center for Atmospheric Research's Integrated Surface Flux Facility / EBEX 2000 - August 15 to 21, 2000

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To measure evapotranspiration from the cotton field, would you want to place a micrometeorological tower at the edge of the field or in the middle

## Importance of:

- Fetch
- Source area



# Oasis effect

Advectively driven  $Q_E$  due to a wet patch existing within a larger dry environment (desert oasis, urban park, irrigated field).

This contributes sensible heat to boost  $Q_E > Q^*$ . In some cases  $Q_E$  can be 1.5 to 2 times  $Q^*$ .

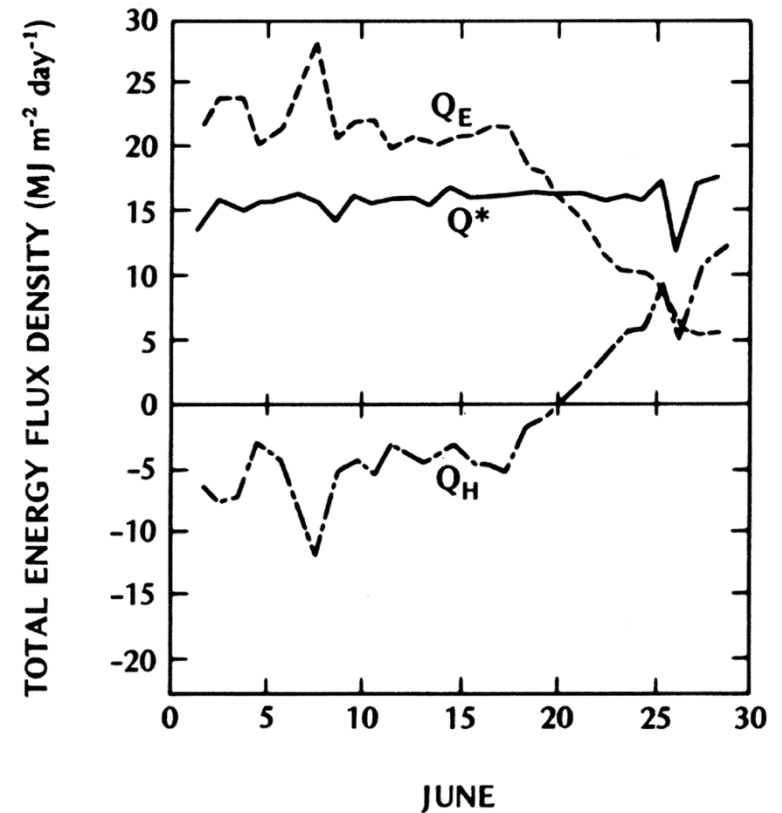
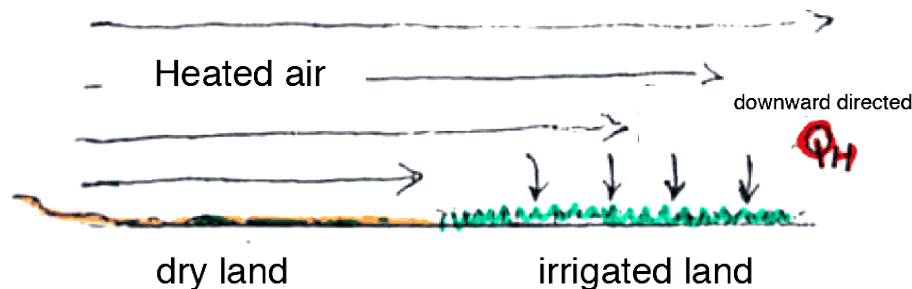


Figure 5.5 Average daily energy balance of an alfalfa crop in June 1964 near Phoenix, Arizona (33°N). The crop was irrigated by flooding in late May and this was followed by drought throughout June (see Figure 4.16) (after van Bavel, 1967).



## 'Clothesline' effect

Advective effects of drier air penetrating **through a vegetation canopy**. Especially seen at crop and forest edge borders. Analogy of the drying effect of air through a clothesline of wet laundry. Enhanced  $Q_E$  of edge plants often causes them to be stunted, open to disease, and soil moisture is drawn down.



Photo: A. Christen

## Take home points

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- Our **one-dimensional approach is limited** as the typical geographical distribution of surface properties (roughness, surface temperatures, evaporation) varies greatly, sometimes sharply.
- This causes momentum, heat and moisture and the corresponding fluxes to depend not only on the underlying surface, but they show a ‘memory’ of **surfaces encountered upwind** - advection.
- Advection can dominate the energy balances, or even invert the direction of turbulent fluxes - **oasis effect** and **‘clothesline’ effect**.