Photo: R. Vogt, Univ. Basel

27 Advection

Today's learning objectives

- 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.

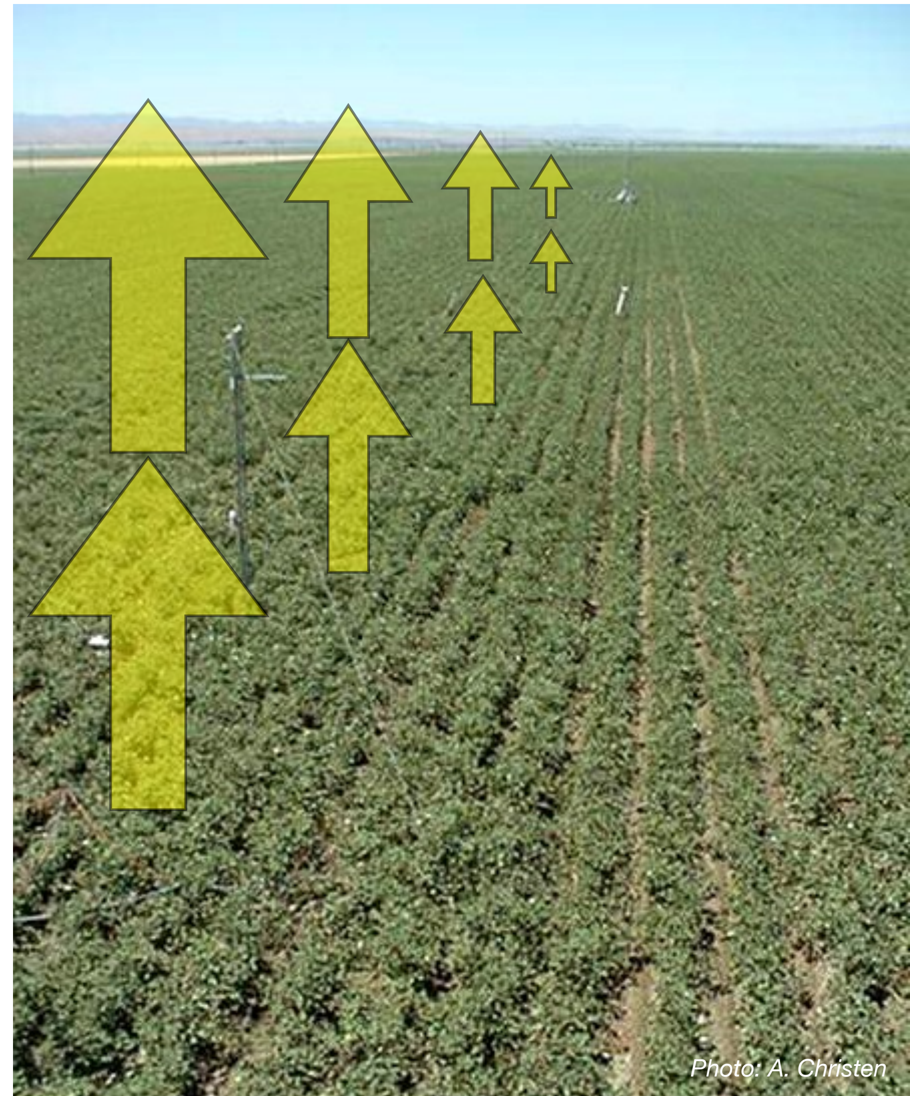
Photo: A. Christen

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.



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.

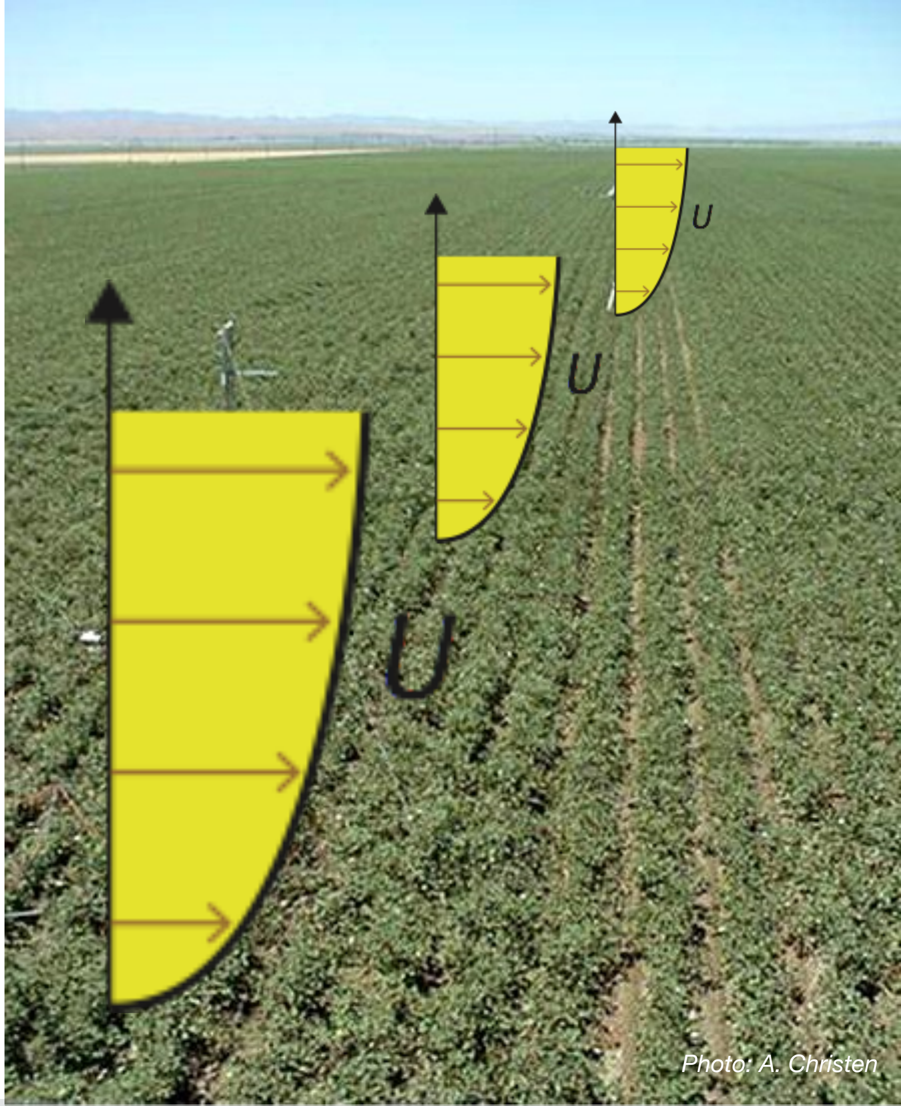
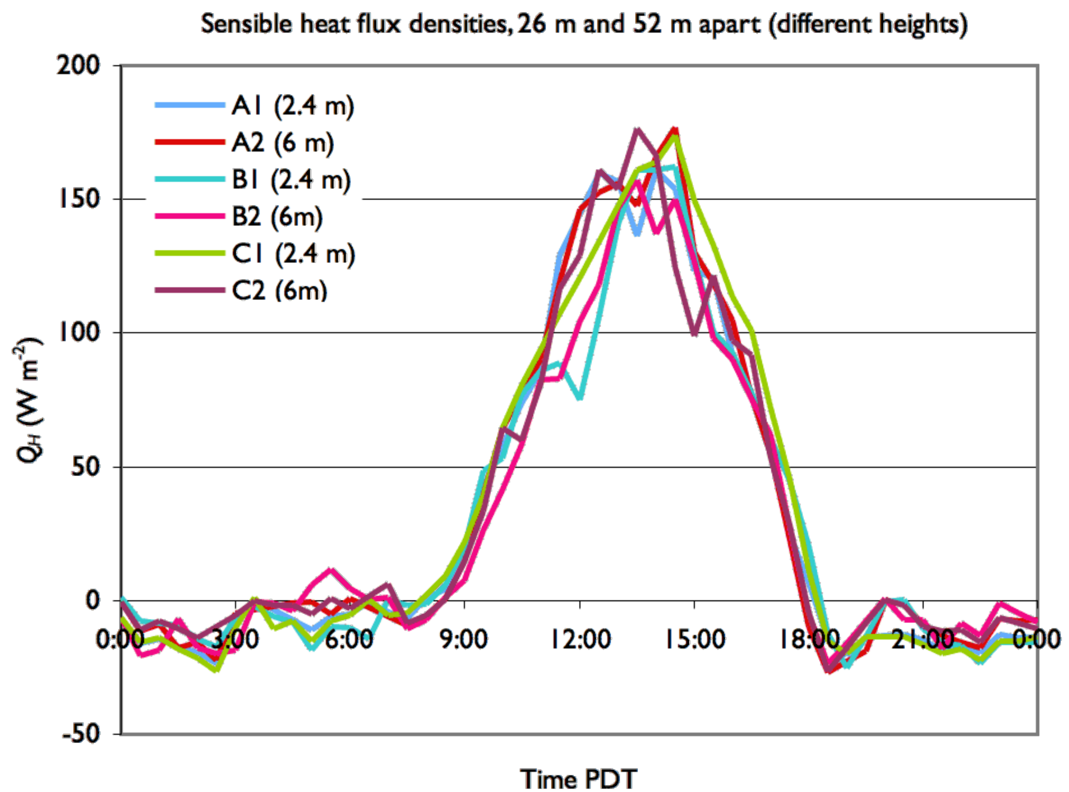


Photo: A. Christen

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 τ, Q_H, Q_E etc. is in the order of 5 to 10%.



Instruments within 50m horizontal distance (EBEX-2000)

Inhomogeneous surfaces

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.

Energy balance Roughness Relief

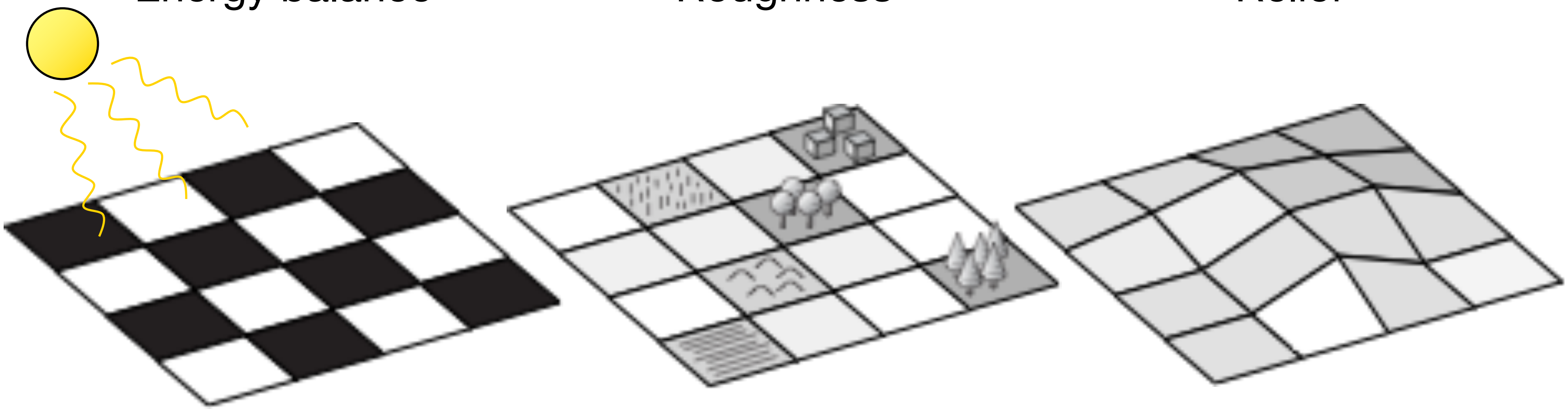



Photo: A. Christen

The complex surface

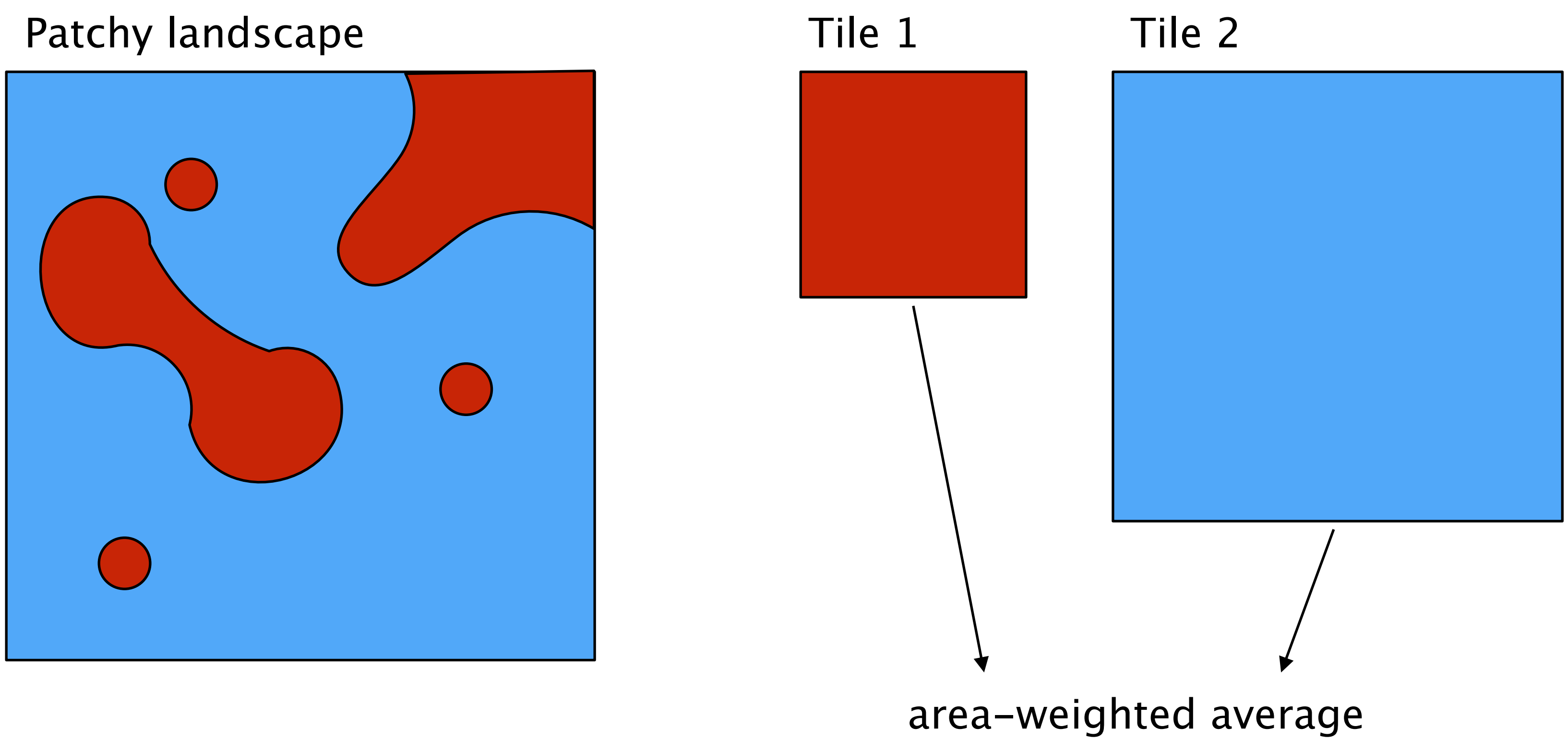
This is the geographical challenge of boundary layer climatology - a 3D reality.

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

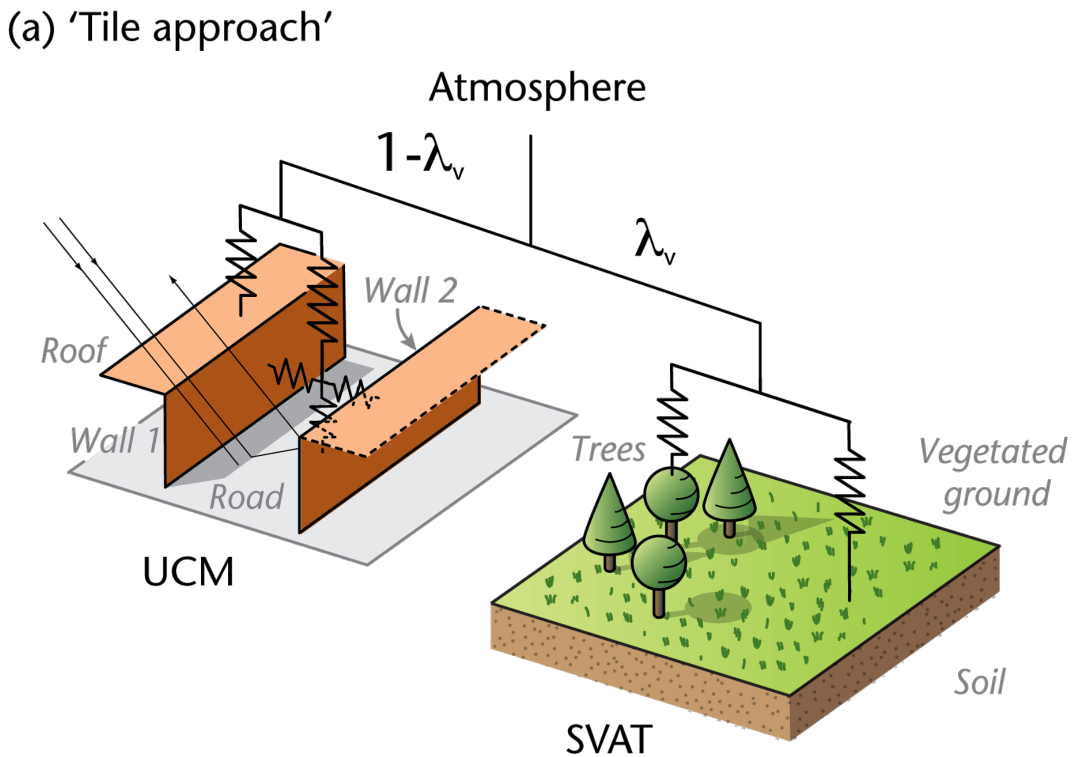
We start with the simplest 2D-steps in surface properties.

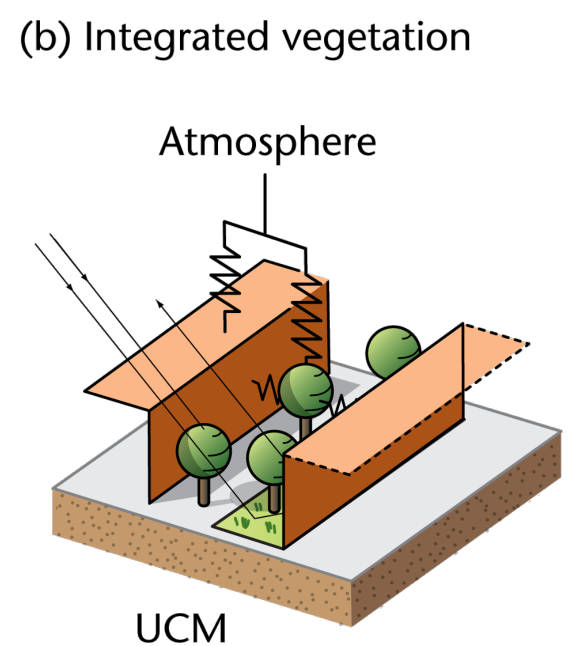
Tile-approach used in weather forecasting

In a ‘tile approach’ we calculate the exchange of different patches separately and then average them by factional occurrence:



Why the tile approach might not work

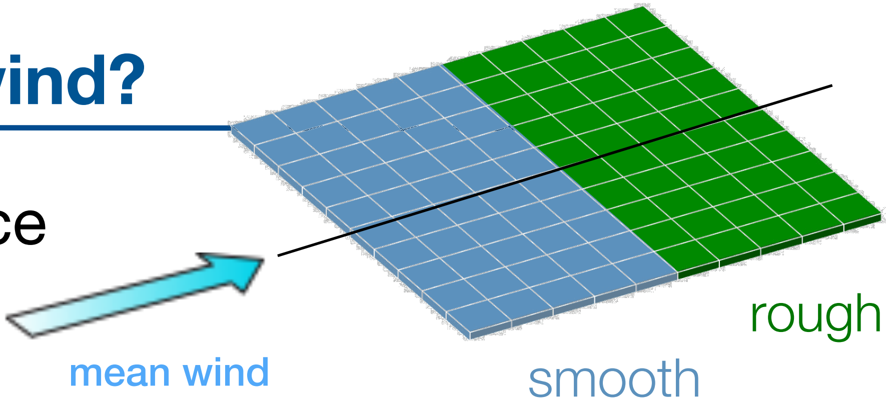


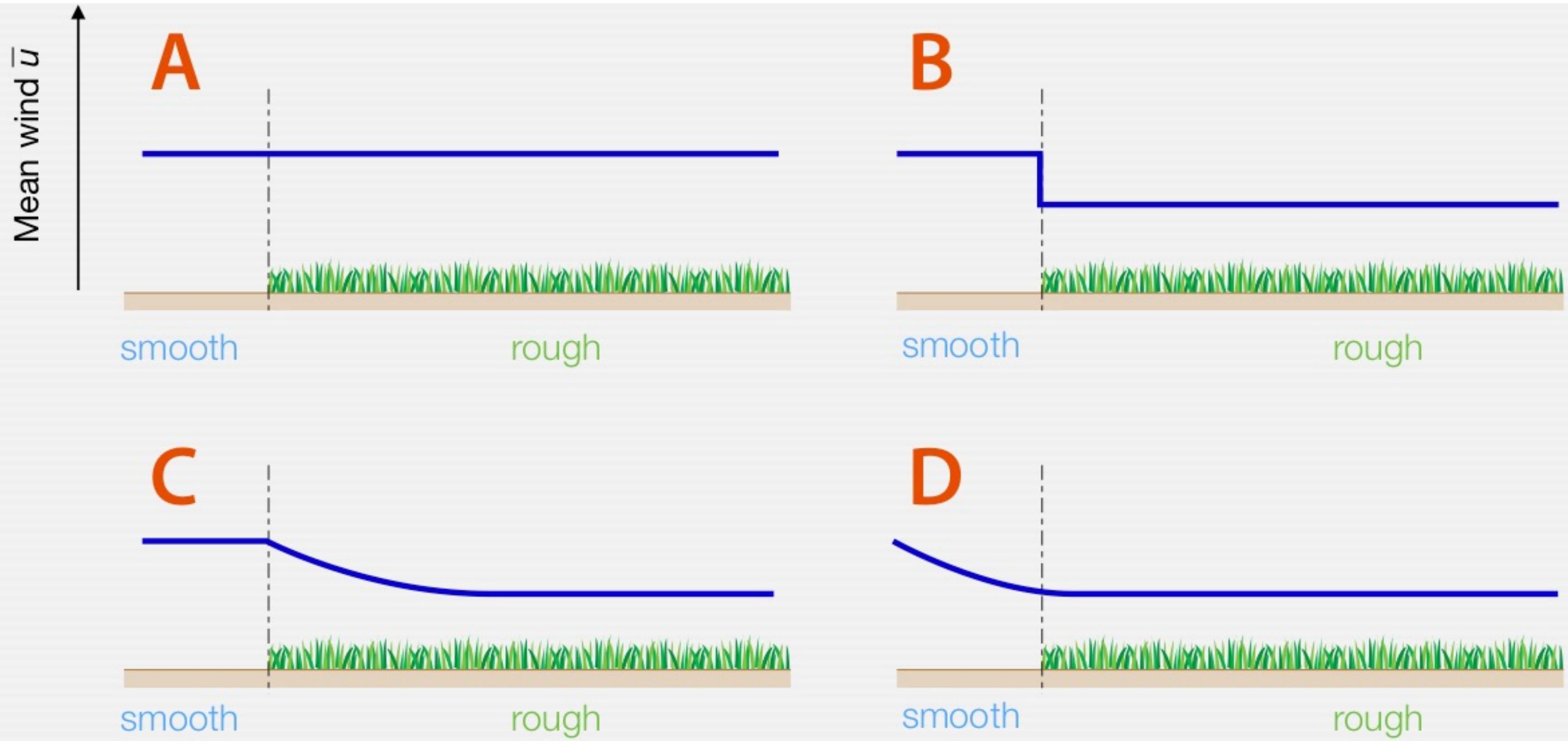


Soil–vegetation–atmosphere = SVAT
Urban Canyon Models = UCM

Change in roughness - effect on wind?

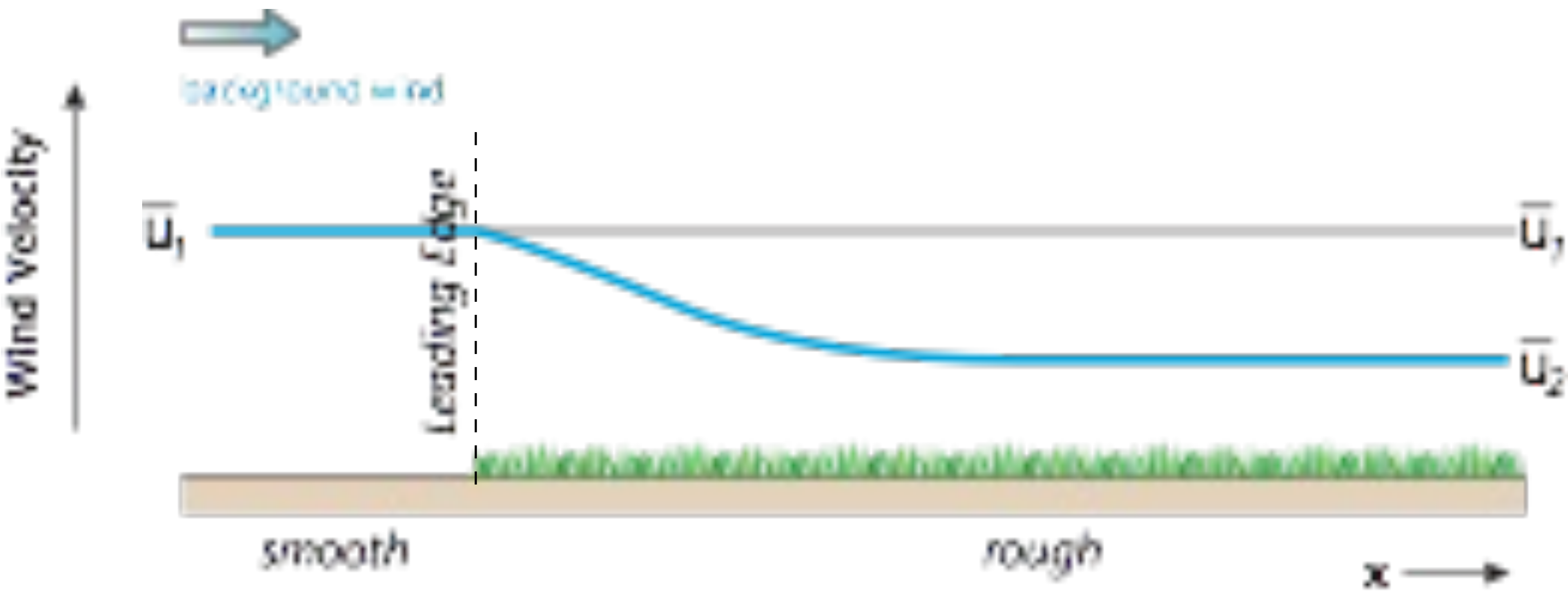
How does **mean wind $\bar{u}$** near the surface change for a transition from a smooth to a rough patch?





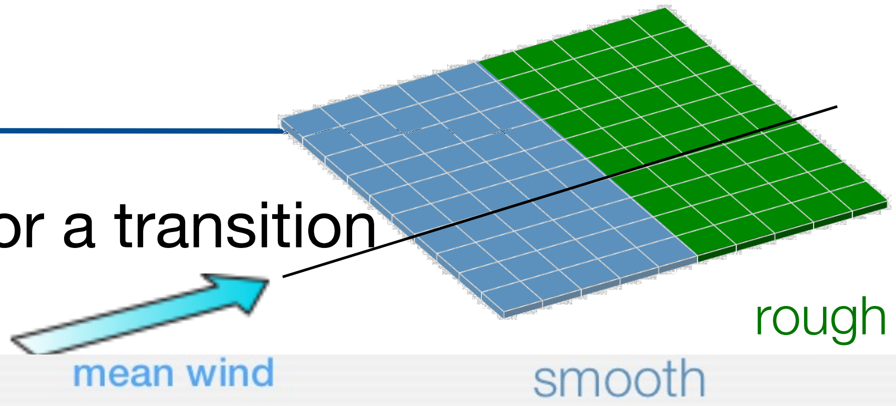
Mean wind is slowed.

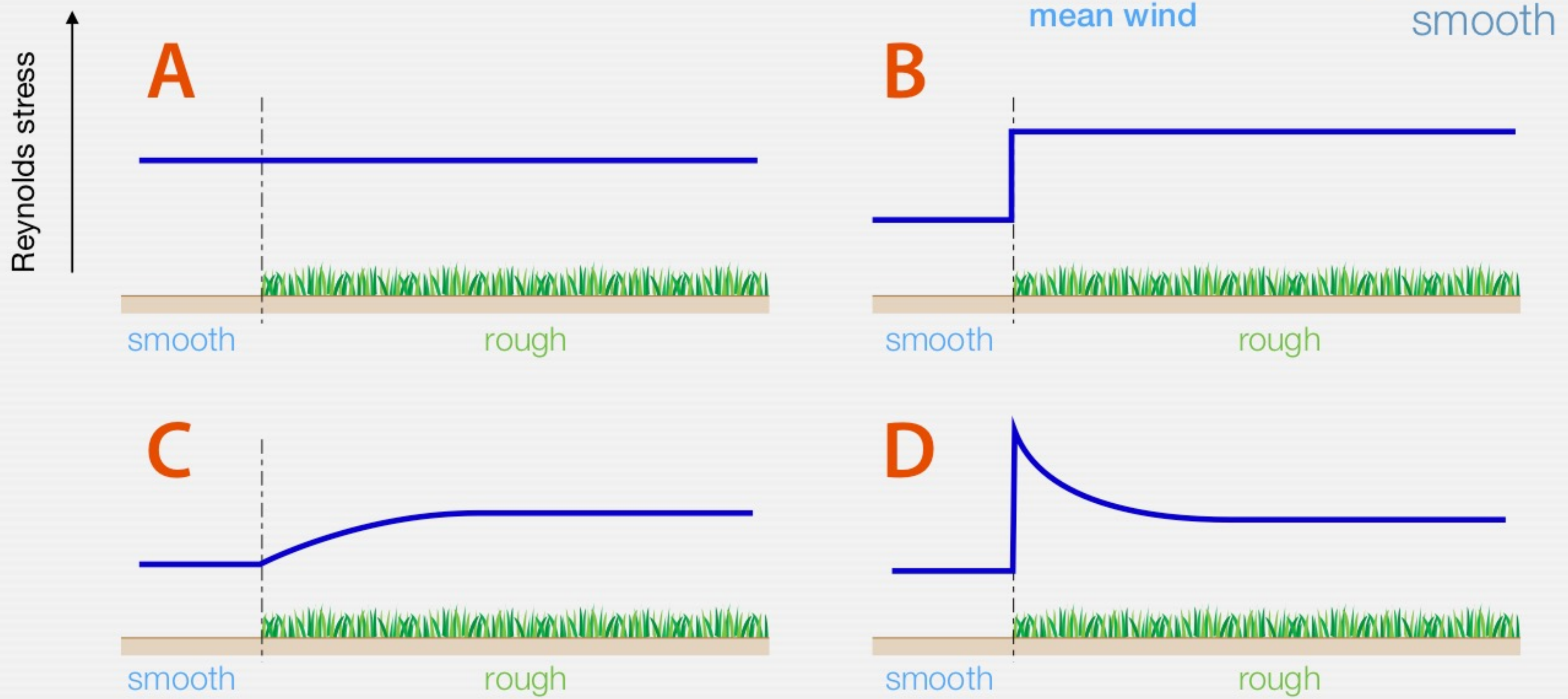
The correct answer is **C**. Mean wind will be slowed once it reaches the rough surface - but slowing does not happen immediately (inertia)



Change of Reynolds stress?

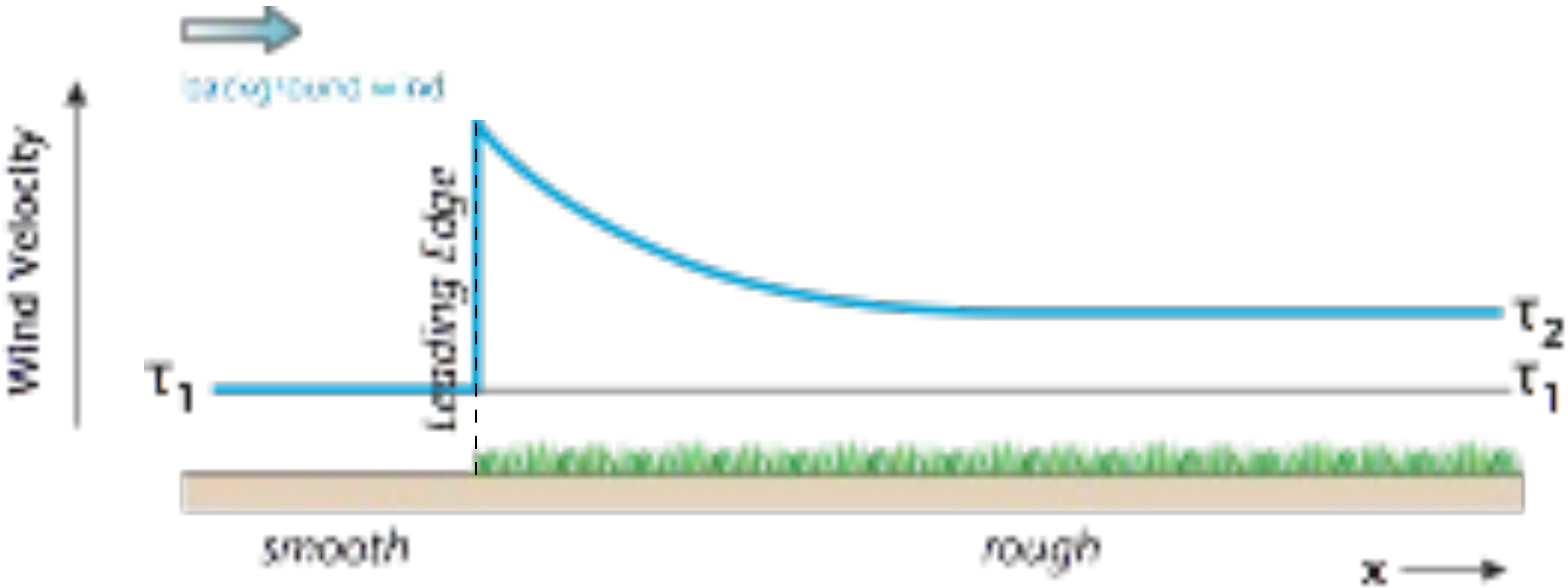
How does **Reynolds stress τ** change for a transition from a smooth to a rough patch?





Reynolds stress is ‘overshooting’.

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



We conclude: Reynolds stress is ‘**overshooting**’ and readjusts afterwards to its new value τ_2.

Relevance of step-changes in landscapes.

◀ Forest edges are generally more susceptible to damage

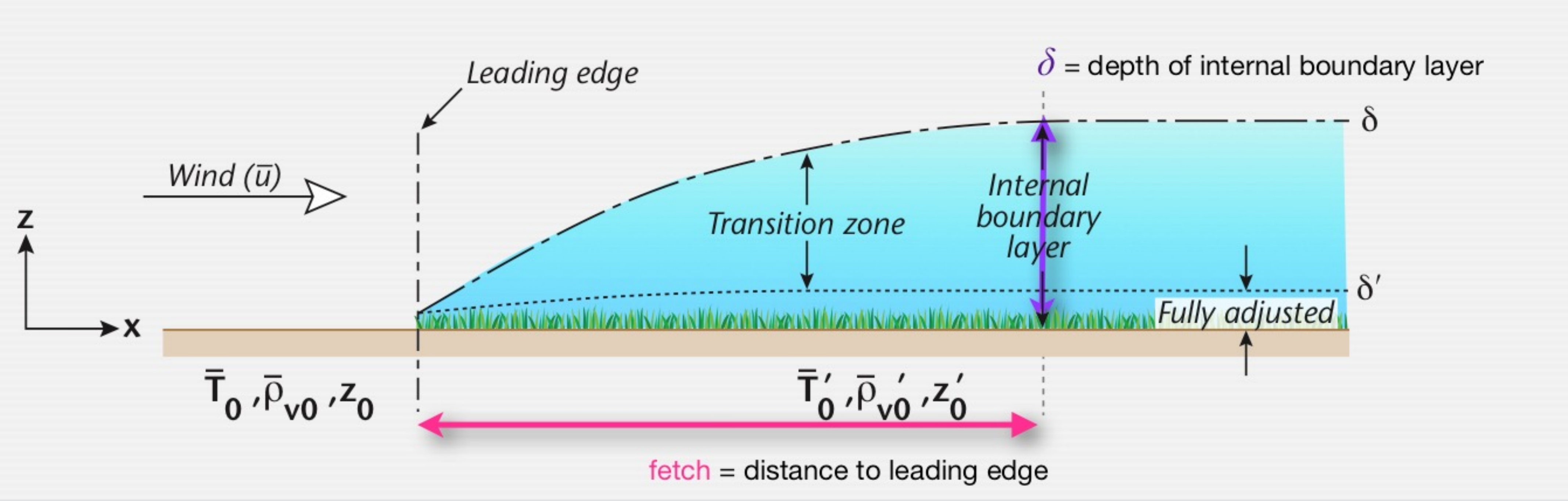
▲ Windbreaks protect crops from wind erosion and excessive Evapotranspiration (conserve water)

Photos: A. Christen

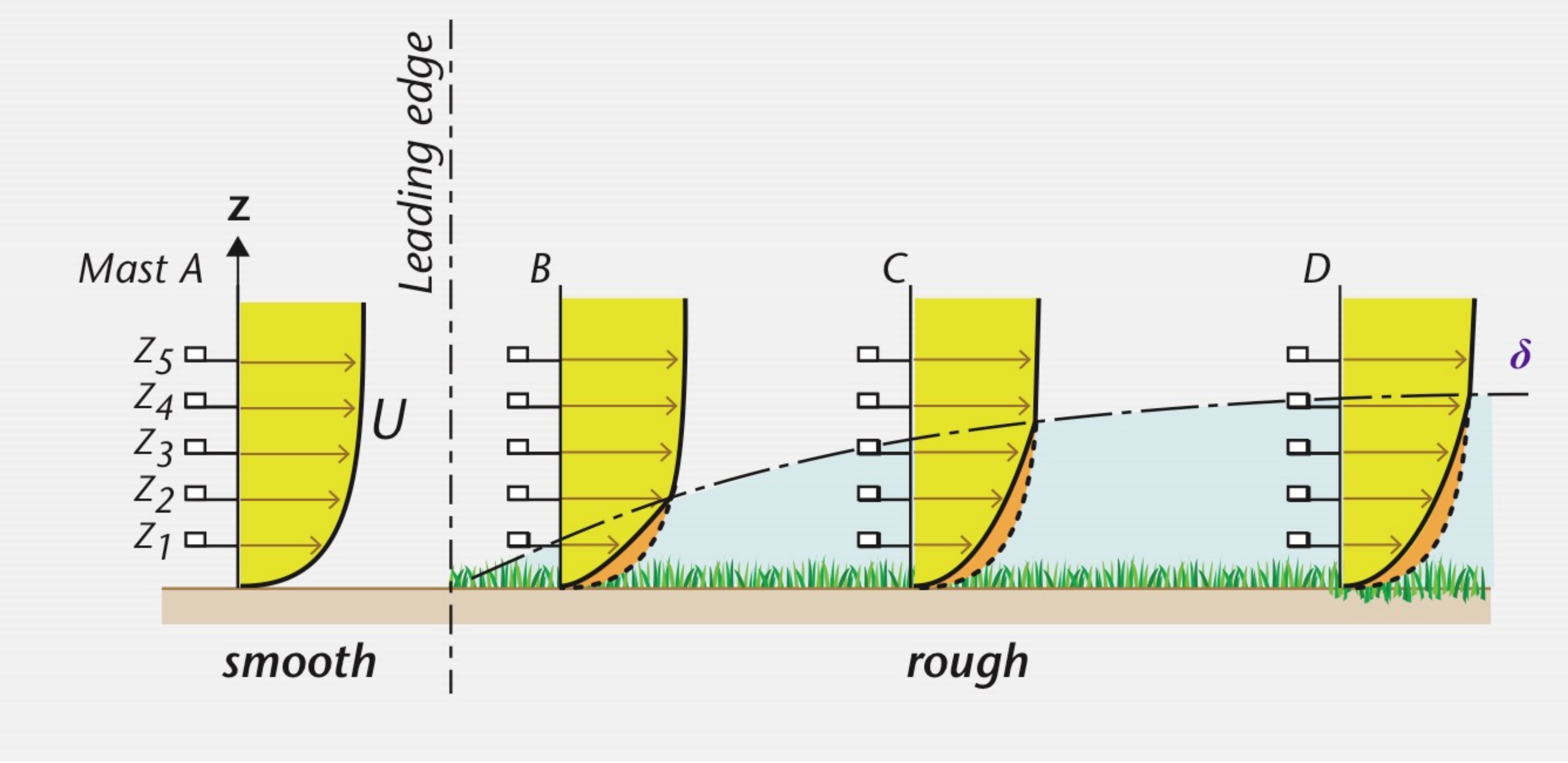
Internal boundary layer.

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

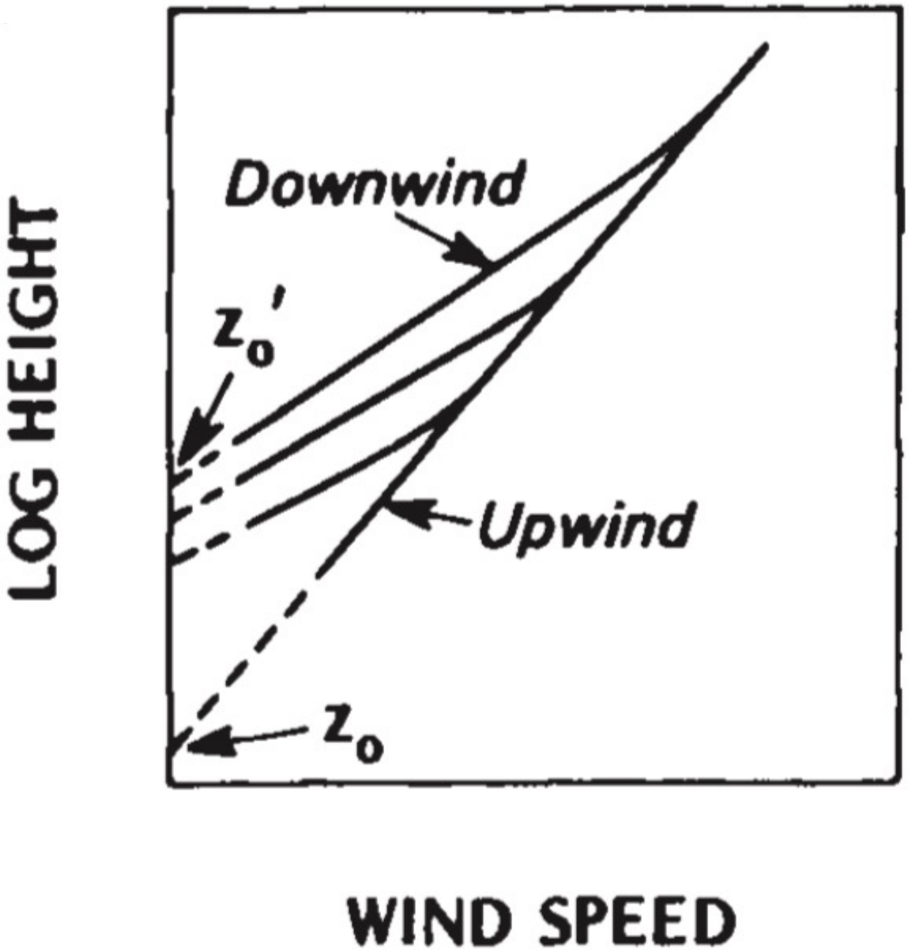
Modification affects an even deeper layer (δ - known as the **internal boundary layer depth**) at greater distances (x - known as **fetch**):



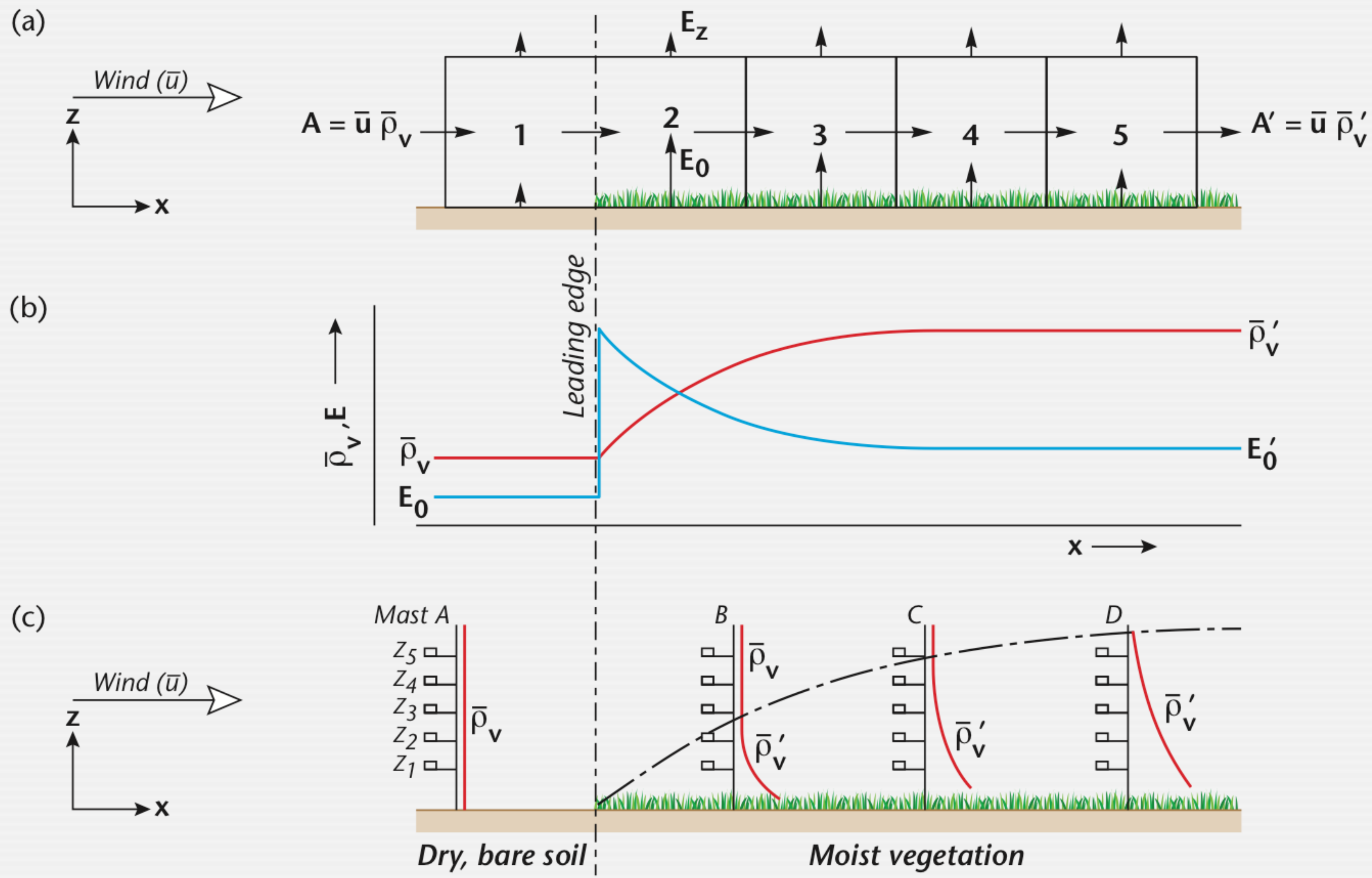
Changes to the wind profile across a step change.



Adjustment of wind profile



Changes in evaporation.



Depth of the internal boundary layer

Only the lowest 10% of the internal boundary layer depth δ are fully in equilibrium with the new surface (δ') and the rest (δ-δ') 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:

$$\frac{\delta}{z_{0(1)}} = a_{\mathrm{IBL}} \left(\frac{x}{z_{0(1)}} \right)^{b_{\mathrm{IBL}}}$$

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

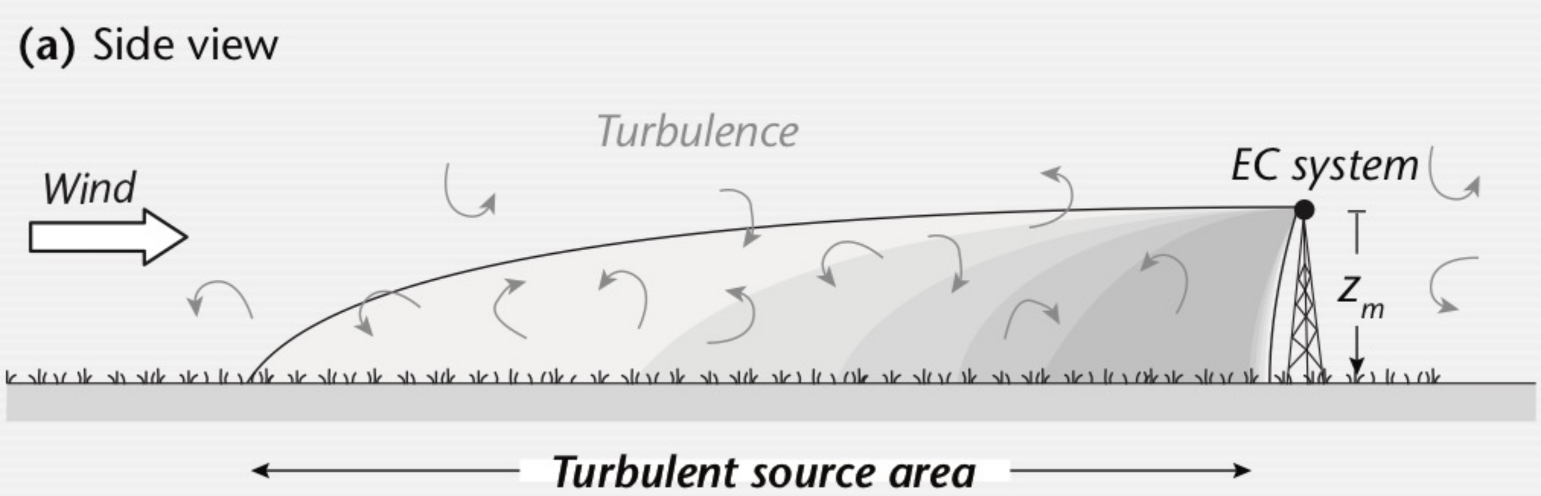
Empirical constant **b** (0.8 for neutral, and 0.6 to 0.7 for unstable)

Depth of the internal boundary layer

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

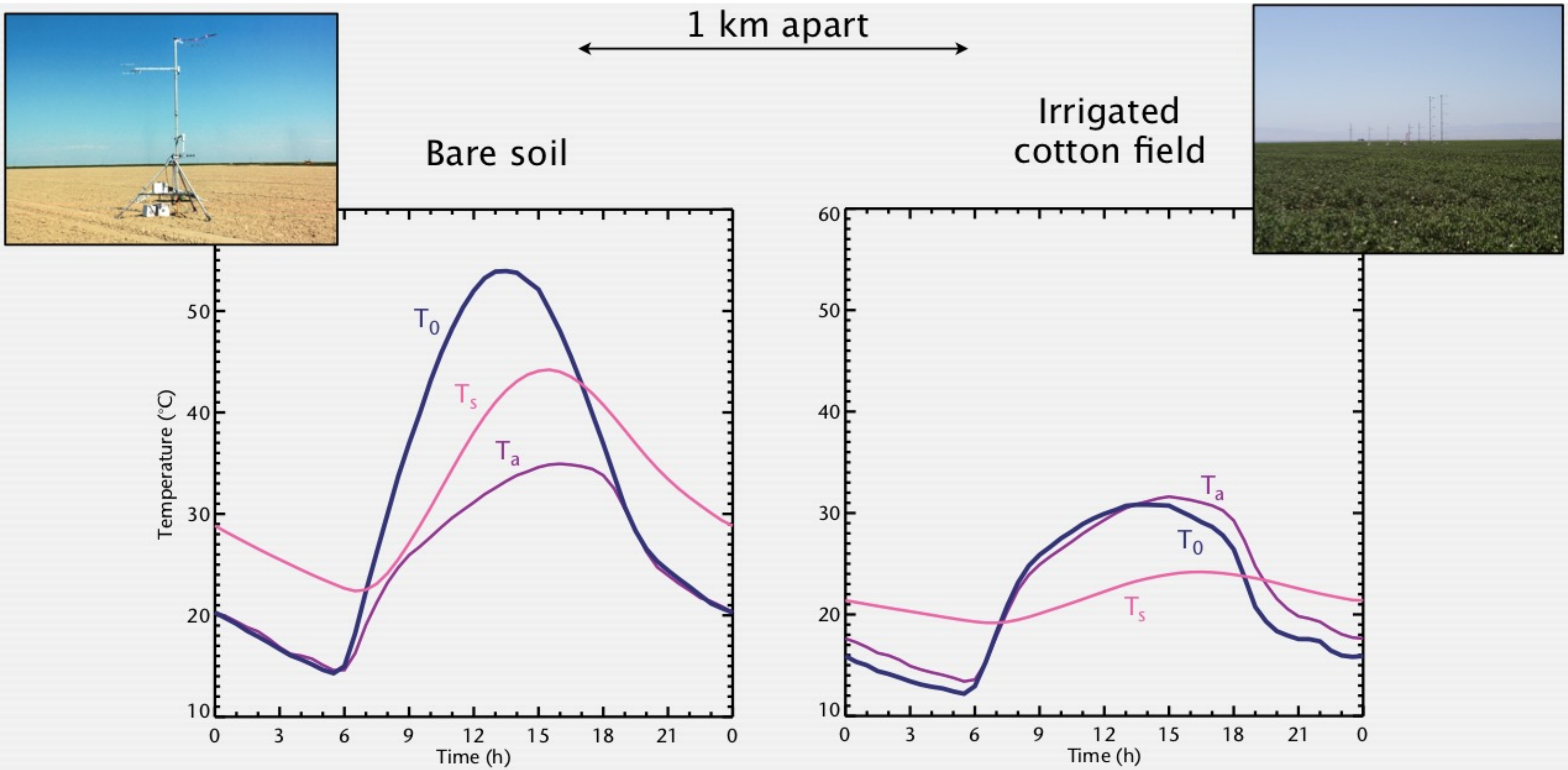
$$a_{\mathrm{IBL}} = 0.75 + 0.03 \ln\left(\frac{z_{0(2)}}{z_{0(1)}}\right)$$

Knowledge of IBL is relevant to see what a sensor at height δ measures:



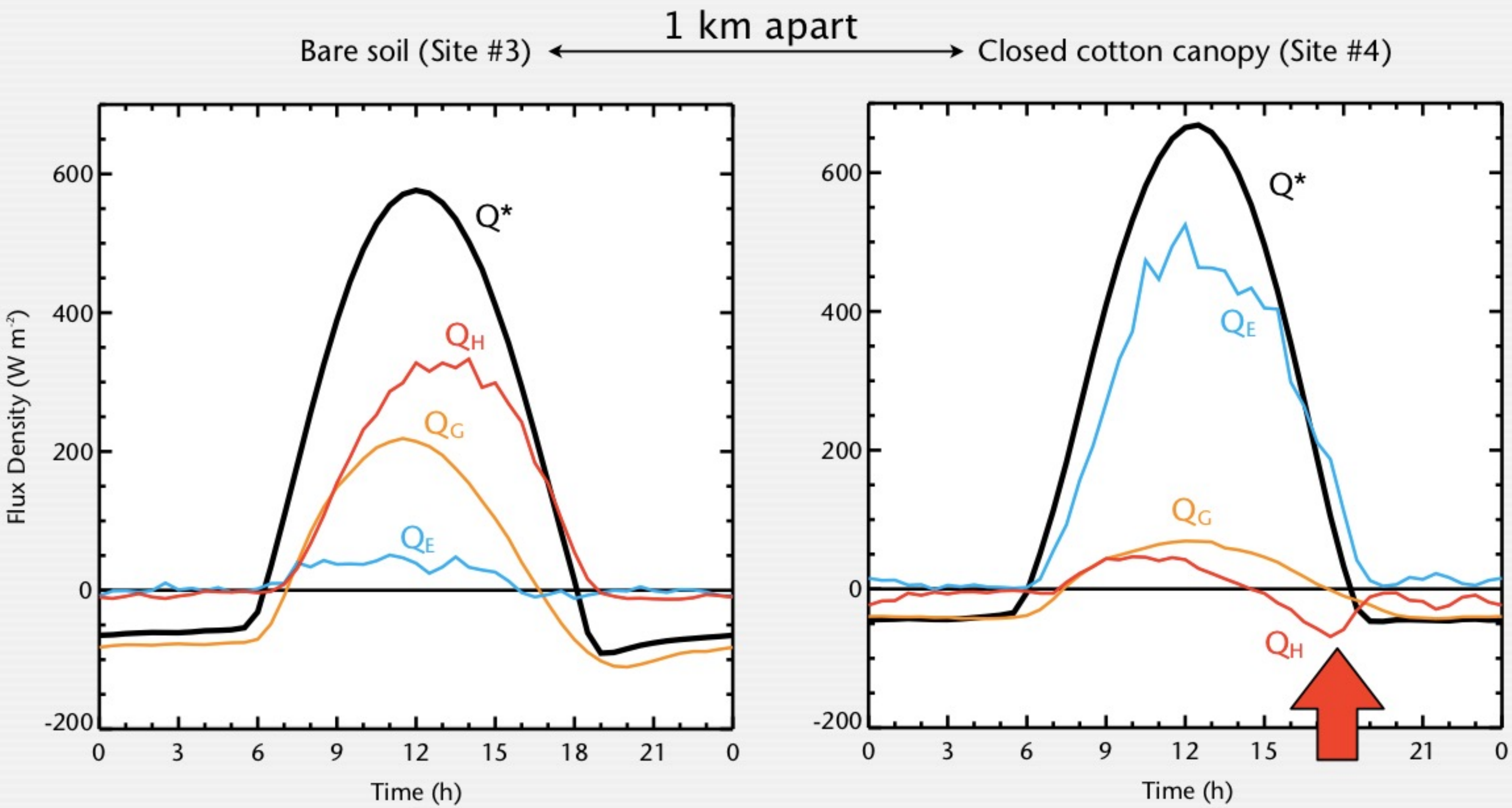
Photos: S. Oncley, NCAR

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

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

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

Photos: S. Oncley, NCAR

Importance of:

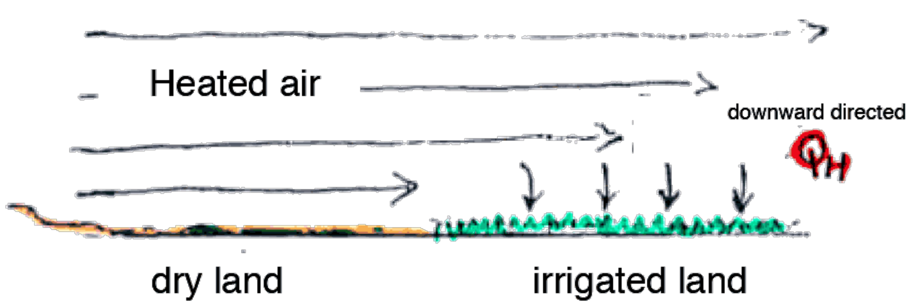
- Fetch
- Source area

Photos: S. Oncley, NCAR

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^*.



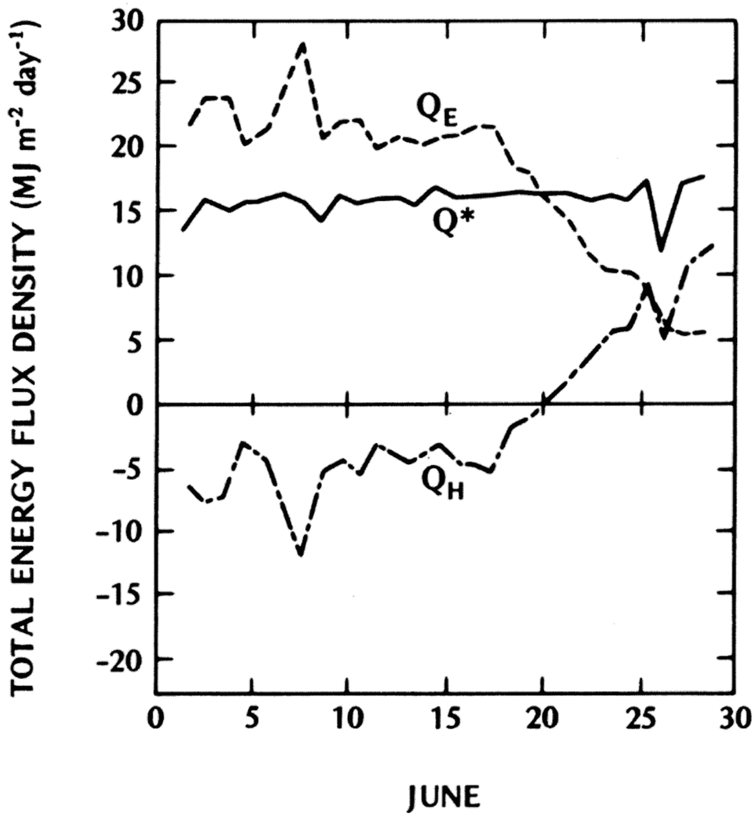


Figure 5.5 Average daily energy balance of an alfalfa crop in June 1964 near Phoenix, Arizona (33°N). The crop was irrigated by flooding in late May and this was followed by drought throughout June (see Figure 4.16) (after van Bavel, 1967).


Photo: A. Christen

‘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.

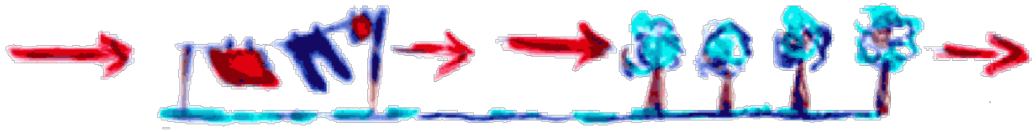



Photo: A. Christen

Take home points

- 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**.