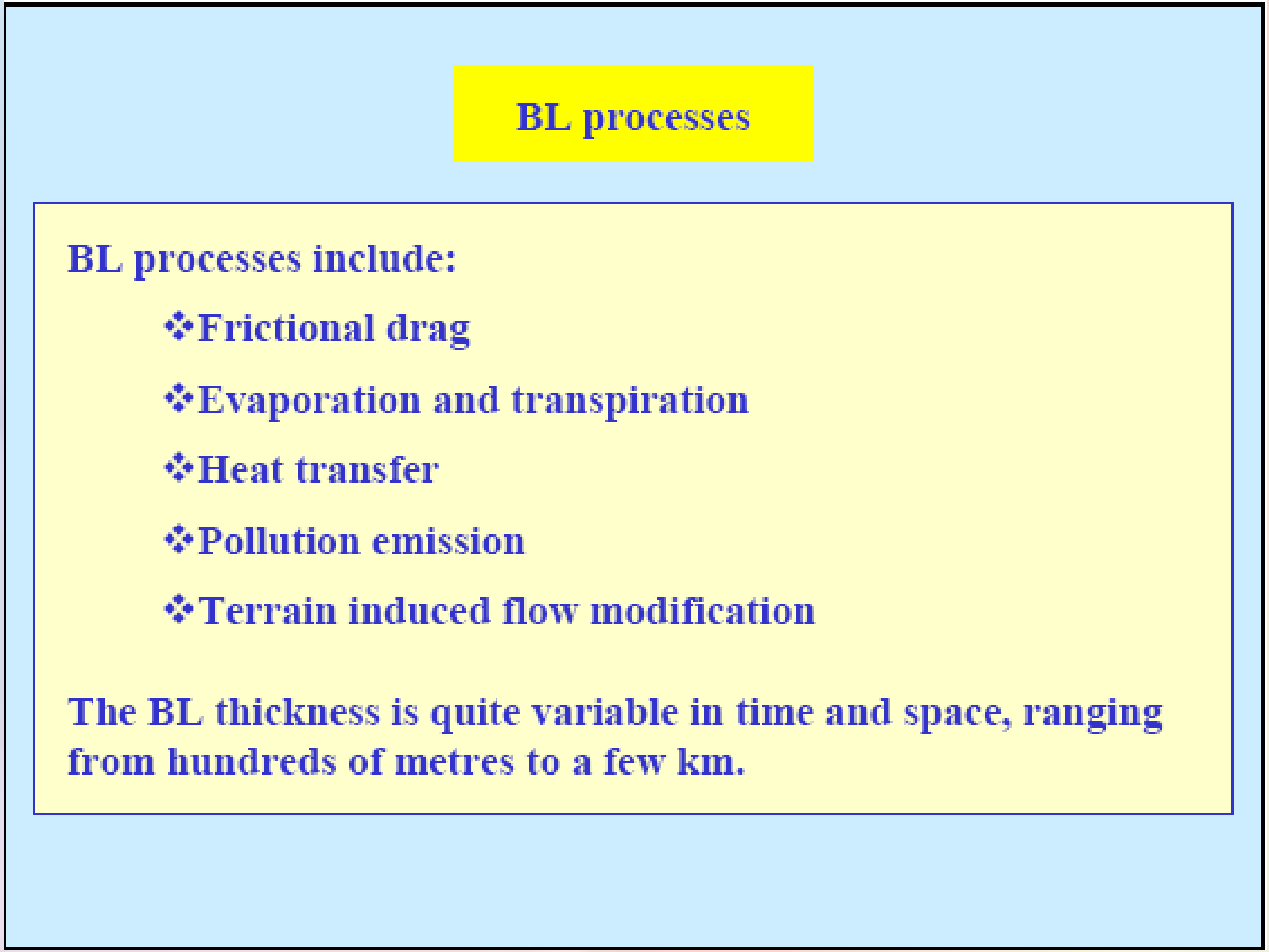
Micrometeorology

Lecture 3

Sahraei

https://sci.razi.ac.ir/~sahraei



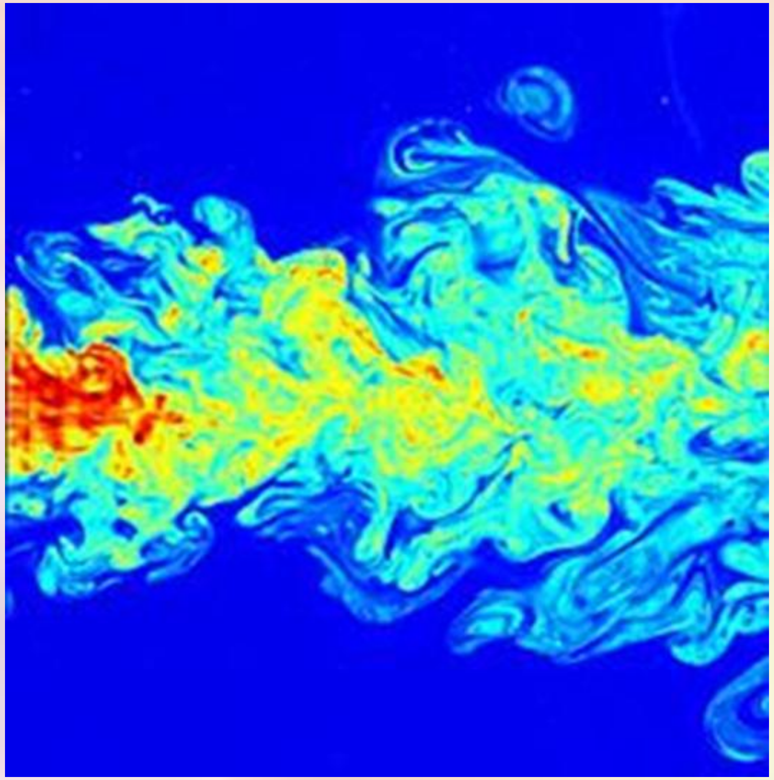
BL processes

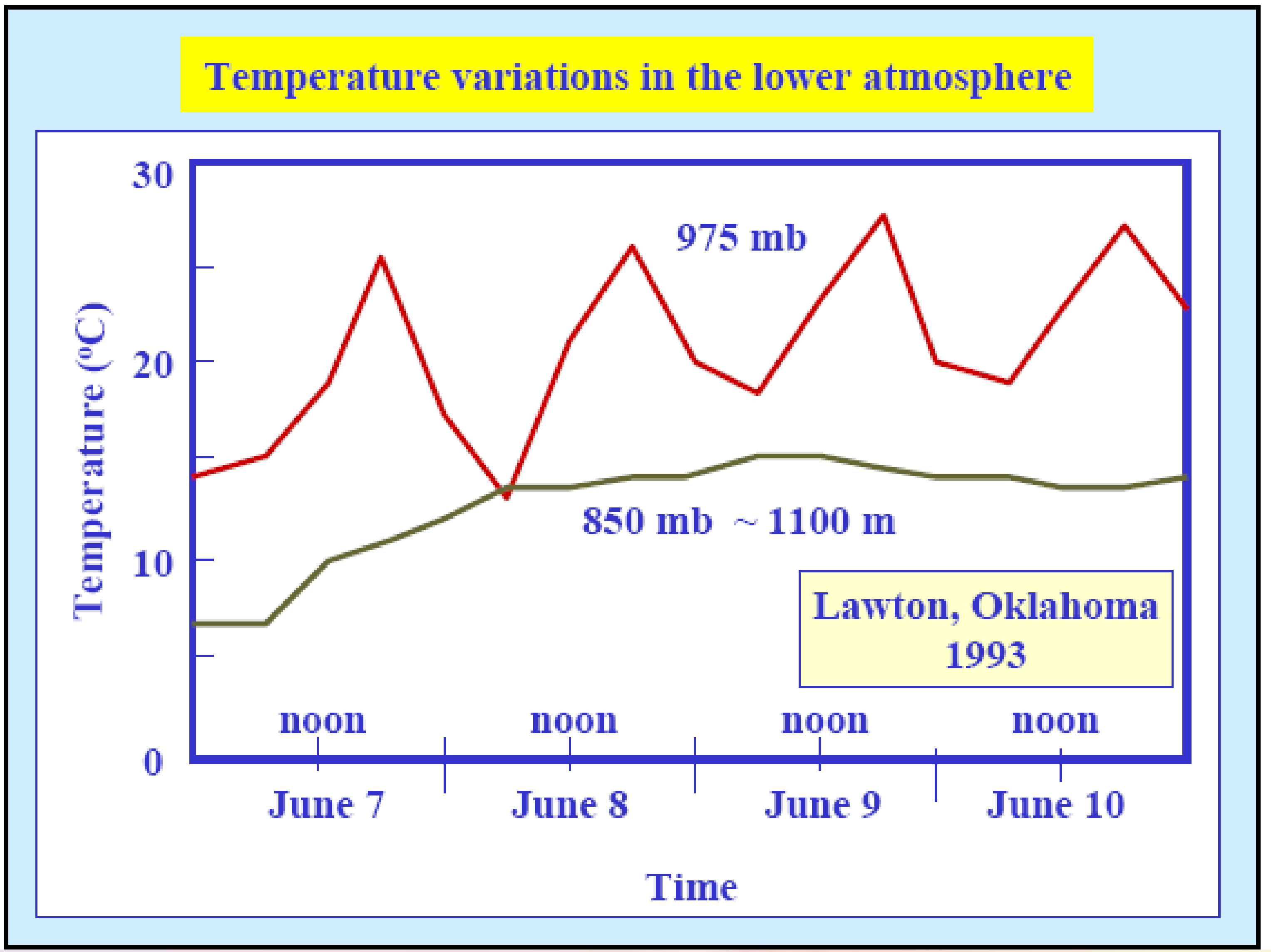
BL processes include:

- Frictional drag
- Evaporation and transpiration
- Heat transfer
- Pollution emission
- Terrain induced flow modification

The BL thickness is quite variable in time and space, ranging from hundreds of metres to a few km.

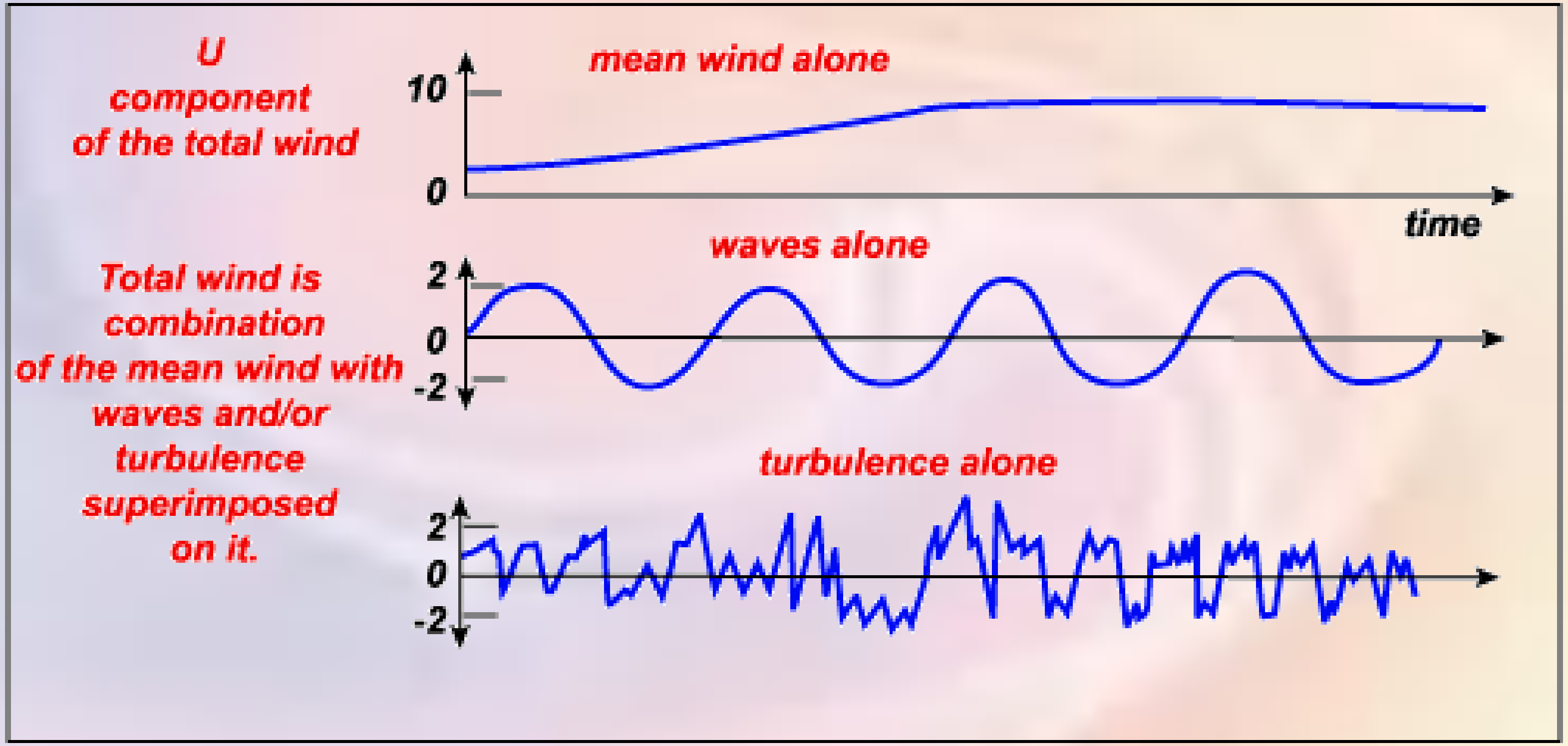
Turbulence





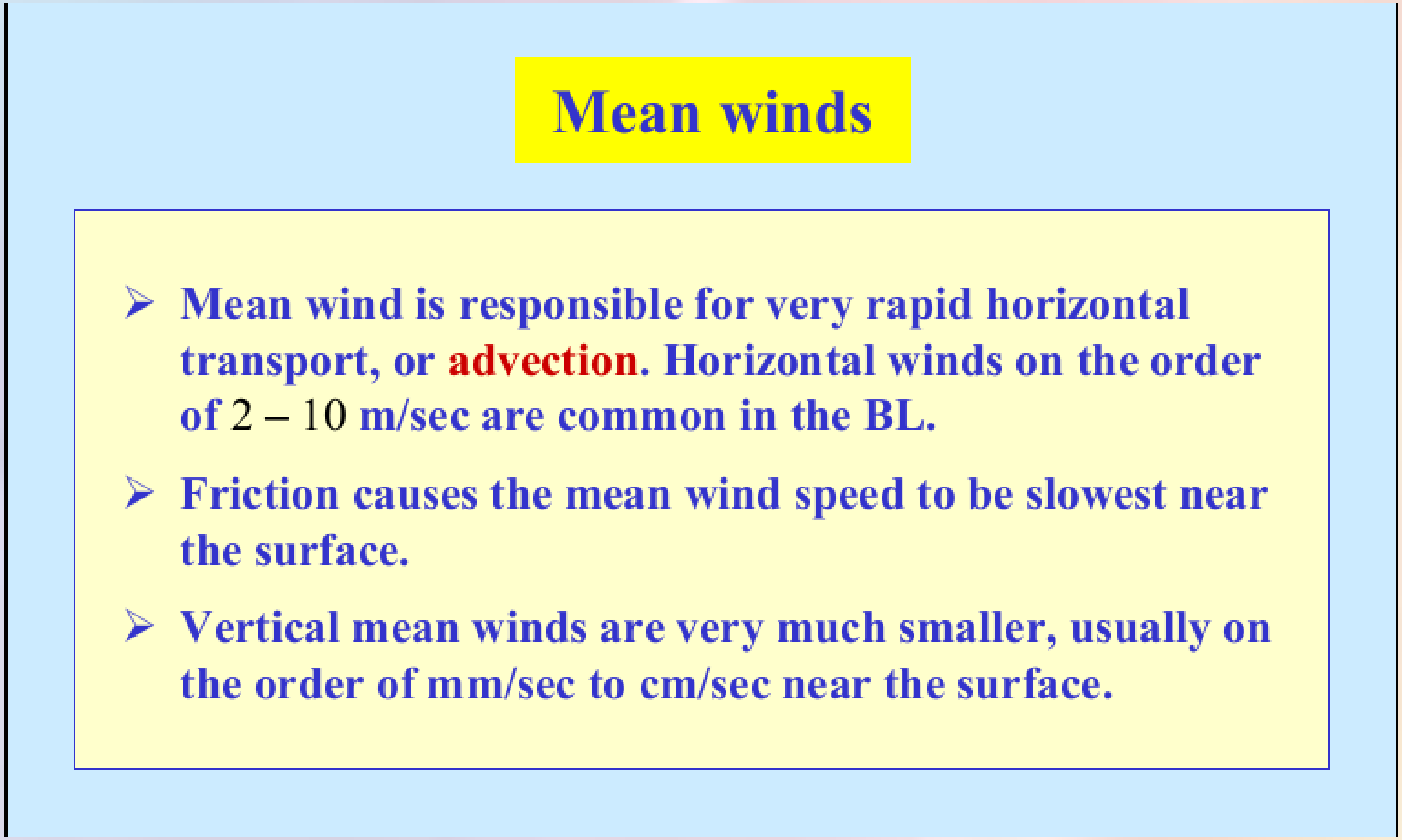
Temperature variations in the lower atmosphere

Turbulence inside the boundary layer



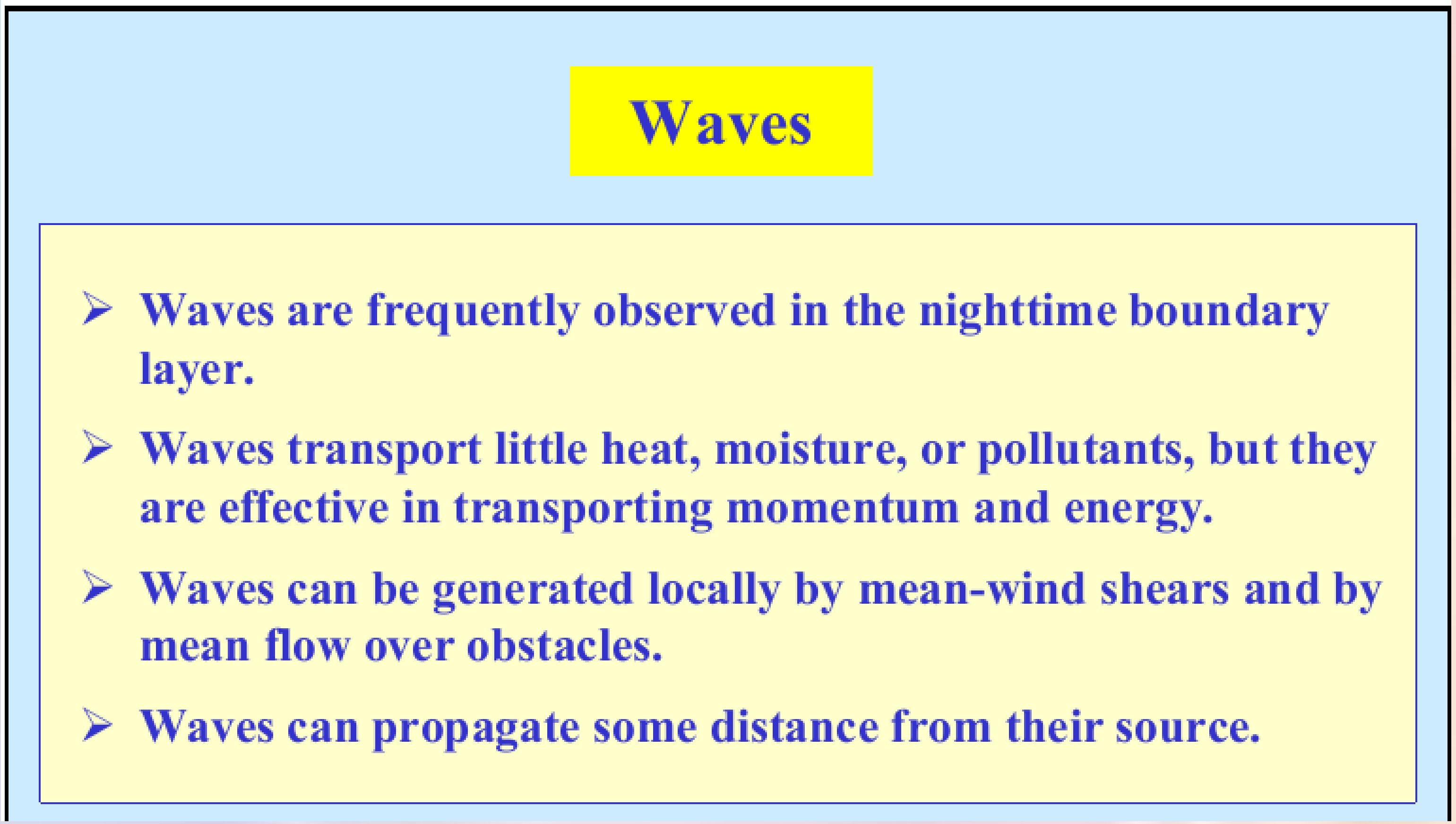
U
component
of the total wind

Total wind is
combination
of the mean wind with
waves and/or
turbulence
superimposed
on it.



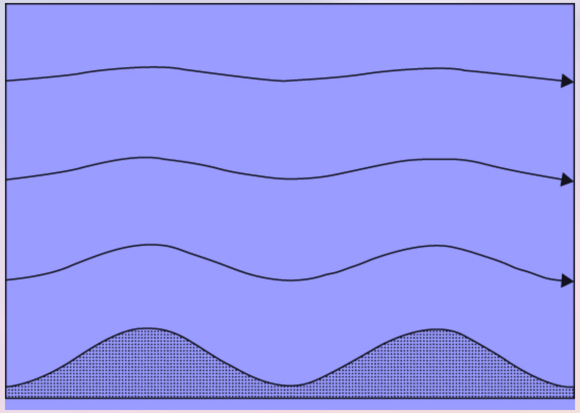
Mean winds

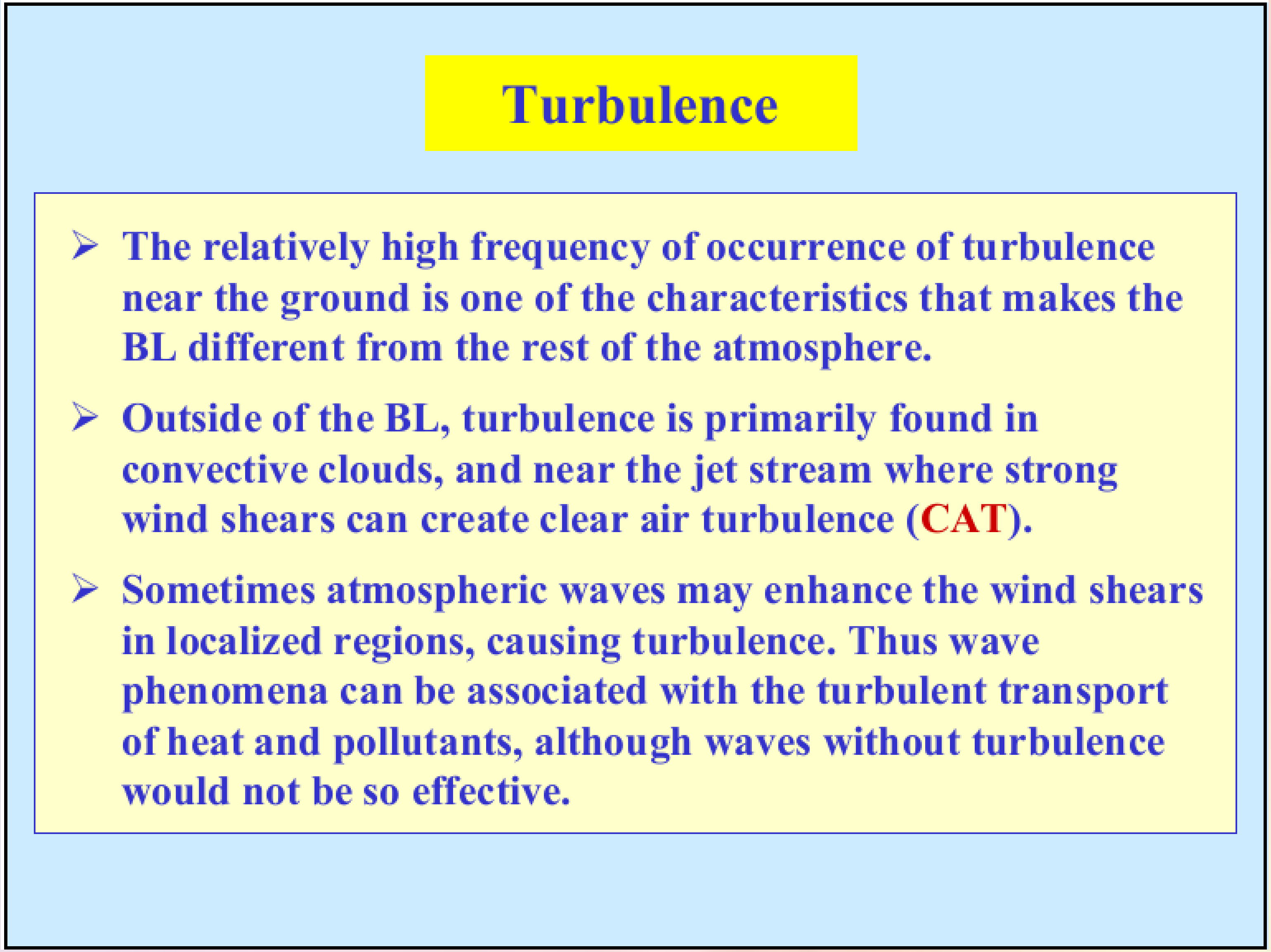
- Mean wind is responsible for very rapid horizontal transport, or **advection**. Horizontal winds on the order of 2 – 10 m/sec are common in the BL.
- Friction causes the mean wind speed to be slowest near the surface.
- Vertical mean winds are very much smaller, usually on the order of mm/sec to cm/sec near the surface.



Waves

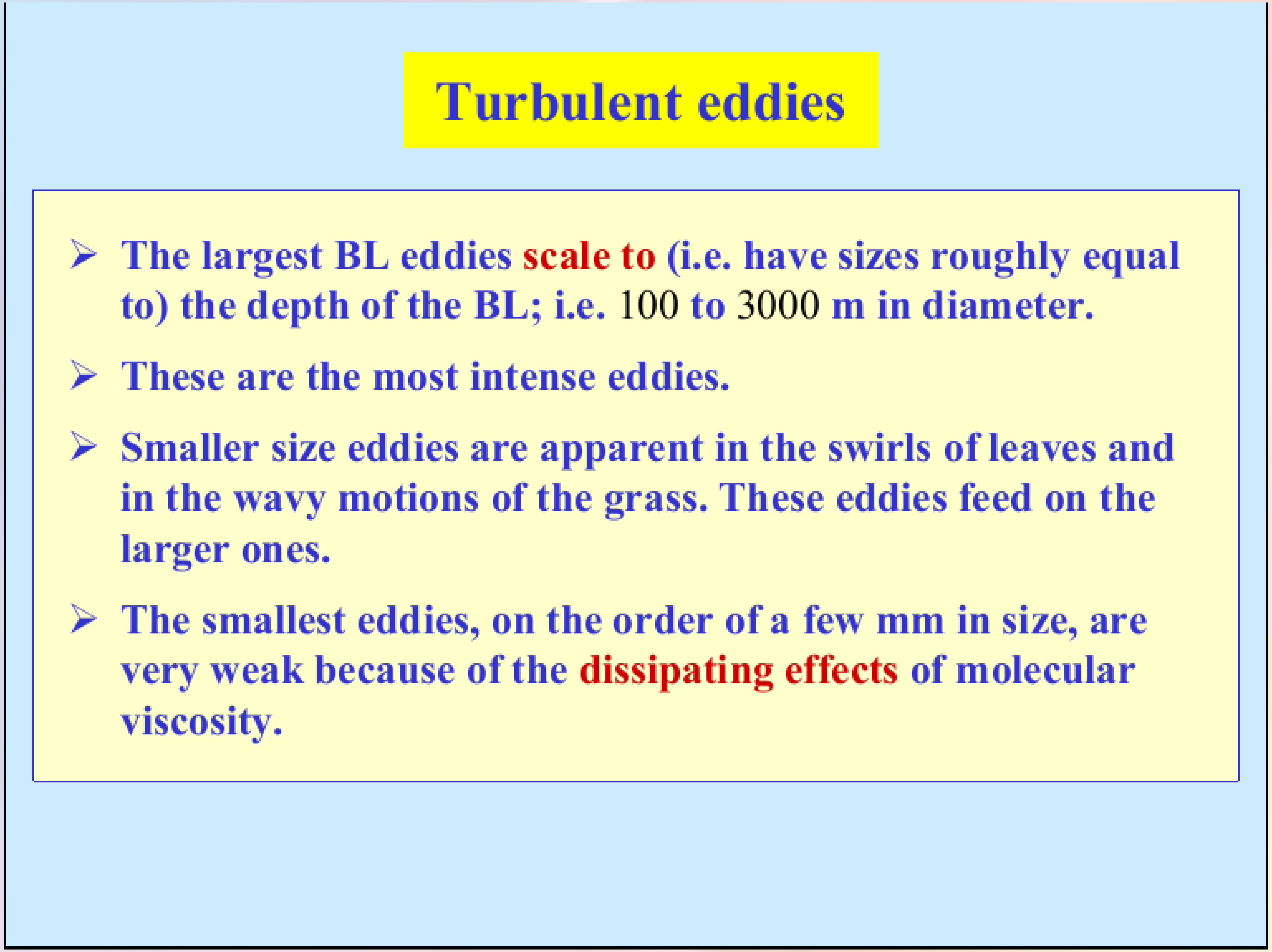
- Waves are frequently observed in the nighttime boundary layer.
- Waves transport little heat, moisture, or pollutants, but they are effective in transporting momentum and energy.
- Waves can be generated locally by mean-wind shears and by mean flow over obstacles.
- Waves can propagate some distance from their source.





Turbulence

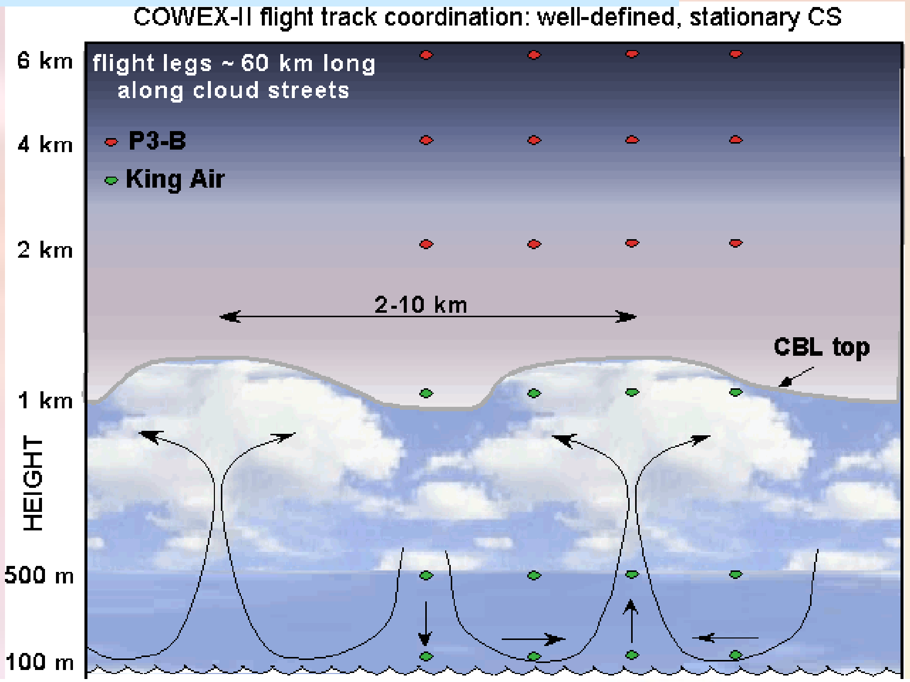
- The relatively high frequency of occurrence of turbulence near the ground is one of the characteristics that makes the BL different from the rest of the atmosphere.
- Outside of the BL, turbulence is primarily found in convective clouds, and near the jet stream where strong wind shears can create clear air turbulence (**CAT**).
- Sometimes atmospheric waves may enhance the wind shears in localized regions, causing turbulence. Thus wave phenomena can be associated with the turbulent transport of heat and pollutants, although waves without turbulence would not be so effective.

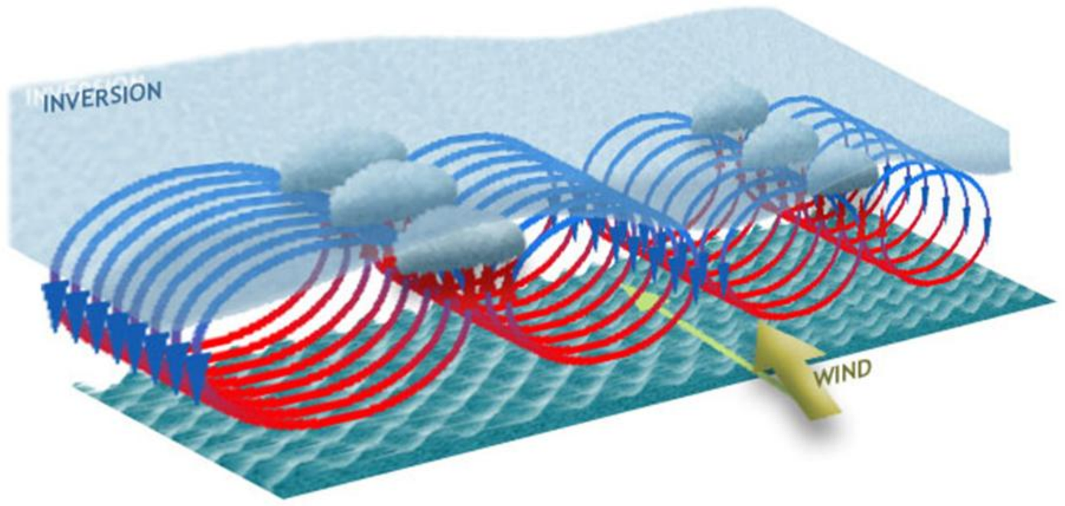


Turbulent eddies

- The largest BL eddies scale to (i.e. have sizes roughly equal to) the depth of the BL; i.e. 100 to 3000 m in diameter.
- These are the most intense eddies.
- Smaller size eddies are apparent in the swirls of leaves and in the wavy motions of the grass. These eddies feed on the larger ones.
- The smallest eddies, on the order of a few mm in size, are very weak because of the dissipating effects of molecular viscosity.

Evidence of large BL eddies: cloud streets





Simply defined as perturbation from the mean

$$u(t) = \overline{u} + u'(t)$$

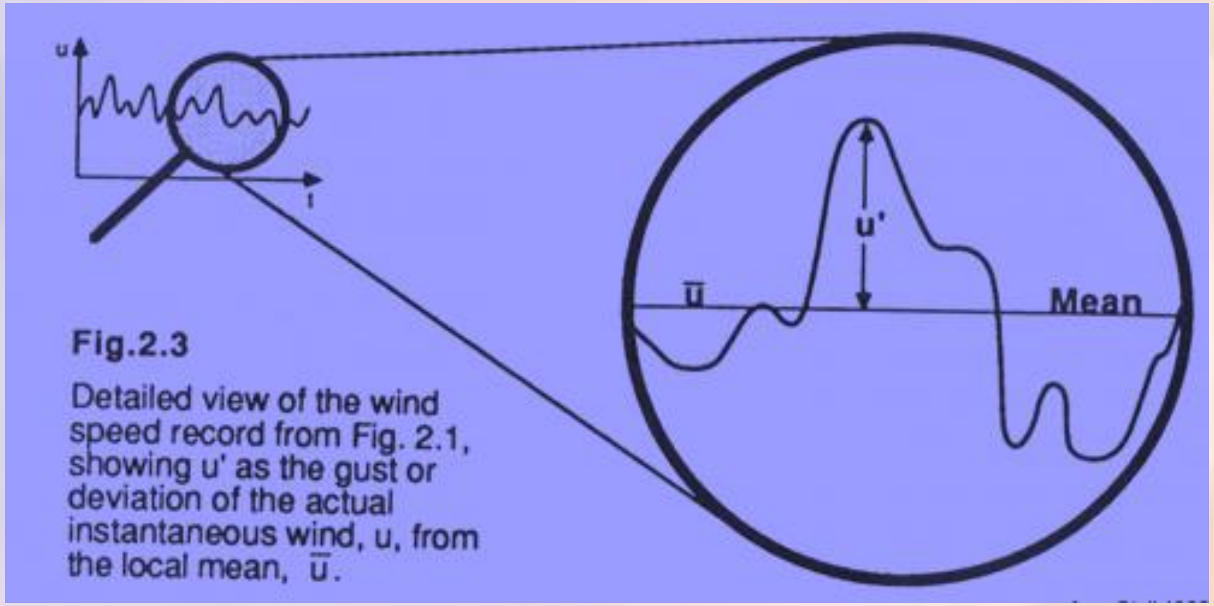


Fig.2.3

Detailed view of the wind speed record from Fig. 2.1, showing u' as the gust or deviation of the actual instantaneous wind, u, from the local mean, $\overline{u}$.

How do we measure u′ ?

A sonic anemometer measures at very high sampling rates. This is typically at 10 or 20 Hz. Data from a high temporal resolution time series is used to calculate the mean of the time series and subsequently a perturbation from the mean.

Once the perturbations are calculated, turbulent statistics can be calculated.

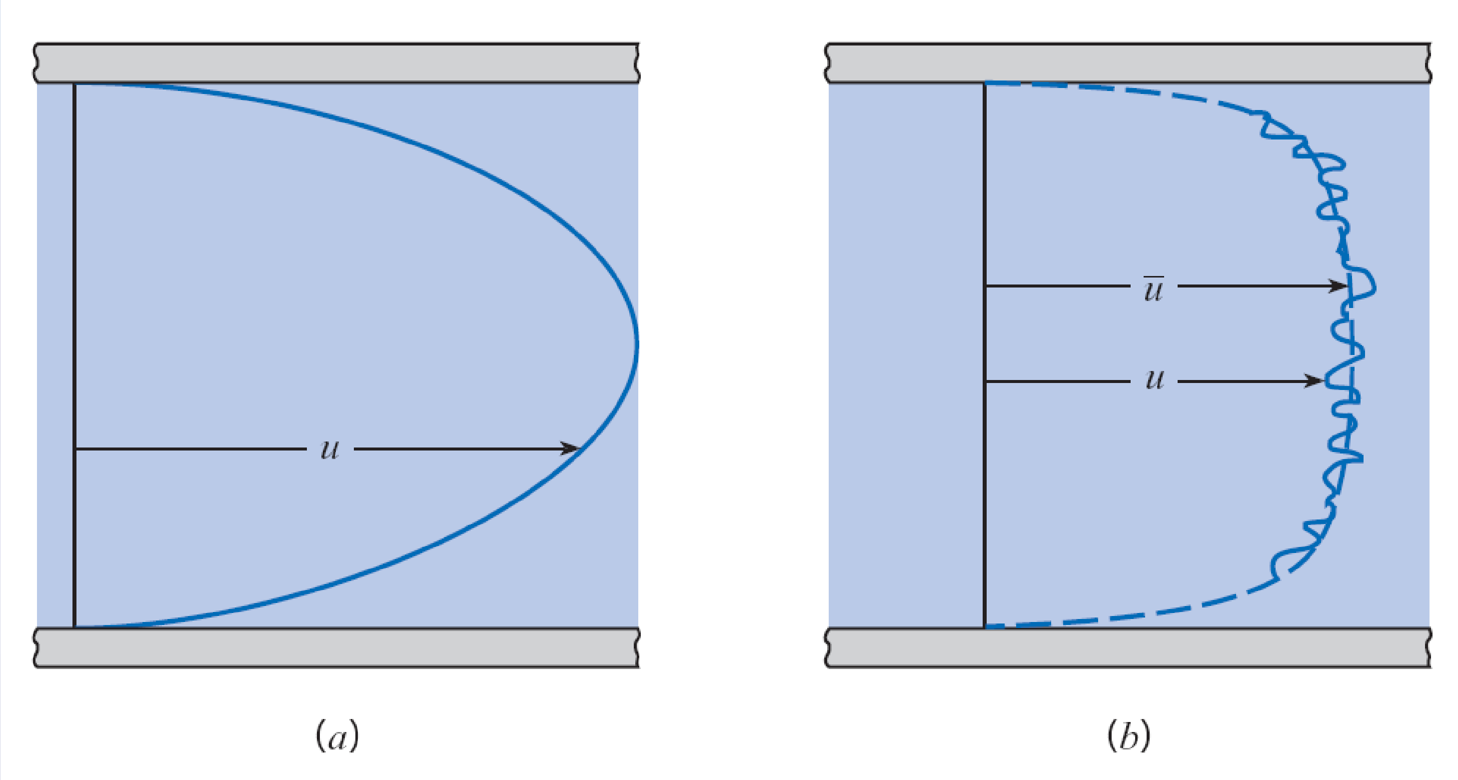
$$\begin{cases} u' = u - \bar{u} \\ v' = v - \bar{v} \\ w' = w - \bar{w} \end{cases}$$

$$T' = T - \bar{T}$$

$$r' = r - \bar{r}$$

Flow inside a pipe

Laminar Turbulent



(a) (b)

Turbulent flow is nearly constant across a pipe

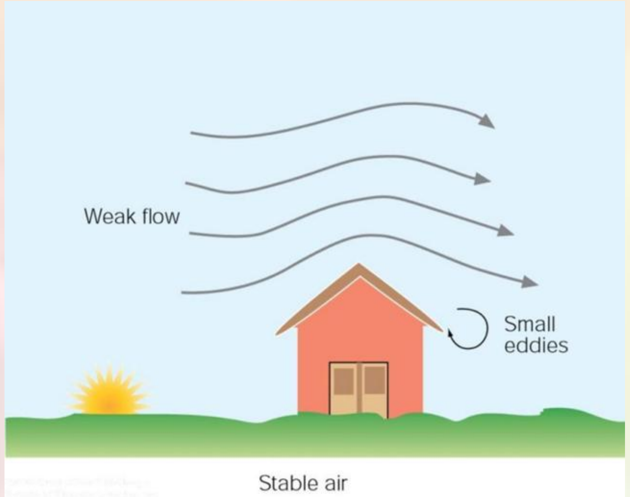
Flow in a pipe becomes turbulent either because of high velocity, because of large pipe diameter, or because of low viscosity.

Eddies

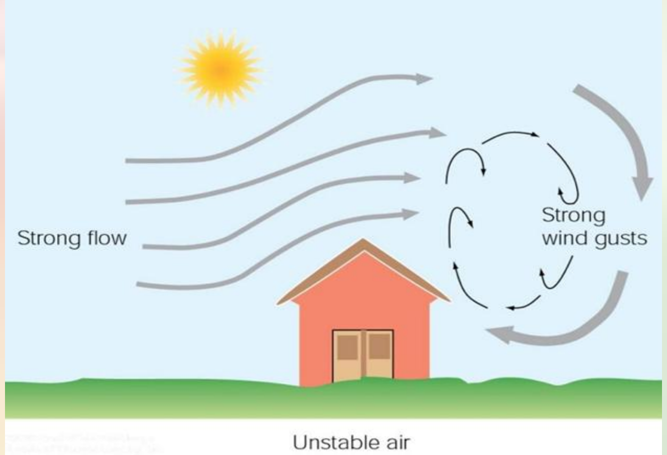
When the wind encounters a solid object, a whirl of air or eddy forms on the object's downwind side. The size and shape of the eddy often depends upon the size and shape of the obstacle and the speed of the wind.

Winds flowing past an obstacle.

(a) In stable air, light winds produce small eddies and little vertical mixing.



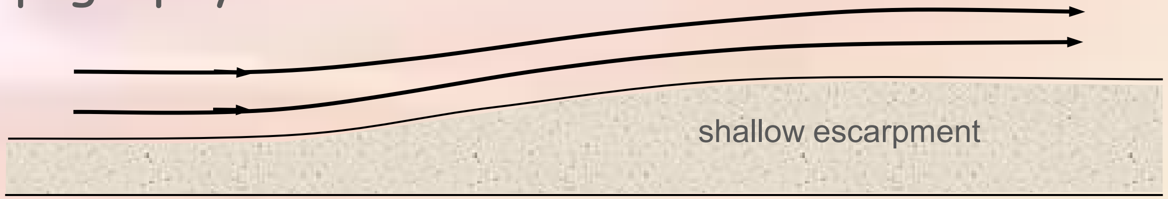
Greater winds in unstable air create deep, vertically mixing eddies that produce strong, gusty surface winds.

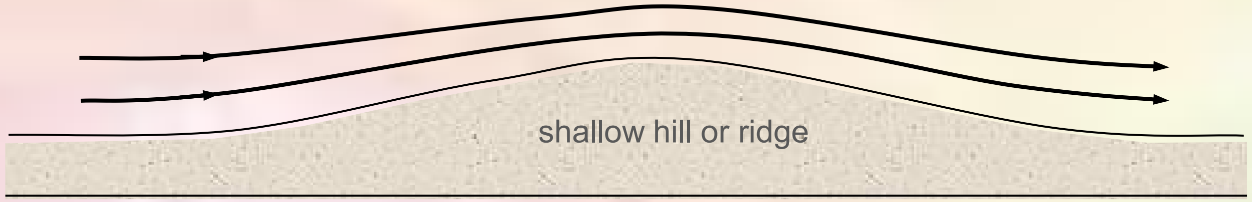


Atmospheric boundary layers and turbulence

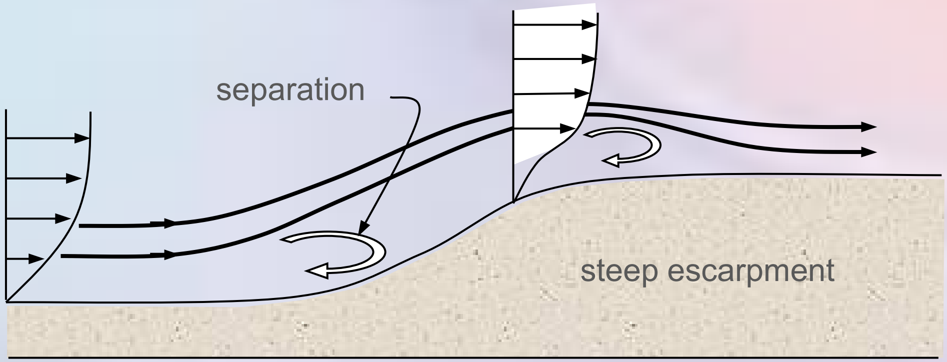
Effects of topography :

Shallow topography : no separation of flow (follows contours)





Predictable from computer models, wind-tunnel models



Steep topography : separation of flow occurs

Less predictable from computer models, wind-tunnel models OK at large enough scale

Inviscid and Viscous Flows

Viscosity

- The VISCOSITY of a fluid is a measure of its resistance to shearing.

- Air has a very low viscosity, the viscosity of ice is very high, and water has an intermediate viscosity between the two.

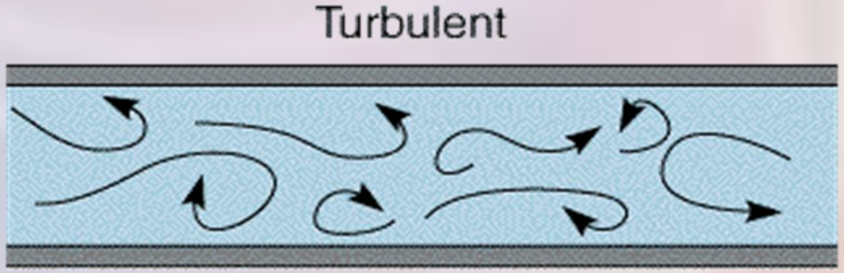
Viscosity is the fluid property that measures the resistance of the fluid to deforming due to a shear force.

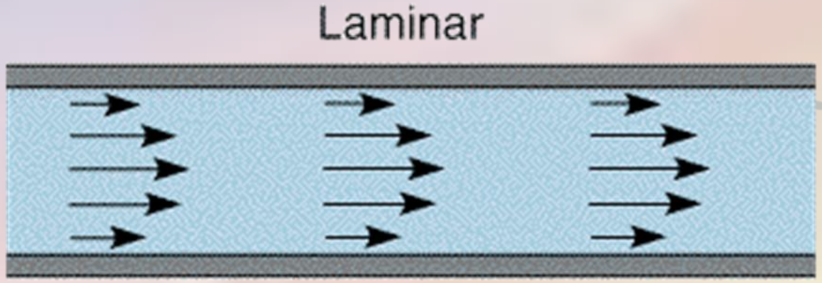
An ideal fluid is one that is incompressible and has no viscosity.

- Flow velocity
  - Flow velocity determines the type of fluid flow:
    - Laminar
    - turbulent

Laminar fluid motion is basically parallel to the underlying surface and only down current or downwind.

In turbulent flow (characteristic of water flowing at high velocity), masses of material move in an apparently random pattern. Eddies of upwelling and subsidence develops





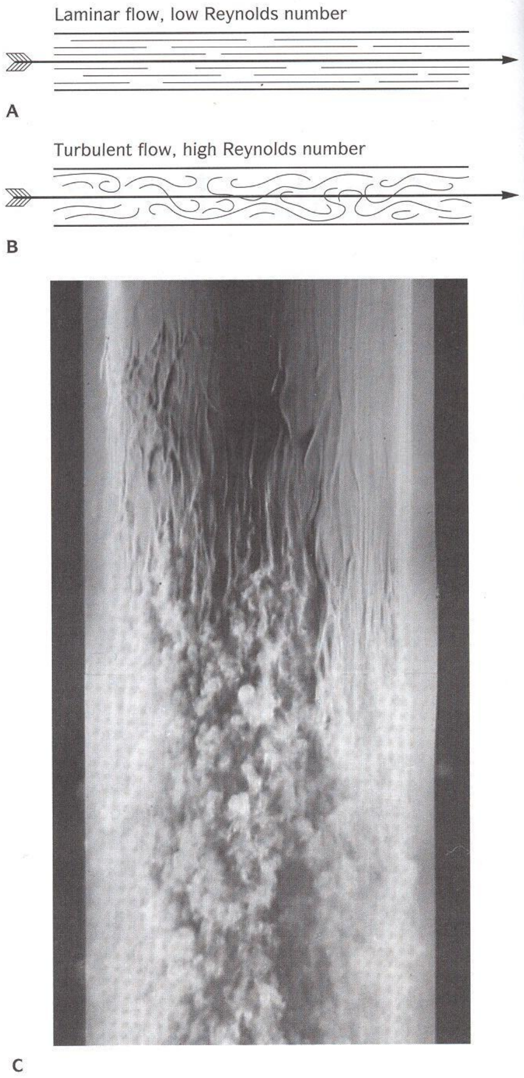


Figure 3.1

Contrasting flow streamlines for (A) laminar and (B) turbulent flow. In laminar flow, discrete parcels of fluid (streamlines) move in a parallel, sheetlike fashion and propel any sedimentary clasts downstream. In turbulent flow, streamlines become intertwined, and up and down eddies develop. Turbulent flow not only propels clasts downstream but also can lift particles into the flow. (C) The transition from laminar (*bottom*) to turbulent flow in water on a flat plate as seen by dye injection. Such a sharp transition is known as a hydraulic jump. (From Siever, 1988, *Sand*, p. 42; by permission of W. H. Freeman, New York.)

Turbulence

Group of eddies of different size. Eddies range in size from a couple of millimeters to the size of the boundary layer.

Reynolds Stress

Stress

Force per unit area (e.g. N m^{-2} or kg m^{-1} s^{-2})

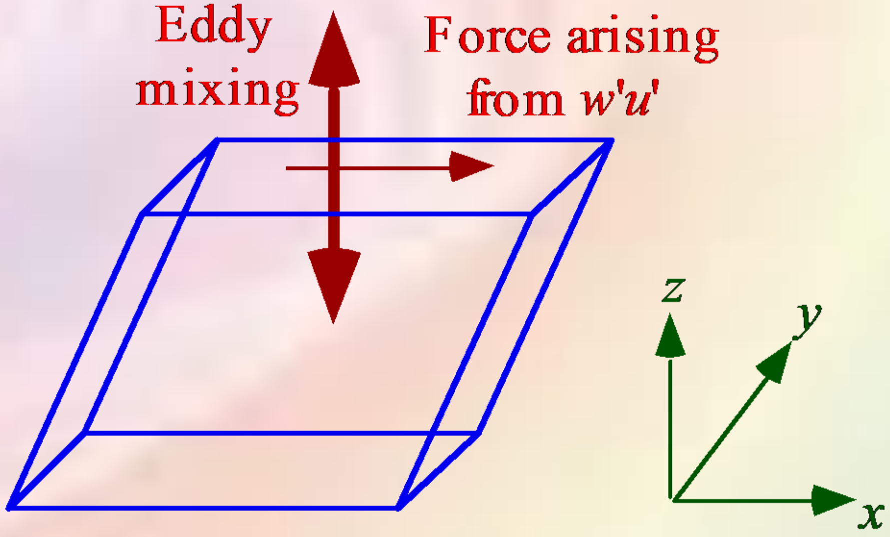
Reynolds stress

Stress that causes a parcel of air to deform during turbulent motion of air

Deformation by vertical momentum flux

$$\overline{w'u'}$$

Stress from vertical transfer of turbulent *u*-momentum



$$\tau_{zx} = -\rho_a \overline{w'u'}$$

zx = stress acting in x-direction, along a plane (x-y) normal to the z-direction

Momentum Fluxes

Magnitude of Reynolds stress at ground surface

$$\left|\tau_z\right| = \rho_a \left[\left(\overline{w'u'} \right)^2 + \left(\overline{w'v'} \right)^2 \right]^{1/2}$$

Kinematic vertical turbulent momentum flux ($m^2\ s^{-2}$)

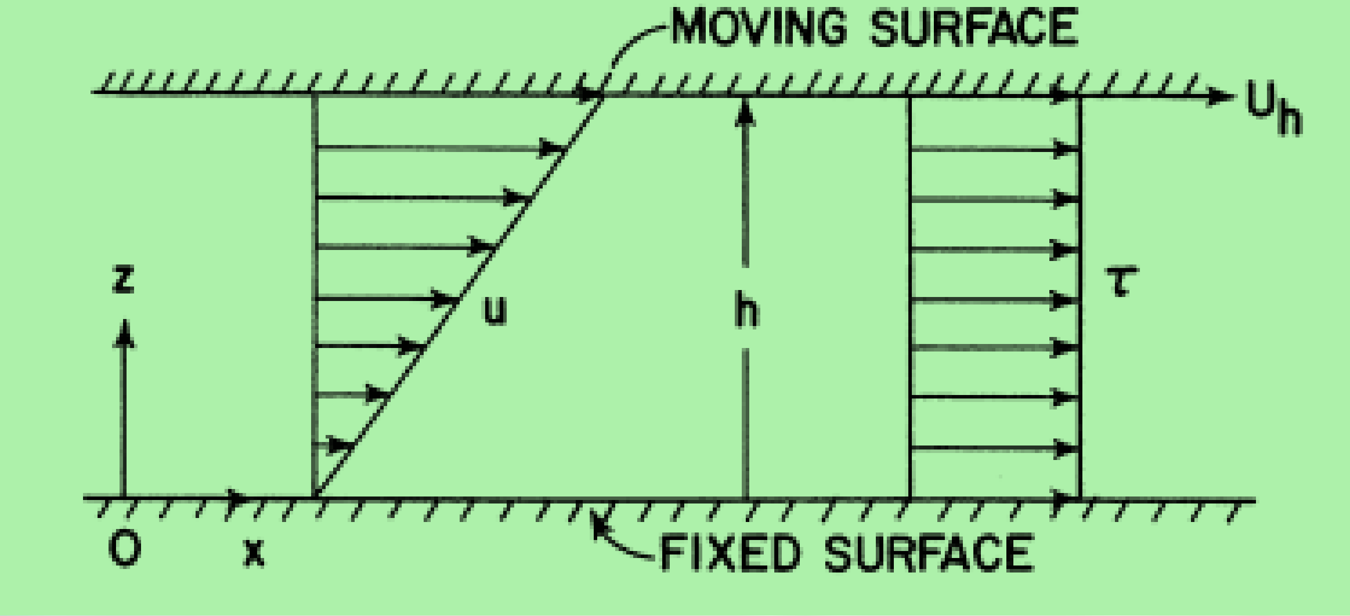
$$\overline{w'u'} = -\frac{\tau_{zx}}{\rho_a}$$

$$\overline{w'v'} = -\frac{\tau_{zy}}{\rho_a}$$

Friction wind speed ($m\ s^{-1}$)

Scaling param. for surface-layer vert. flux of horiz. momentum

$$u_* = \left[\left(\overline{w'u'} \right)_s^2 + \left(\overline{w'v'} \right)_s^2 \right]^{1/4} = \left(\left| t_z \right| / \rho_a \right)_s^{1/2}$$



$$\tau = \mu(\partial u/\partial z)$$

$$\begin{aligned}
\tau_{xy} &= \tau_{yx} = \mu(\partial u/\partial y + \partial v/\partial x)\\
\tau_{xz} &= \tau_{zx} = \mu(\partial u/\partial z + \partial w/\partial x)\\
\tau_{yz} &= \tau_{zy} = \mu(\partial v/\partial z + \partial w/\partial y)
\end{aligned}$$