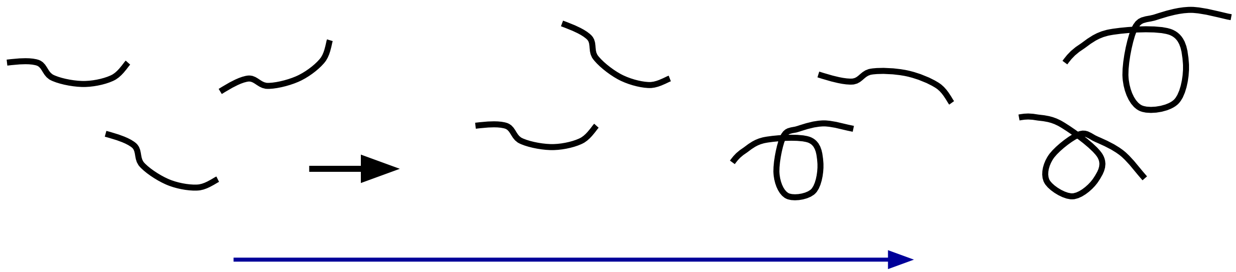
Atmospheric turbulence

The atmosphere is known to be in nonstop motion. Individual particles move randomly follow chaotic trajectories.

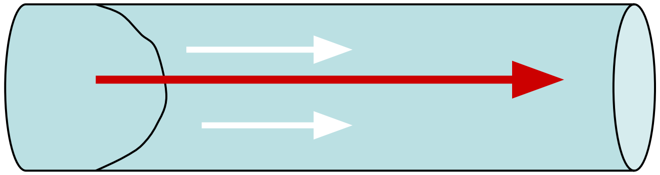


However, basically the particles move in a certain direction.

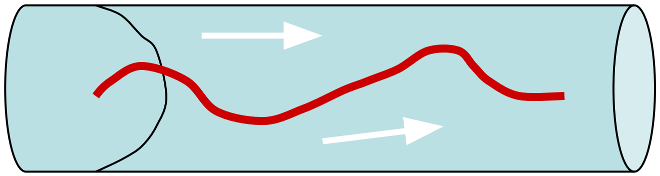
This regime of motion is called *turbulent regime of motion.*

At this regime, the motion velocity pulsates. A moving particle sharply changes its velocity.

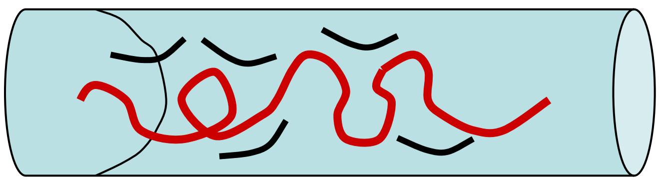
Turbulent motion makes a remarkable impact on the state of the atmosphere and the physical processes in it.



Small speed of motion. Particles move parallel each other. Laminar motion.



Speed of the ink particle are faster than the speed of general motion. The ink jet starts meandering.



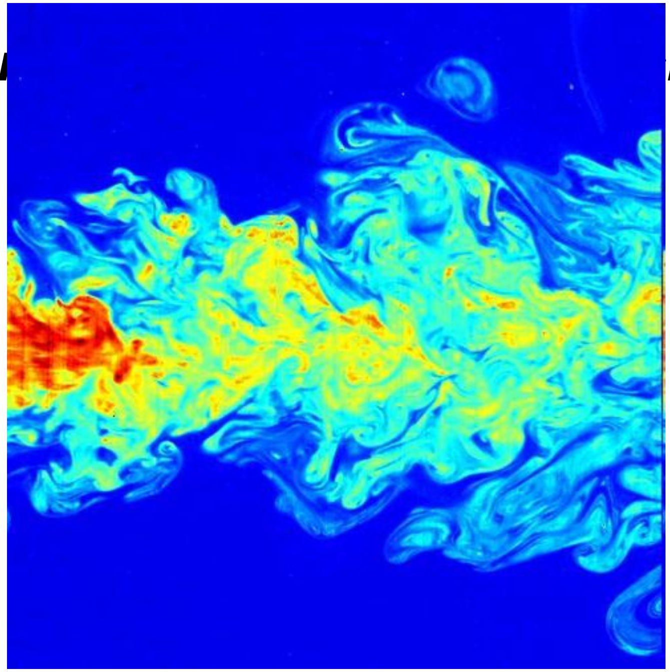
Fast motion. Trajectories of the motion distorted. That is *turbulent motion.*

Small vortexes produced by the turbulence are known as *EDDIES*.

*Water-pipe tap is opened just slightly → A small water jet is smooth (**laminar motion**).*

*Water pipe tap is opened widely → The water jet is rough (**Turbulent or eddy motion**)*

Lami ***igarette smoke***



Laminar and turbulent flow of cigarette smoke

- *For pipe flow, a Reynolds number above about 4000 will most likely correspond to turbulent flow,*
- *while a Reynold's number below 2100 indicates laminar flow.*
- *The region in between (2100 < Re < 4000) is called the transition region.*

Theoretical and experimental studies have shown that the character of liquid (gas) motion is suggested by *Reynolds Number.*

$$Re = \frac{\rho \cdot c \cdot l}{\eta}$$

- **Speed of motion** (c)
- **Distinctive (typical) scale of motion** (l)
- **Density of the liquid (gas)** (ρ)
- **Dynamic coefficient of molecular viscosity** (η)

Critical value of the number Re is different for different substances and conditions. As the number of Re reaches its critical value, the motion is transferred into turbulent character.

In case ρ and η are constant (that is true for a certain medium), the number Re depends on the speed and distinctive scale of motion.

Calculation Re numbers for the atmosphere suggested that the motion in the atmosphere are always turbulent.

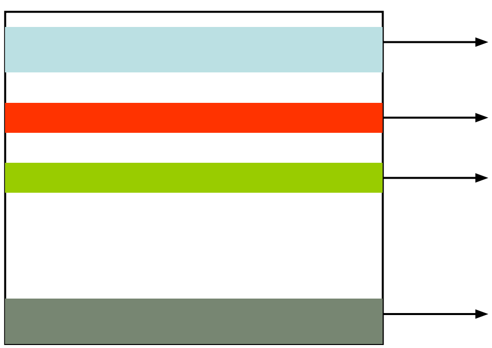
Along with Re number there are some others criteria for character of motion and intensity of the eddy development.

Turbulent motion of air results in disordered and rapid fluctuation of meteorological parameters. However, along with chaotic motion, all air particles are subjects to move with a mean speed. Therefore, *momentary speed of motion* c^* **can be presented as:**

$$c^* = c + c' \quad \text{or} \quad \vec{c}^* = \vec{c} + \vec{c}'$$

Mean speed (c) ***Pulsation*** (c')

Notion of admixture specific content



Mass of water vapor

Mass of ozone

Mass of CO_2

Mass of solid and liquid aerosols

A unit of air mass

Mass of a substance in a unit or air mass is called ADMIXTURE SPECIFIC CONTENT (ASC)

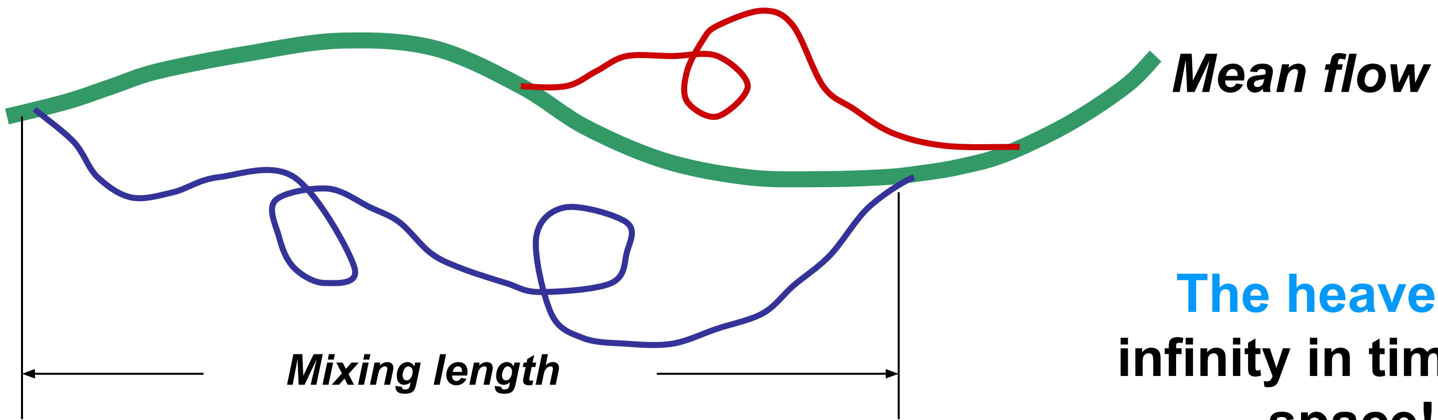
ASC vary in a wide range both in horizontal and vertical directions

For instance, the water vapor content is known as ***specific humidity (s),*** *or* ***fraction of water vapor.***

Eddy mole and mixing length

A separate particle taking part in eddy mixing is called

EDDY (TURBULENT) MOLE.

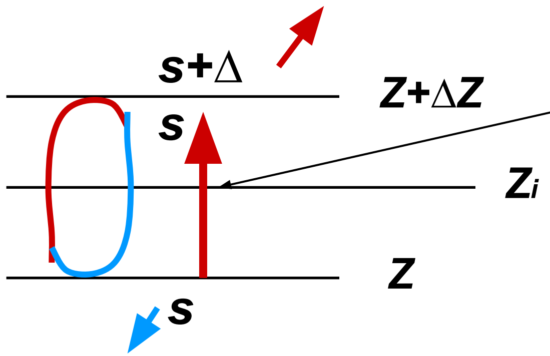


The heaven is infinity in time and space!

Any man is an insignificant particle in this infinity and boundlessness. What is the symbol of the infinity and boundlessness on the Earth? Certainly, it is the heaven! Any one appears from the infinity and goes into the infinity after his life is over, like an eddy mole, being formed in an atmospheric current, after a while mixes into the current and disappears there forever! (prof. G.G.Tarakanov)

When moving, the eddy moles transfer admixture and some physical properties of the air such as heat, moisture, and momentum. The most remarkable mixing takes place in vertical direction.

Usually ASC decreases with height (Δs<0), but in some rare cases, it can be opposite (Δs>0). Eddy mixing results in equalization of ASC.



The mass of admixture transferred by the eddy mixing for a unit of time through a unit of the surface at the altitude Z_i is called FLUX OF ADMIXTURE (Q).

It is obvious that the eddy flux must be proportional to the difference of ASC at the level Z and ΔZ related to a unit of the distance between those levels, i. e. $\Delta s / \Delta Z$

$$Q = -A \frac{\Delta s}{\Delta Z}$$

$$Q = -\lim_{\Delta Z \to 0} A \frac{\Delta s}{\Delta Z} = -A \frac{\partial s}{\partial Z}$$

Coefficient of eddy exchange (mixing coefficient)

$$\frac{\partial s}{\partial Z} \to m^{-1}; A \to kg \cdot s^{-1} \cdot m^{-1}$$

$$K = {}^{A}\!/_{\rho} \longrightarrow$$

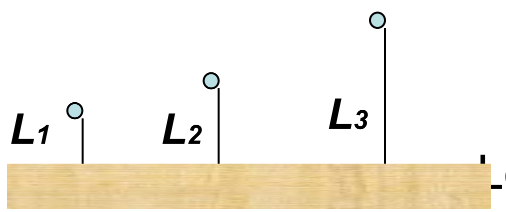
Coefficients *A* and *K* are not constants. Their value depend on: wind velocity and its variation, static stability, properties of the underlying surface, etc

Postulate of eddy exchange

During an interval of time, the amount of transferred substances through a surface upward and downward <u>must be equal.</u>

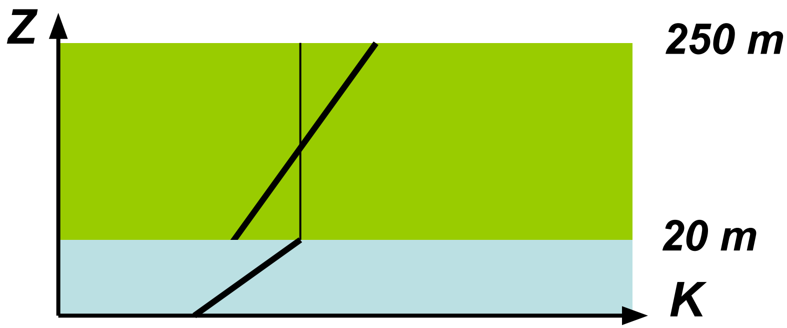
A* and *K* values** ← ***Wind pulsation ⇄ ***Mixing length, L***

$$\frac{\partial A}{\partial Z} > 0 \qquad \frac{\partial K}{\partial Z} > 0$$



Surface layer

The layer of the atmosphere, where eddy coefficient increases with height is called *SURFACE LAYER*



The most frequently S. L. height is 50 – 100 m

K values vary from 10^{-1} **to** 10^{1}

There are also molecular fluxes of various substances

***D* is molecular diffusion coefficient**

$$Q_m = -\rho D \frac{\partial s}{\partial Z}$$

$$T = 0^0 C \rightarrow D \approx 0{,}198 \cdot 10^{-4}$$

$$T = 20^0 C \rightarrow D \approx 0{,}283 \cdot 10^{-4}$$

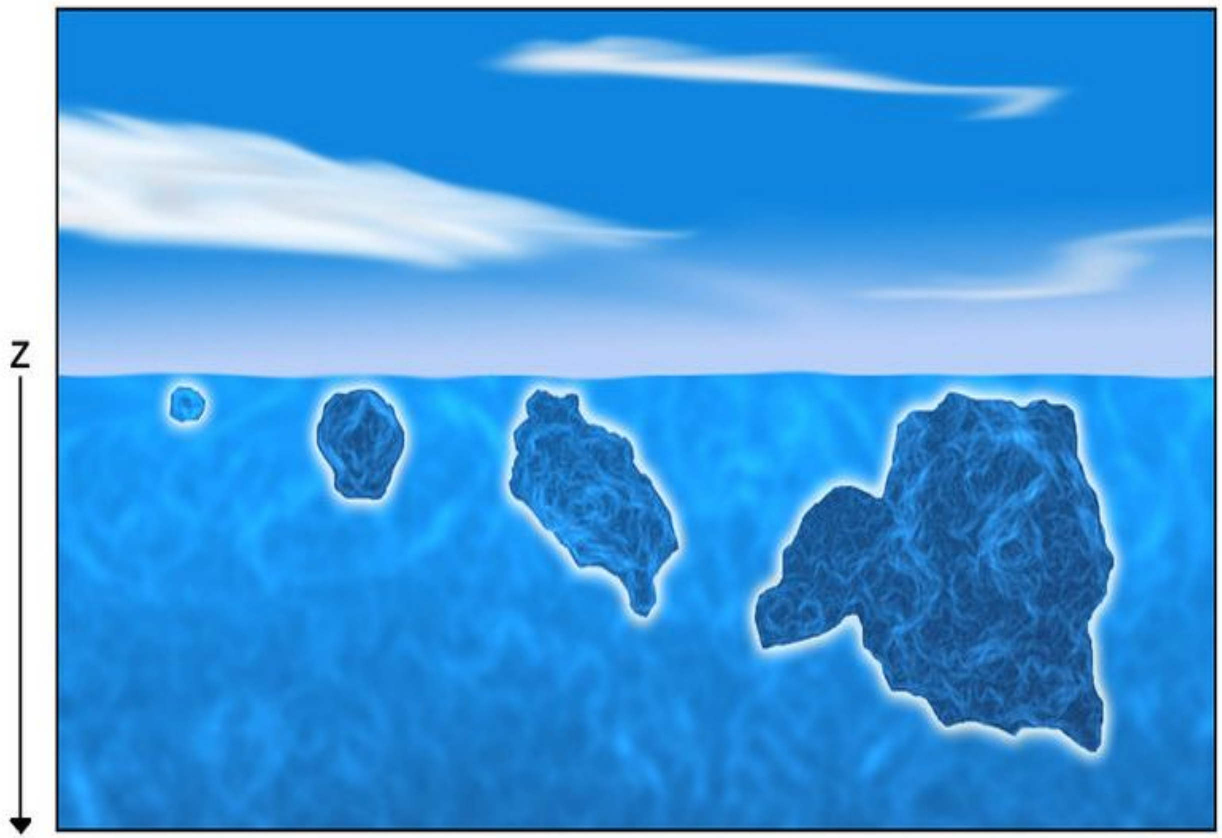
$$D << K$$

$$Q / Q_m \approx 10^5$$

We may neglect molecular fluxes

- Planetary boundary layer – k is close to 0 (few km)
- Surface layer – k increases (decimals –hundreds of m)
- Subsurface layer – laminar motion (close to Earth surface, 2 mm)

The surfac… bulent eddy is lin… objects hi… se size is constra… the surface.



The surface layer is the layer in a fluid where the scale of turbulent eddy is limited by the eddies' proximity to an interface. The objects highlighted in white above are turbulent eddies whose size is constrained by the proximity of the center of each eddy to the surface.

http://en.wikipedia.org/wiki/Surface_layer

Eddy exchange in horizontal directions

$$Q_x = -A'\frac{\partial s}{\partial x} = \rho K'\frac{\partial s}{\partial x} \qquad Q_y = -A'\frac{\partial s}{\partial y} = \rho K'\frac{\partial s}{\partial y}$$

$$A' << A \qquad K' << K$$

$$A/A' \approx 10^5 \qquad K/K' \approx 10^5$$

Horizontal eddy mixing can be neglected

- Semi empirical turbulent theory or “k” theory is a theory based on eddy coefficient notion.