Transport due to a macroscopic flow

convection
(advection by a macroscopic flow $\mathbf{u}$)

mass flux $\mathbf{J_C} = C\mathbf{u}$

heat flux $\mathbf{J_C} = \rho C_p T\mathbf{u}$

$$\frac{\partial T}{\partial t} + \mathbf{u}.\nabla T = \kappa \Delta T + \frac{R}{\rho C}$$

$$\frac{\partial C}{\partial t} + \mathbf{u}.\nabla C = D \Delta C + R$$

convection-diffusion equations

Convection vs diffusion :

Peclet number

Heat transfer $Pe = \frac{UL}{\kappa}$

Mass transfer $Pe = \frac{UL}{D}$

$Pe \to \infty$

No diffusion, pure advection by the flow

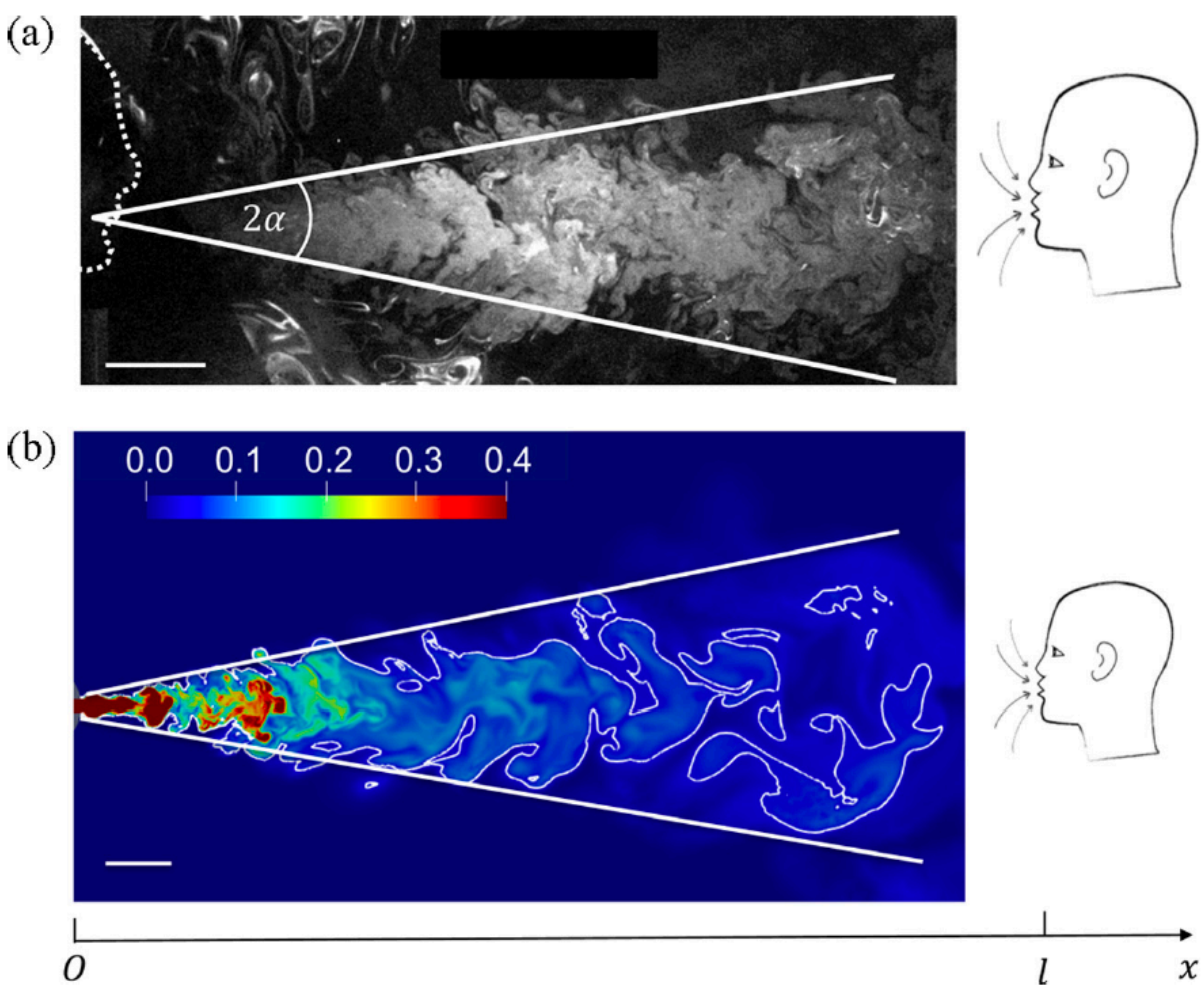
In random velocity fields (porous media, turbulent flows) : dispersion by the flow

$Pe \gg 1$

Convection dominates, diffusion cannot be ignored transport fluxes controlled by boundary layers

$Pe \ll 1$

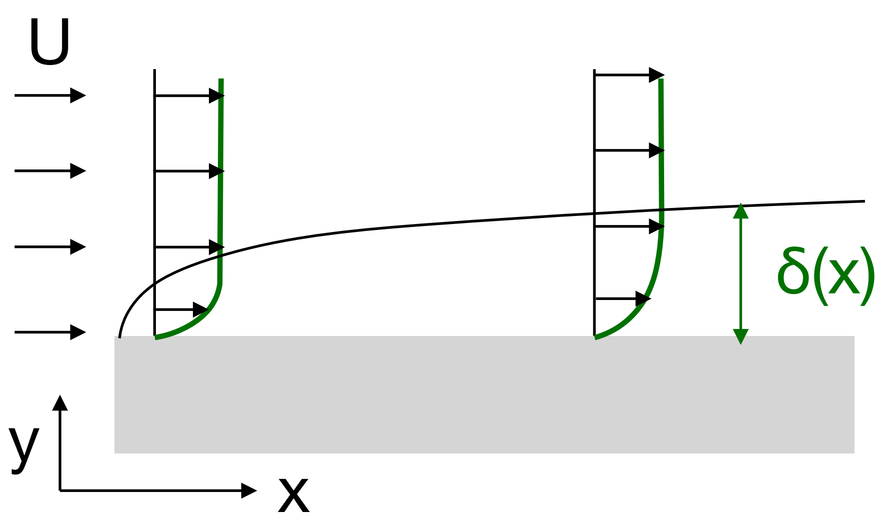
Diffusion dominates, convection is neglected



Towards improved social distancing guidelines: Space and time dependence of virus transmission from speech-driven aerosol transport between two individuals, F. Yang, et al., Phys. Rev. Fluids 5, 122501(R) (2020)

Boundary layers and the Reynolds analogy

Transport of momentum



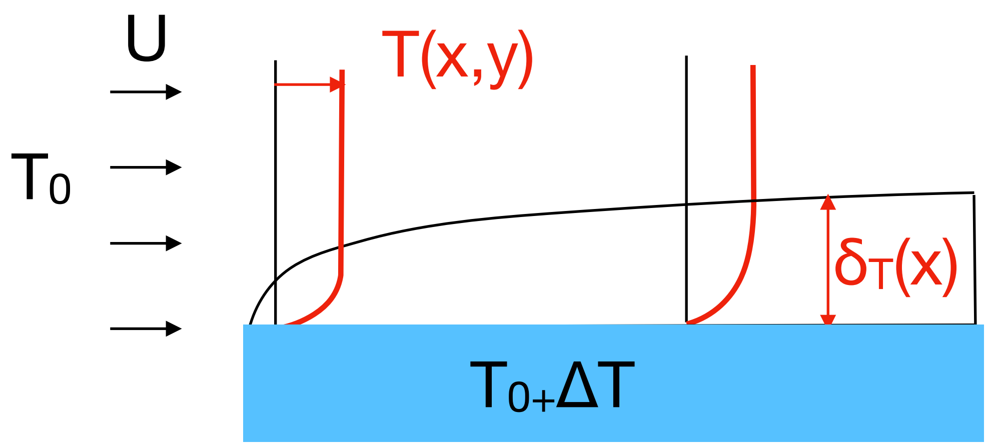
$$\delta(x) \sim \sqrt{\frac{\nu x}{U}}$$

$$\delta(x) \sim x \ Re_x^{-1/2}$$

Friction drag ~ wall shear stress

$$\sigma_{xy} = \eta \frac{\partial u_x}{\partial y} \sim \eta \frac{U}{\delta(x)}$$

Transport of heat or mass



$$\delta_T(x) \sim x \left(\frac{Ux}{\kappa}\right)^{-\alpha}$$

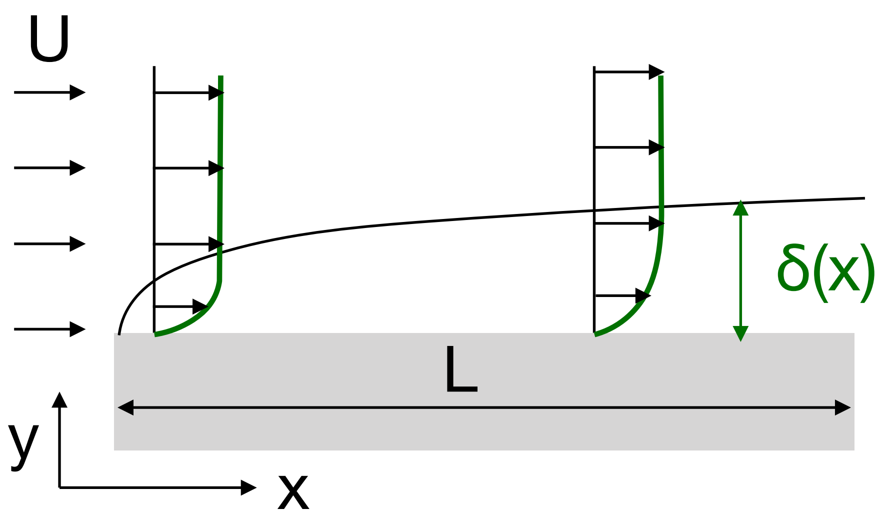
$$\delta_T(x) \sim x \ Pe_x^{-\alpha}$$

Flux at the wall

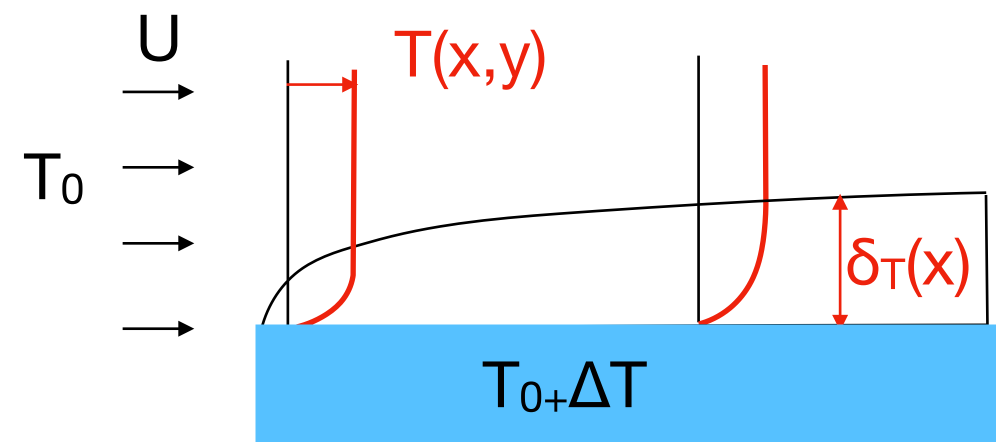
$$J_Q(x) = -\lambda \frac{\partial T}{\partial y} \sim \lambda \frac{\Delta T}{\delta_T(x)}$$

Boundary layers and the Reynolds analogy

Transport of momentum



Transport of heat or mass



$$Re \gg 1$$

↓

Thin momentum boundary layer

$$\delta \ll L$$

↓

Velocity gradient at the wall

↓

Friction drag

$$Pe \gg 1$$

↓

Thin temperature boundary layer

$$\delta_T \ll L$$

↓

Temperature gradient at the wall

↓

Heat flux to the wall