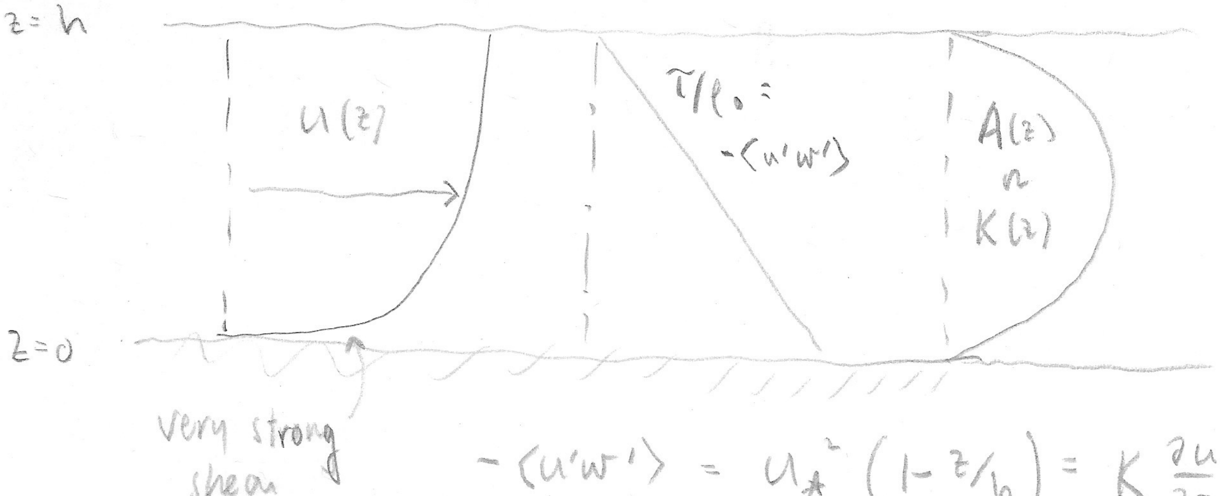
RG

"Phenomenology" of Boundary-Layer Turbulence

7/24/2014

1

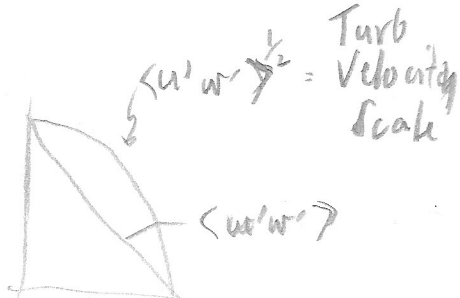
- what we observe; what we think matters



$$-\langle u'w'\rangle = u_*^2 (1 - z/h) = K \frac{\partial u}{\partial z}$$

You can't have a no slip condition without viscosity

$$K = L^2 T^{-1} = \text{Velocity} \times \text{Length}$$

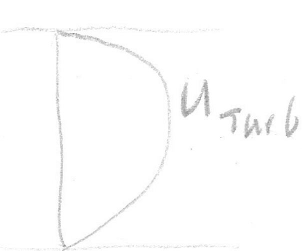


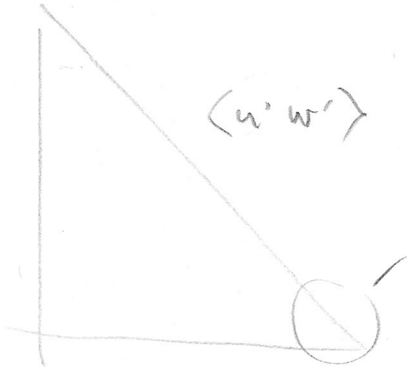
$$u_{Turb} \sim u_* \approx \langle u'w'\rangle^{1/2}$$

$$u_{Turb} \approx u_* \left(1 - \frac{z}{h}\right)^{1/2} \quad \text{and} \quad K = \kappa u_* (1 - z/h)$$

$$K(z) = u_{Turb} L_{Turb} \Rightarrow L_{Turb} = K / u_{Turb}$$

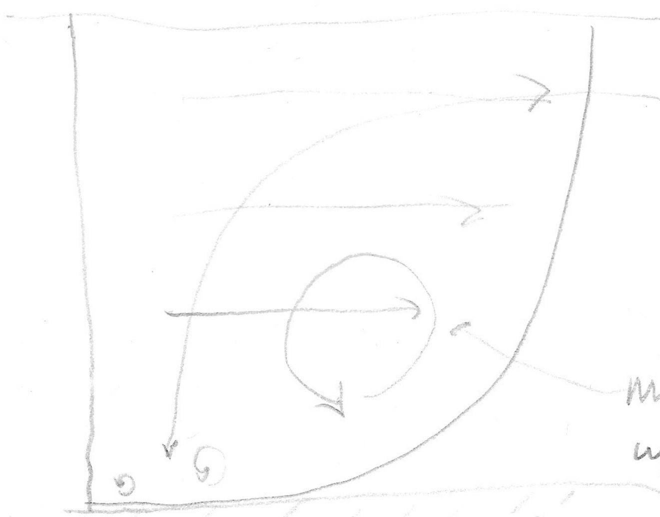
$$L_{Turb} = \kappa z (1 - z/h)^{1/2}$$





bottom 10% of BL called "constant stress layer" and in it $\langle u'w' \rangle \simeq u_*^2$

and log layer fit is most robust there (easy for other physics to affect things higher up.)

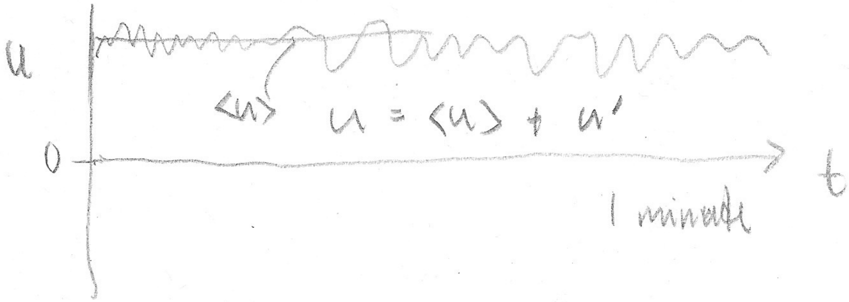


little eddies = small pressure perturbations from $\underline{u}$ that closes back in on itself

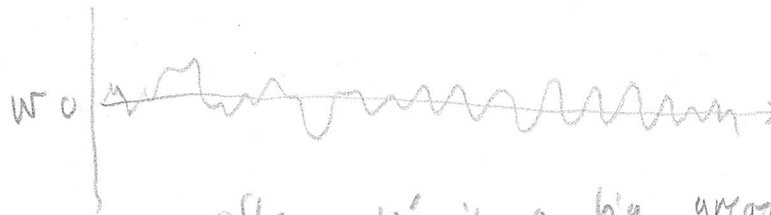
more room for bigger eddies up here

Turbulence ~ isotropic:

Turbulence Spectrum



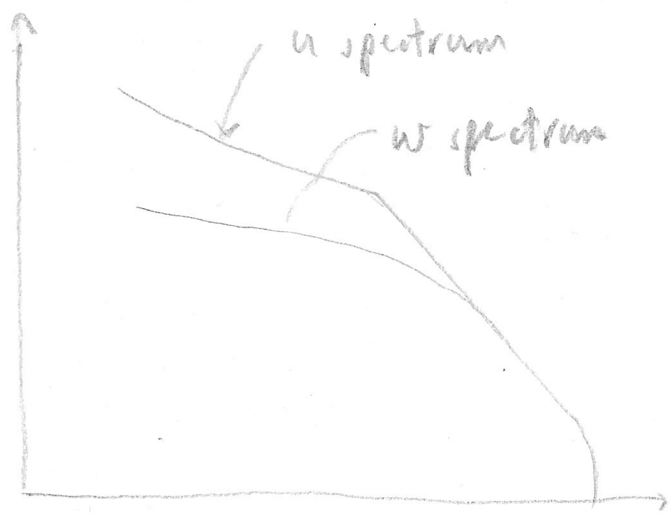
data from the Mast



$w = \langle w \rangle + w'$

often u' is a bit greater than w'

$u'(t) = \sum e^{i\omega_i t}$ FFT



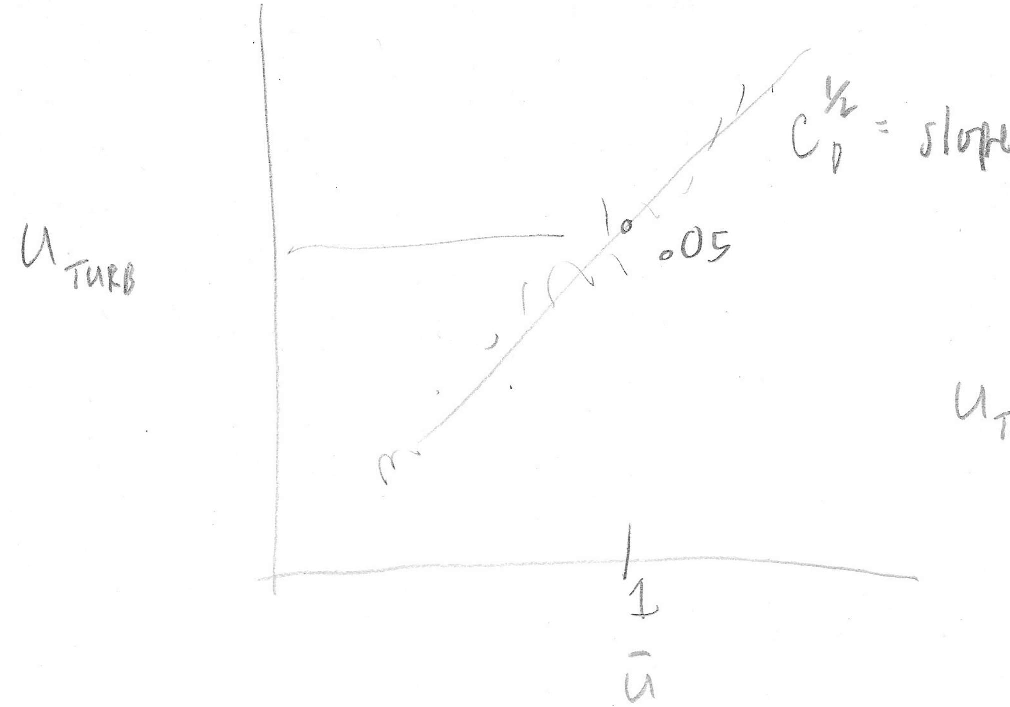
For your study place: what is the turbulent velocity scale, and where in the water column? (extra credit – what is L_{turb}?) and what is $\langle u \rangle$?

$\overline{u'w'} \sim K \frac{\partial u}{\partial z} \sim C_d U^2 \sim 3\times10^{-3} \cdot 1^2$ so $U_{TURB} \lesssim \left(3\times10^{-3}\ \frac{m^2}{s^2}\right)^{\frac{1}{2}}$ $\frac{3}{1000}$ $\frac{1.5}{300}$ $\frac{1}{200}$

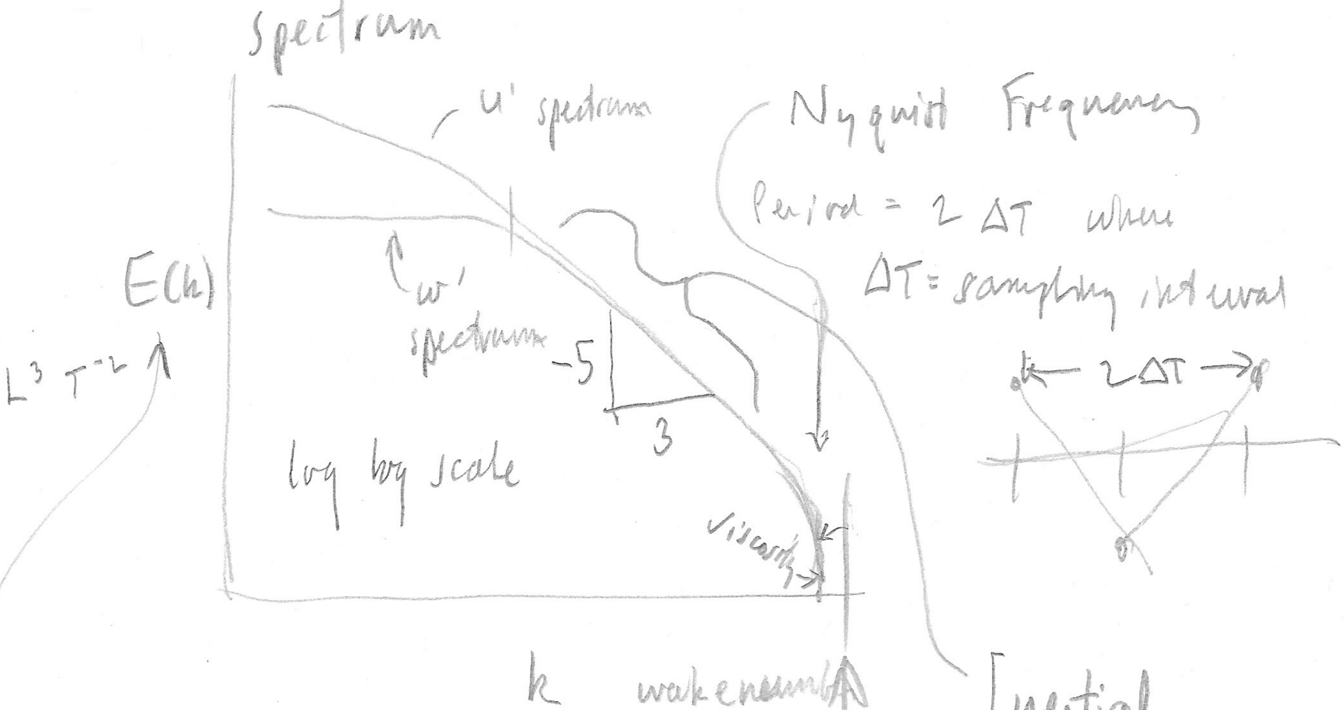
$=$ ~~5 mm/sec~~ !
5 cm/sec

at 1 m) $L_{Turb} \sim .4$ m $\langle u \rangle = 1$ m/s

GI Taylor
Francis Bretherton
Peter Rhines
PM



$$u_{TURB} \sim C_D^{1/2}\,\bar{u}$$



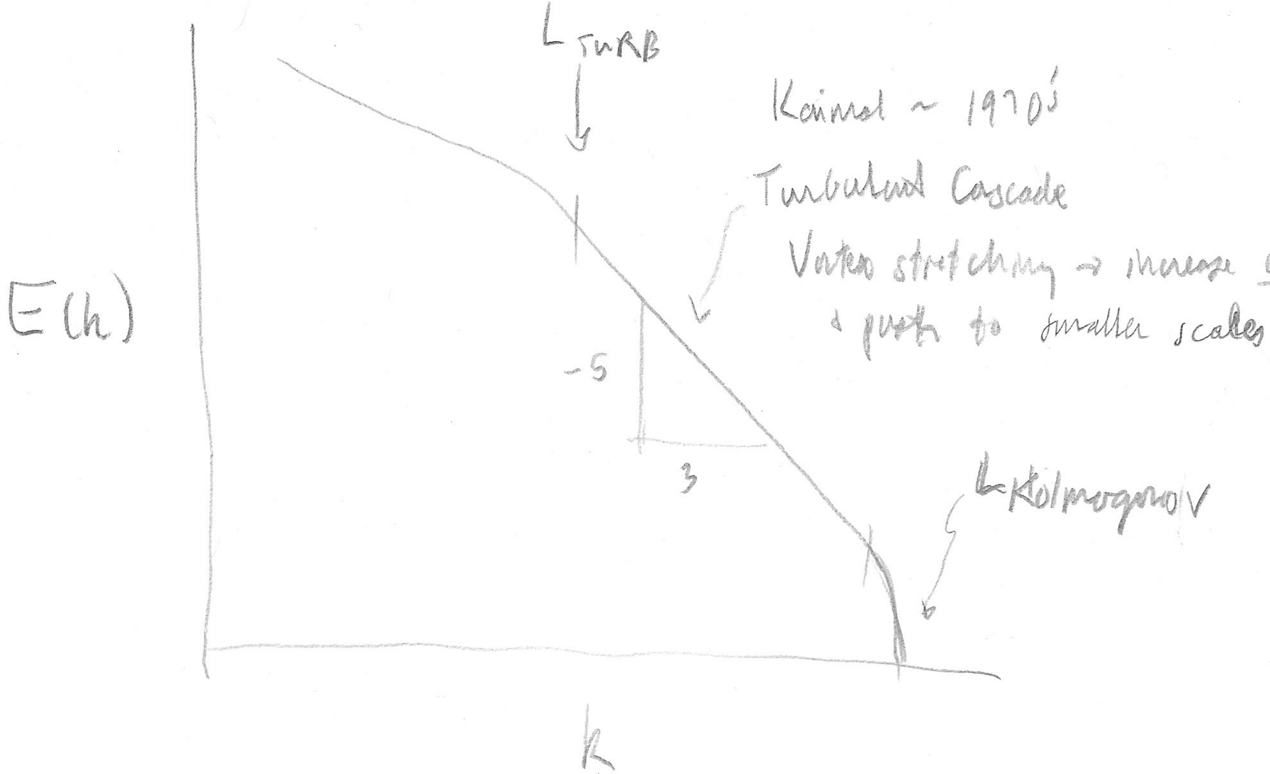
energy / wave number

$$\int_0^{k_{Nyquist}} E\,dk = \langle u'^2 \rangle k$$

Inertial Subrange

L_{TURB} to Dissipation Scale

smallest = Kolmogorov Scale



- When eddies → small scales it is a one way trip → viscosity

like billows in clouds

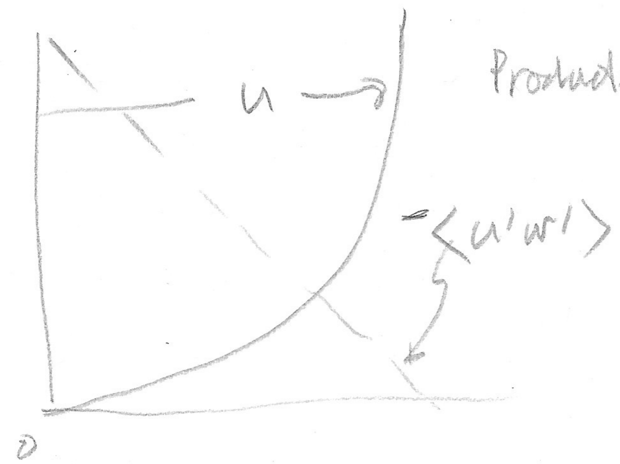
- Generally there is creation of larger & smaller scales (where energy is lost)

TKE equation

$$\cancel{\left(\frac{\partial}{\partial t} + \underline{u}\cdot\nabla\right)}\text{TKE} \cong \text{Production} - \text{Dissipation}$$

Ignore compared to RHS Terms $\Rightarrow$ Production = Dissipation

What is Production?



$$\text{Production} = -\langle u'w' \rangle \frac{\partial \langle u \rangle}{\partial z}$$

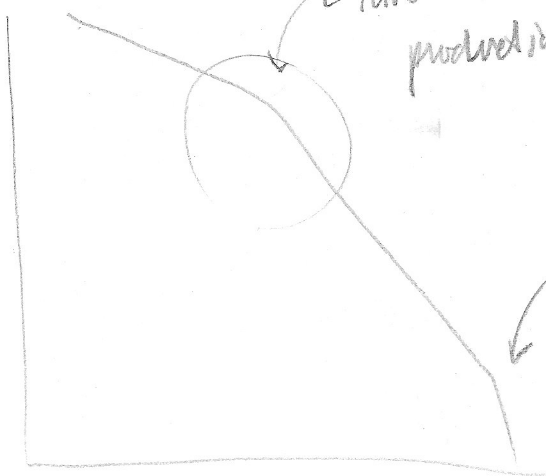
(Derived from an Energy Equation)

Loss of Mean KE
$\Rightarrow$ Gain of TKE

$u^2 + uu' + u'u + u'^2$

$$\langle u_f\, \underline{u}_f \cdot \nabla u_f \rangle = \langle (u + u')\left[(uu)_x + (uv)_y + (uw)_z\right]$$

$$u\langle u'w' \rangle_z = \left[u\langle u'w' \rangle\right]_z - \langle u'w' \rangle \frac{\partial u}{\partial z}$$



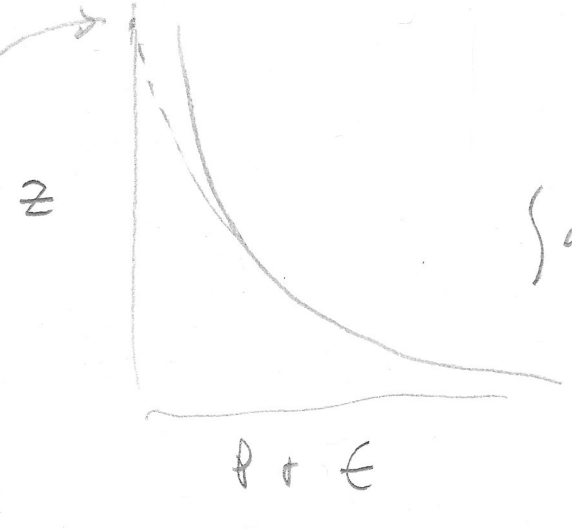
$$\epsilon = \nu\left(\frac{\partial u_i}{\partial x_j}\right)^2$$

$$\frac{L^2}{T}\frac{1}{T^2} \sim \frac{L^2}{T^3} \sim \frac{W}{kg}$$

in the log layer

$$\epsilon = -\underbrace{\langle u'w'\rangle}_{u_*^2}\ \underbrace{\frac{\partial\langle u\rangle}{\partial z}}_{\frac{u_*}{\kappa z}} = \frac{u_*^3}{\kappa z} \qquad \frac{L^2}{T^3}$$

(Production



goes to zero at surface if you consider full expressions.

$\int$ al is finite because we start from z_0 instead of $z = 0$. ✓

at 1 m.a.b. $C_d = 3\times10^{-3}$, $z = 1$ m, $u = 1$ m/s

$u_* \sim \sqrt{C_d} = 0.05$

$$\epsilon = \frac{0.05^3}{.4} = 3\times10^{-4}\ \frac{W}{kg}$$