# TRANSPORT IN LAKES

OVERVIEW: LIMNOLOGY

The study of lakes (Gr.: limnos)

LAKE: Inland basin of water

Most often, but not alway, fresh.

Represent about 2.5 million $km^2$ of earth's surface

Out of ~ 500 mill $km^2$ total so

~ 0.5% of surface

LAKE Water Mass ≃ $2.5 \times 10^{16}$ kg

~ 0.002% of TOTAL WATER

YET STILL LARGE & VITAL

# LAKES ARE TRANSITORY ON GEOLOGIC TIME SCALES

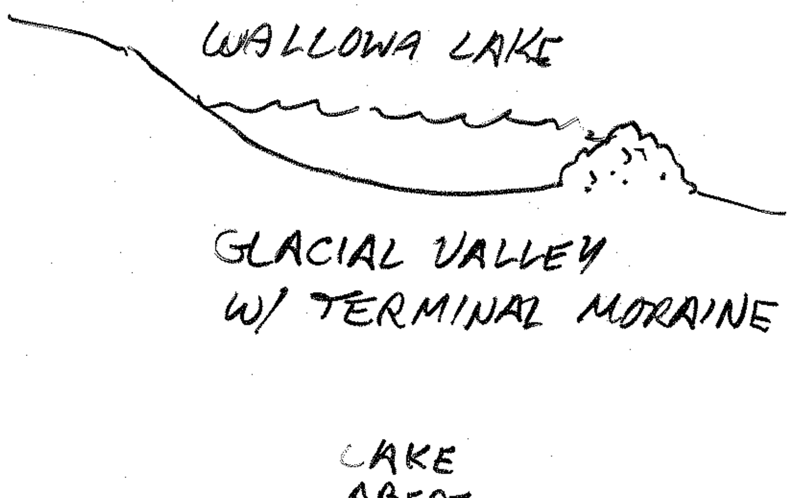
"... usually born of catastrophes, to mature and to die quietly & imperceptibly."

— G. Evelyn Hutchinson
(A Treatise on Limnology)

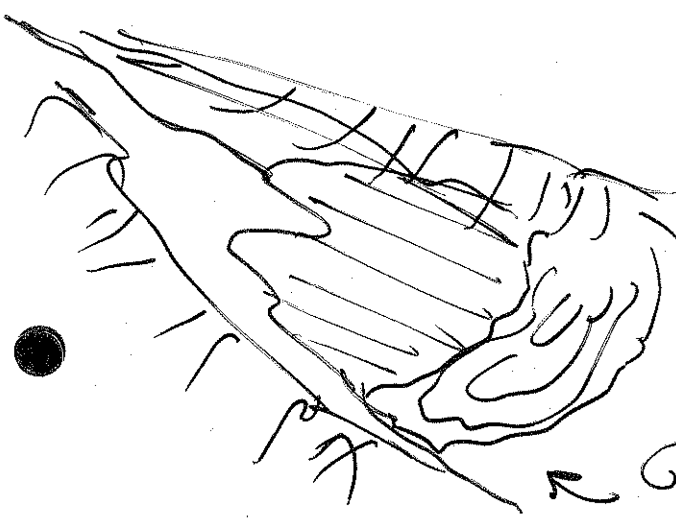
## FORM IN MANY WAYS

CRATER LAKE

CALDERA OF VOLCANO

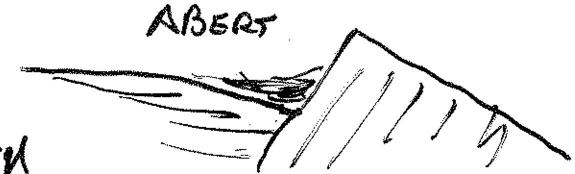



GLACIAL VALLEY W/ TERMINAL MORAINE

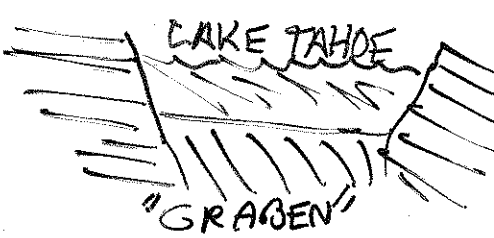


VALLEY BLOCKED BY SLIDE, LAVA, ← GLACIAL ACTION

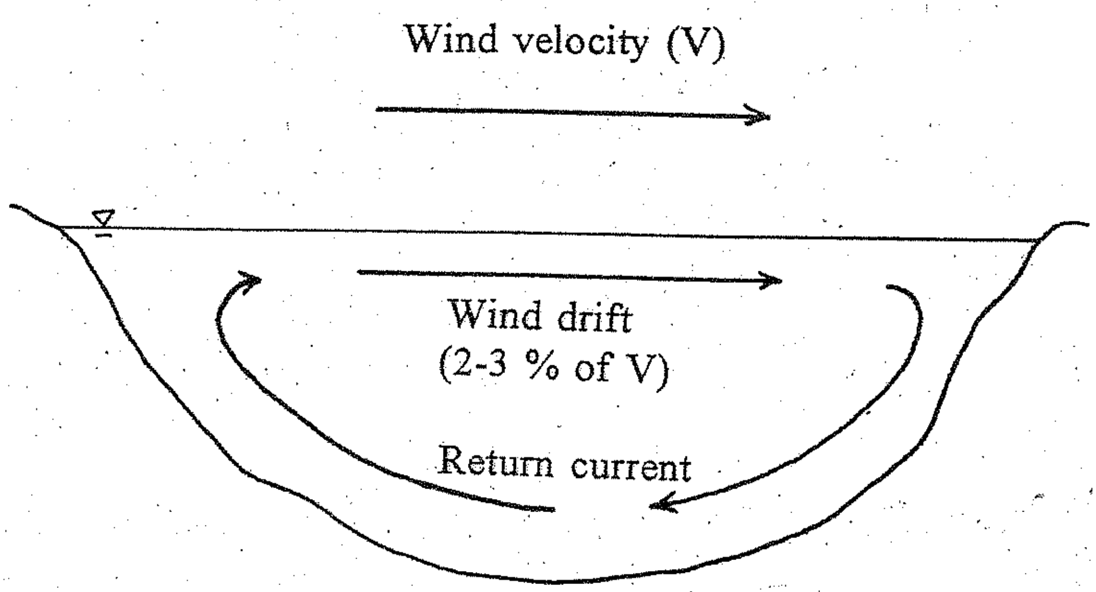
LAKE ABERT



FAULTING

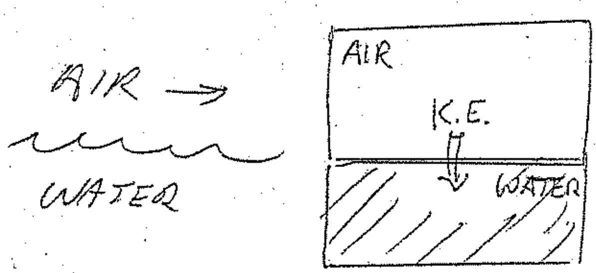



"GRABEN"




Wind-driven currents in a lake. (a) Circulation in a small lake of simple geometry. water current, or *wind drift*, averages 2 to 3% of wind velocity. Deeper in the lake, a *t* is established, returning water to the upwind end of the lake. (b) In a large lake : Michigan, variability of winds, complex lake geometry, and other forces (such as effect) lead to complex patterns of water movement [Ayers *et al.* (1958)] *(Figure*

**Why is current only 2-3% of wind velocity**




Do a kinetic energy balance

At EQUILIBRIUM

$K.E._{AIR} \approx KE_{water}$

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$KE = \frac{1}{2} m V^2$ so...

$$m_a V_a^2 = m_w V_w^2$$

$$\frac{m_a}{m_w} = \frac{V_w^2}{V_a^2} = \left(\frac{V_w}{V_a}\right)^2$$

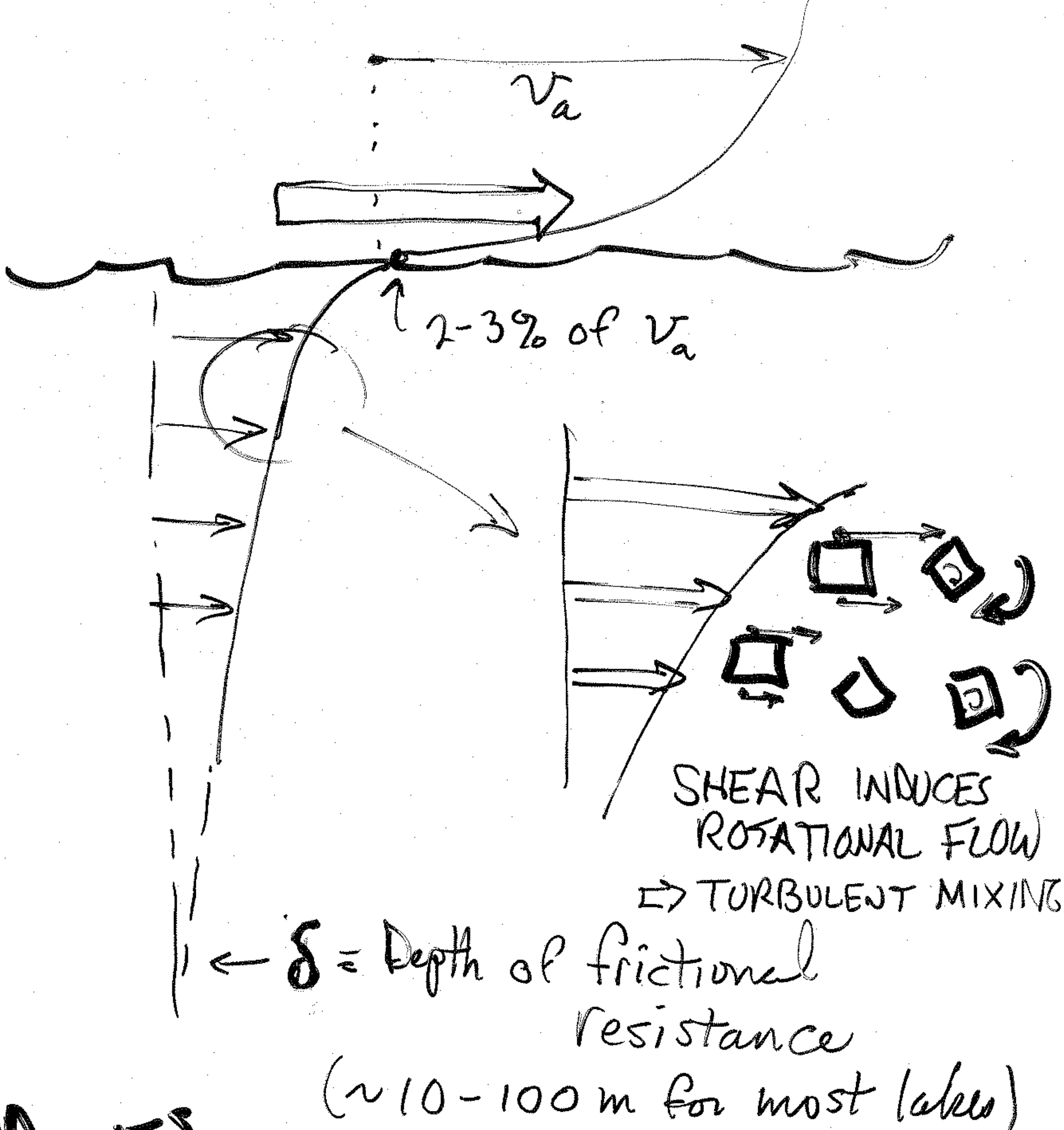
$$\frac{m_a}{m_w} = \left(\frac{Vol_a}{Vol_a}\right)\frac{\rho_A}{\rho_w} = \left|\frac{V_w}{V_a}\right|^2$$

$$\frac{V_w}{V_a} = \sqrt{\frac{\rho_A}{\rho_w}}$$

$$\frac{V_w}{V_a} \approx \sqrt{1/1000}$$

$$\approx 1/30 \approx 0.03$$

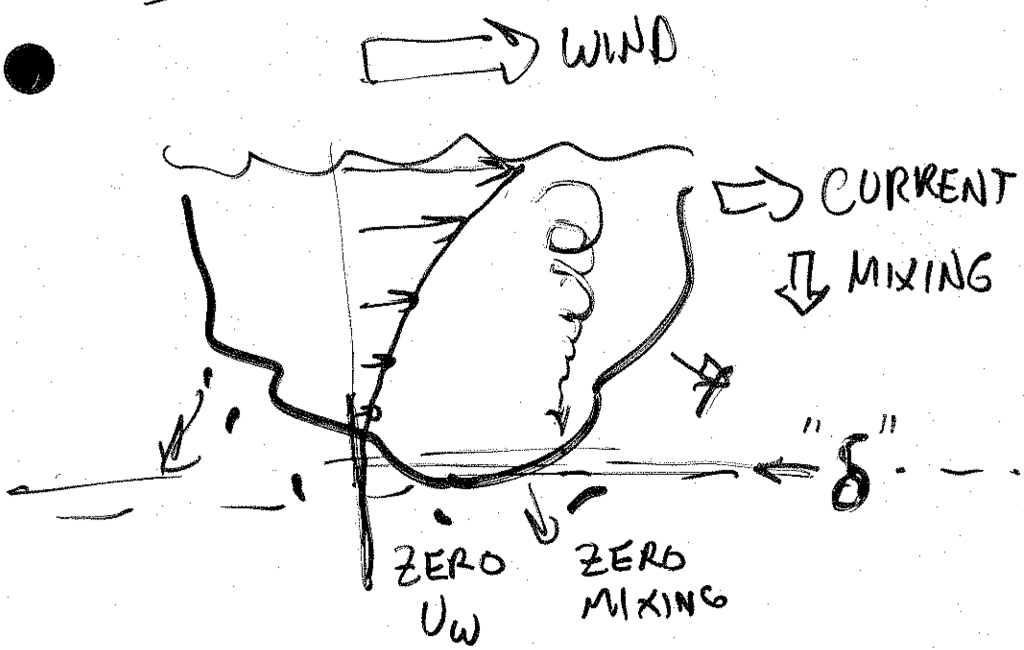
# Vertical Structure of Wind-Driven Flow



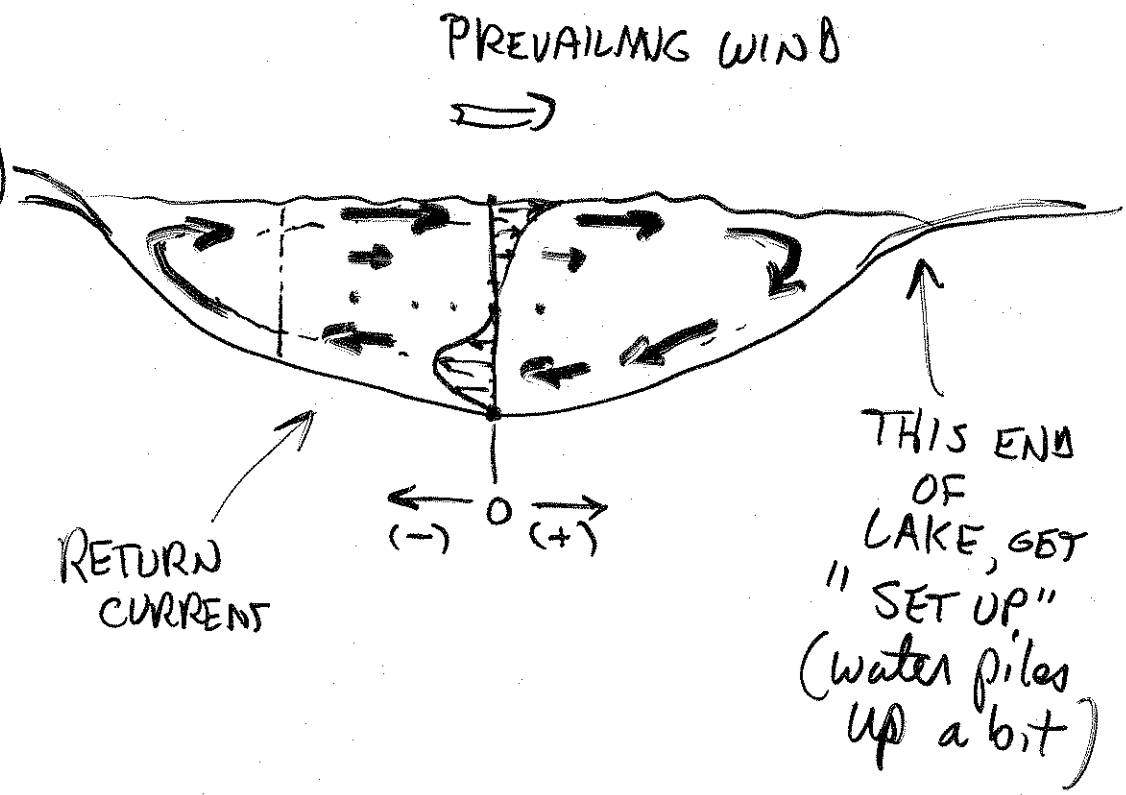

SO WIND CURRENTS LEAD TO:

- Horizontal ADVECTION
- Vertical DISPERSION (MIXING)

# "INFINITE LAKE"




# FINITE LAKE (Real)

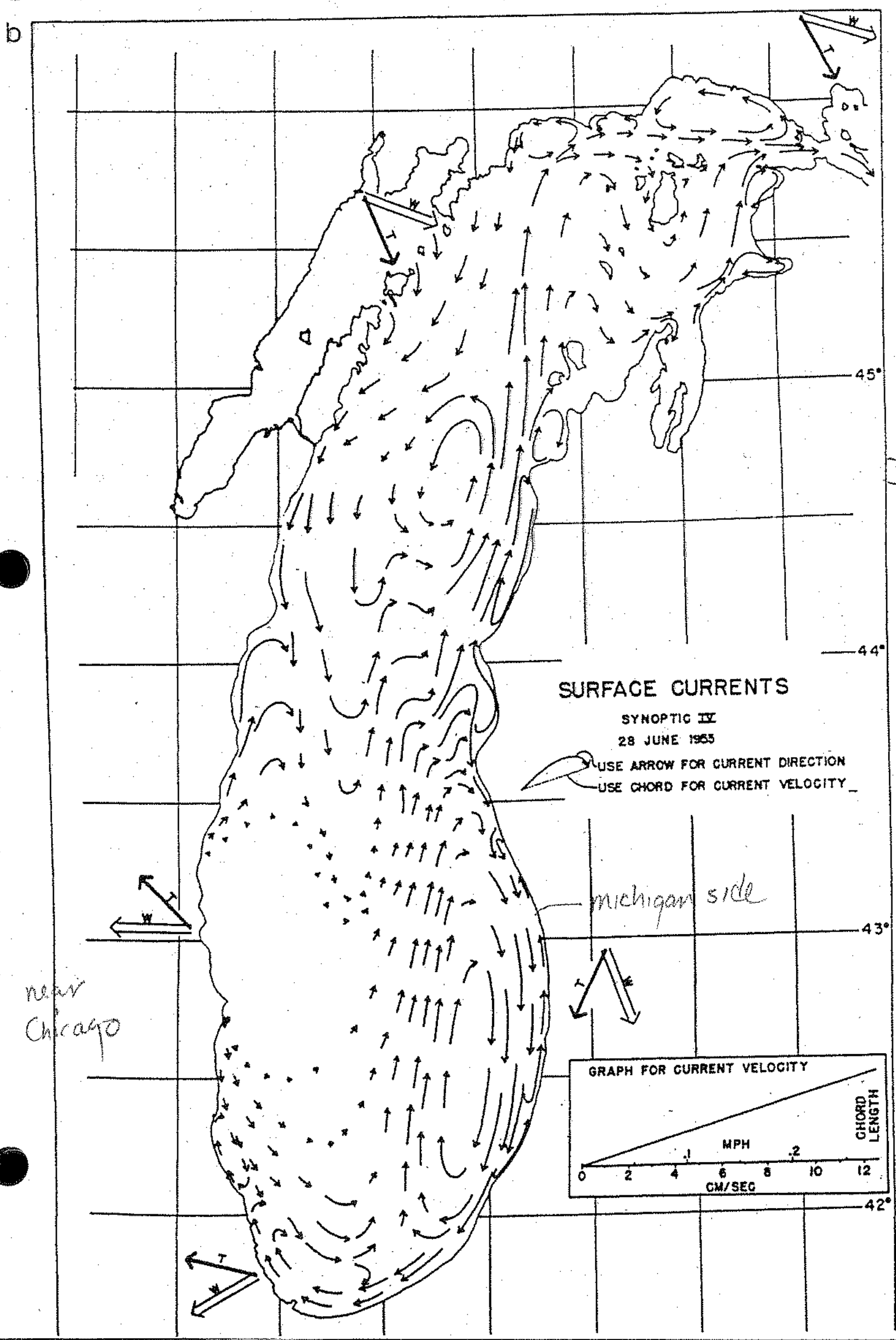


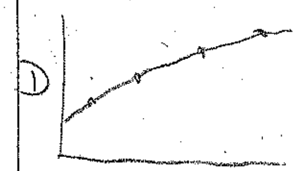
Lake michigan

D is not constant with respect to time

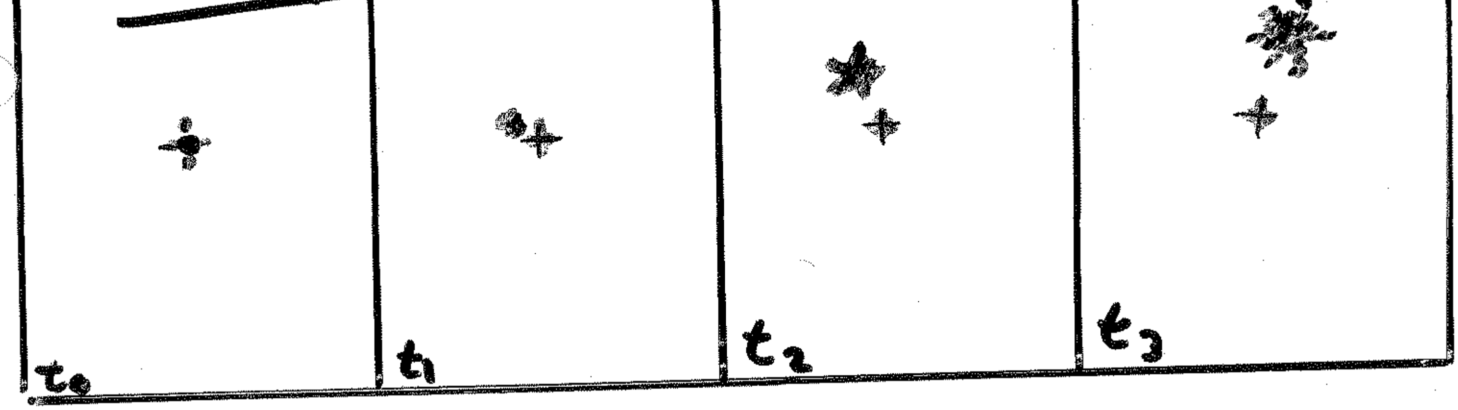
$D_{t_2} = D_{t_1} (\Delta t)^{4/3}$ approximately

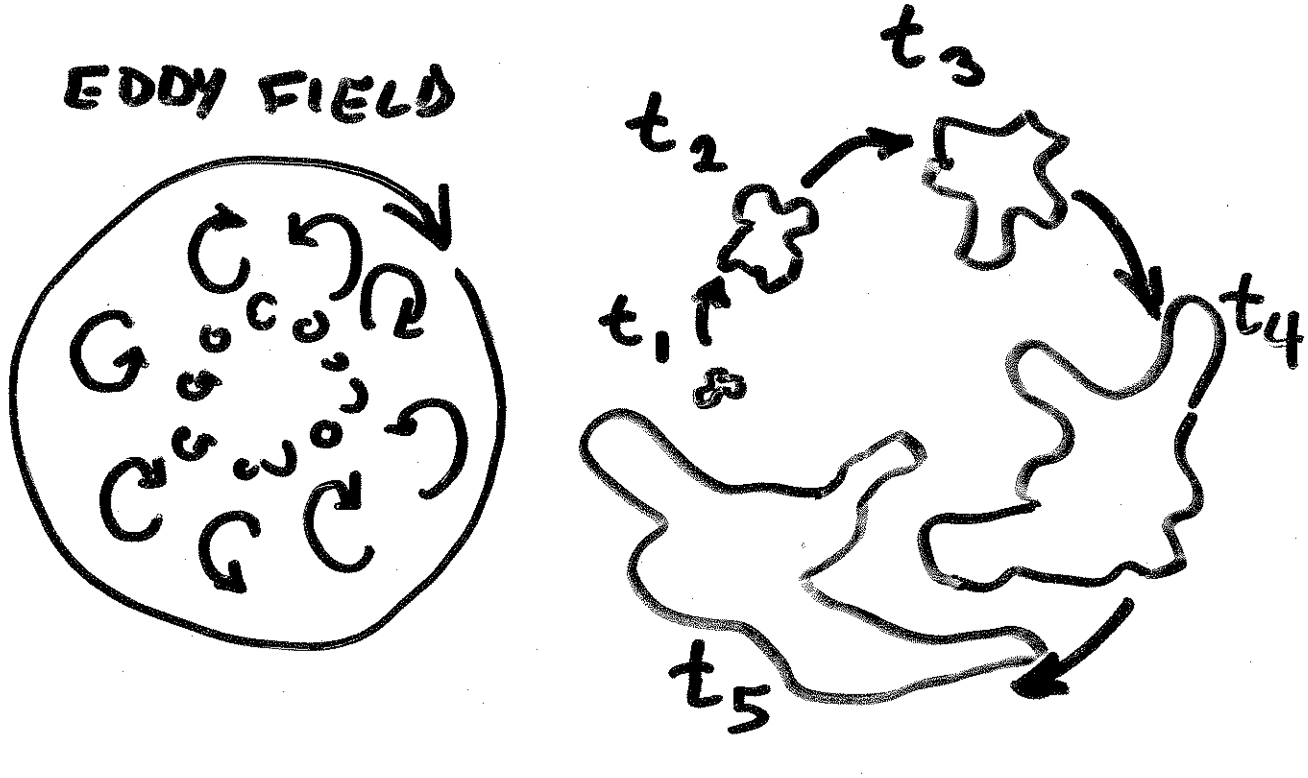
b



# LAKE / OCEAN — SCALE-DEPENDENT TURBULENT DIFFUSION

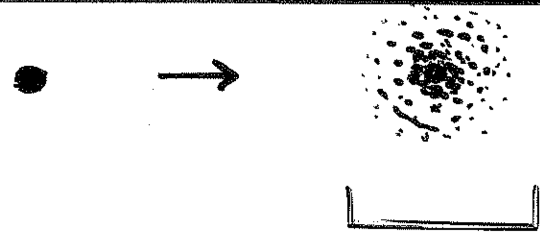



Note the difference (at least over some time scales*) between the ENSEMBLE AVERAGE CONCENTRATION of the "average cloud", and the average concentration about a specific cloud. After enough time passes ($t \gg T$) there should be ~ no difference.

# VISUALIZE DIFFERENT PROCESSES DOMINANT AT DIFFERENT SPACE SCALES

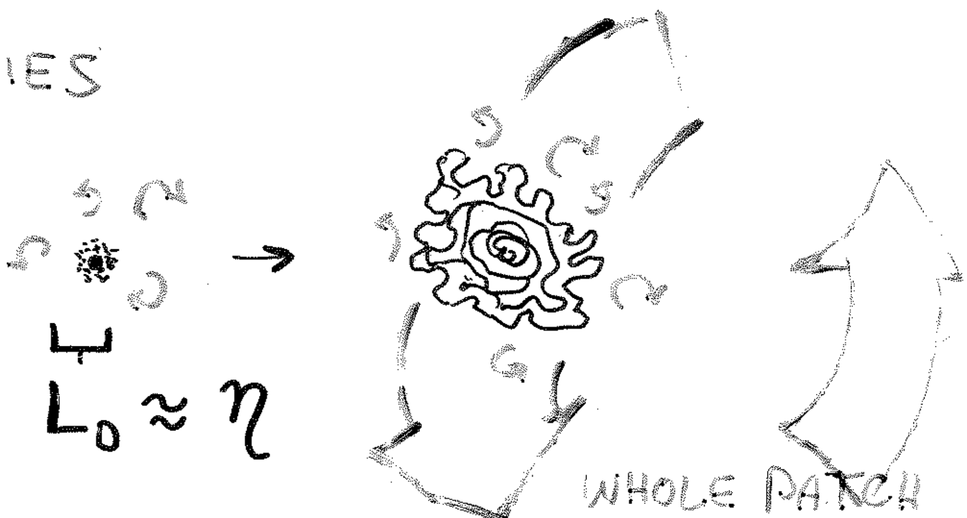
Release a tiny point of dye...



$\Delta t_1$ DIFFUSION (MOL.) DOMINATES

$L_D < \eta$ SMALLEST EDDIES

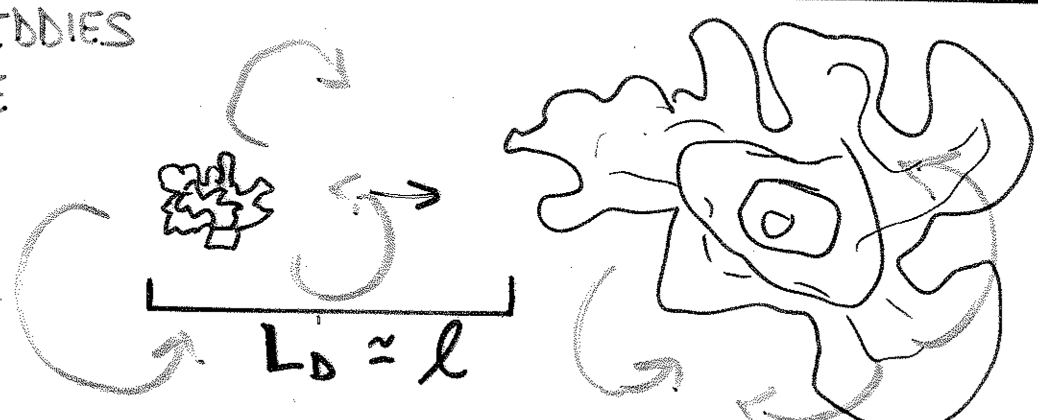
$\Delta t_2$ SMALL EDDIES DOMINATE MIXING



$L_D \approx \eta$

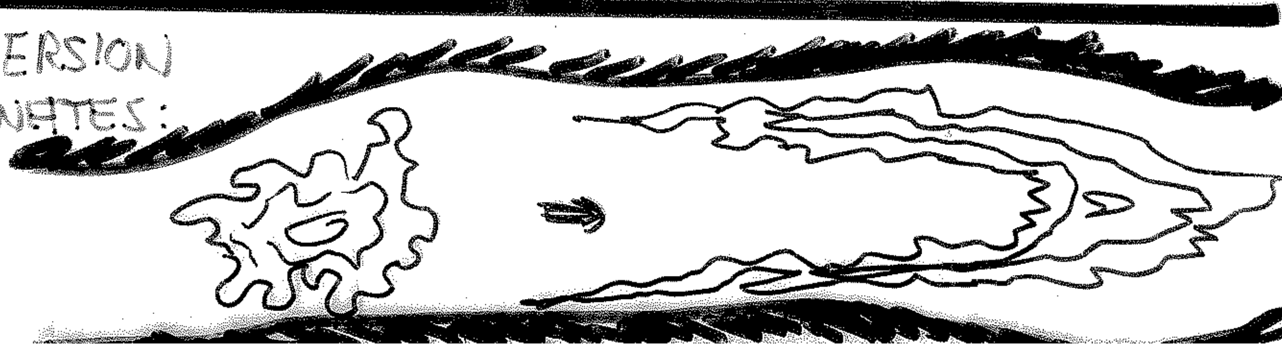
WHOLE PATCH ADVECTED BY LARGE EDDIES

$\Delta t_3$ LARGE EDDIES DOMINATE MIXING



$L_D \approx \ell$

$\Delta t_4$ DISPERSION DOMINATES:



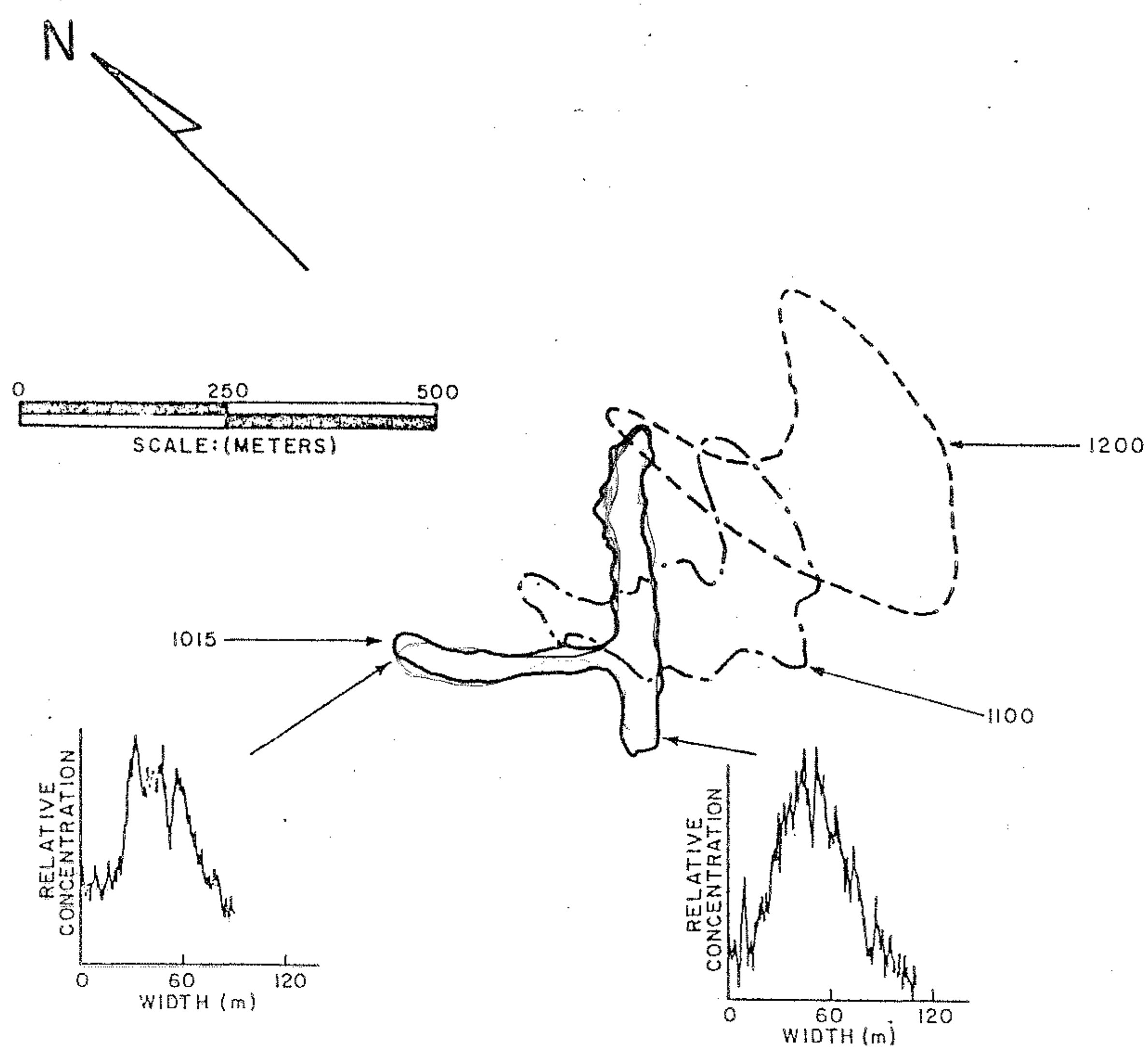



Figure 2.7 Motion of the dye patch deployed on October 27, 1974, from aerial photographs. Relative dye concentration versus distance across each leg of the T is shown where available. These graphs are the average of ten densitometric scans at right angles to the axis of the dye patch.

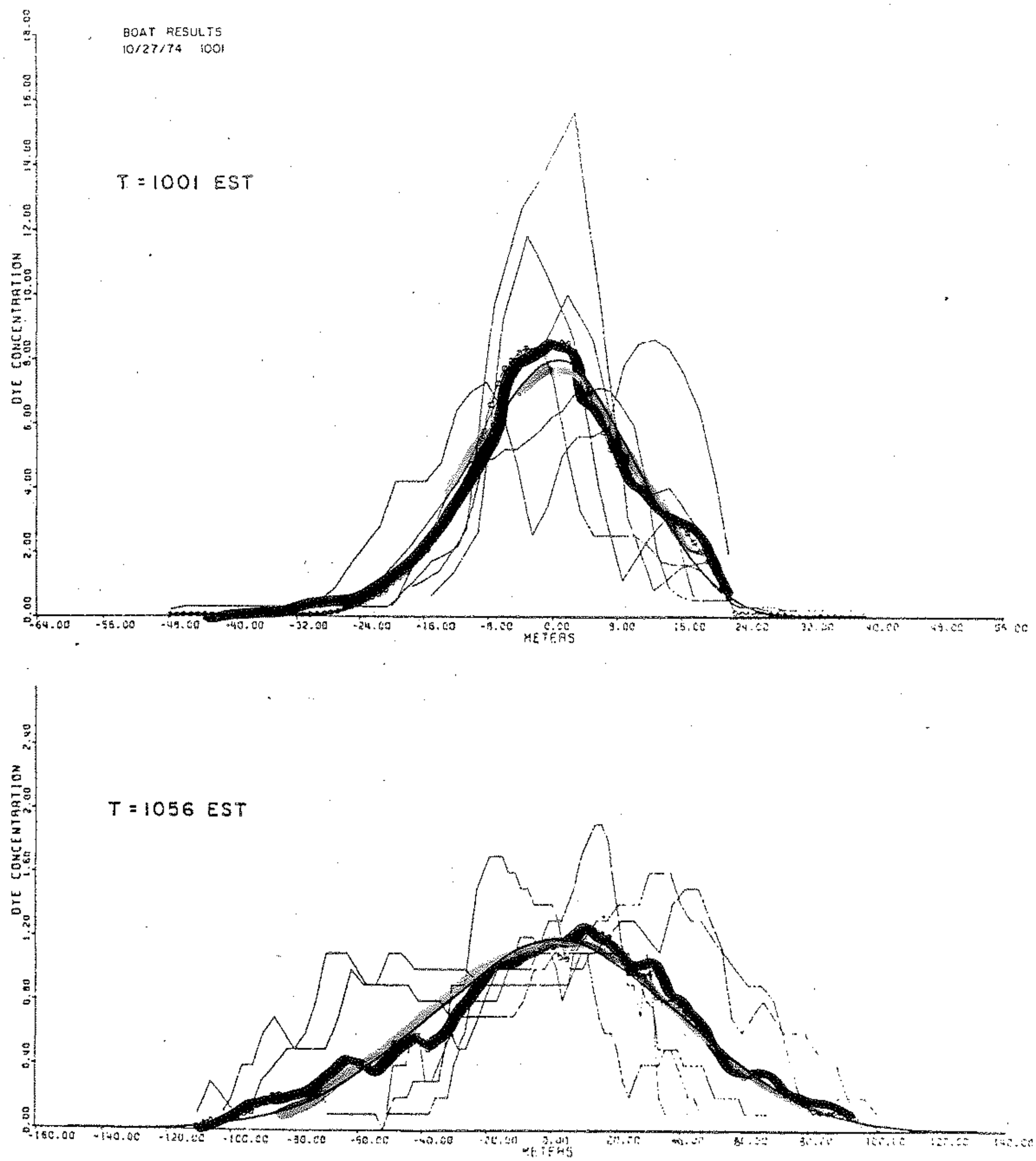
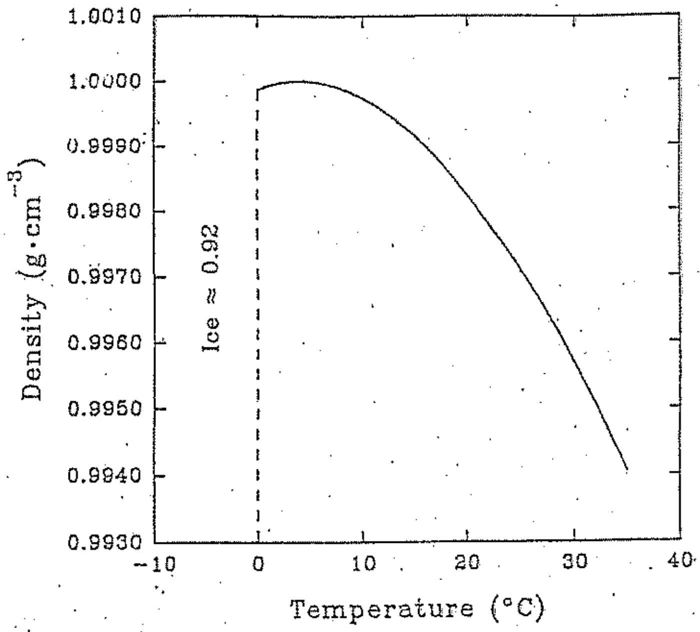



Figure 2.8 Dye concentration profiles across the released dye "T" compared with a Gaussian curve with the same first and second moments. The light lines are individual transects across the "T," the lines with dots are the average of these individual transects, and the heavy lines are the Gaussian curves.



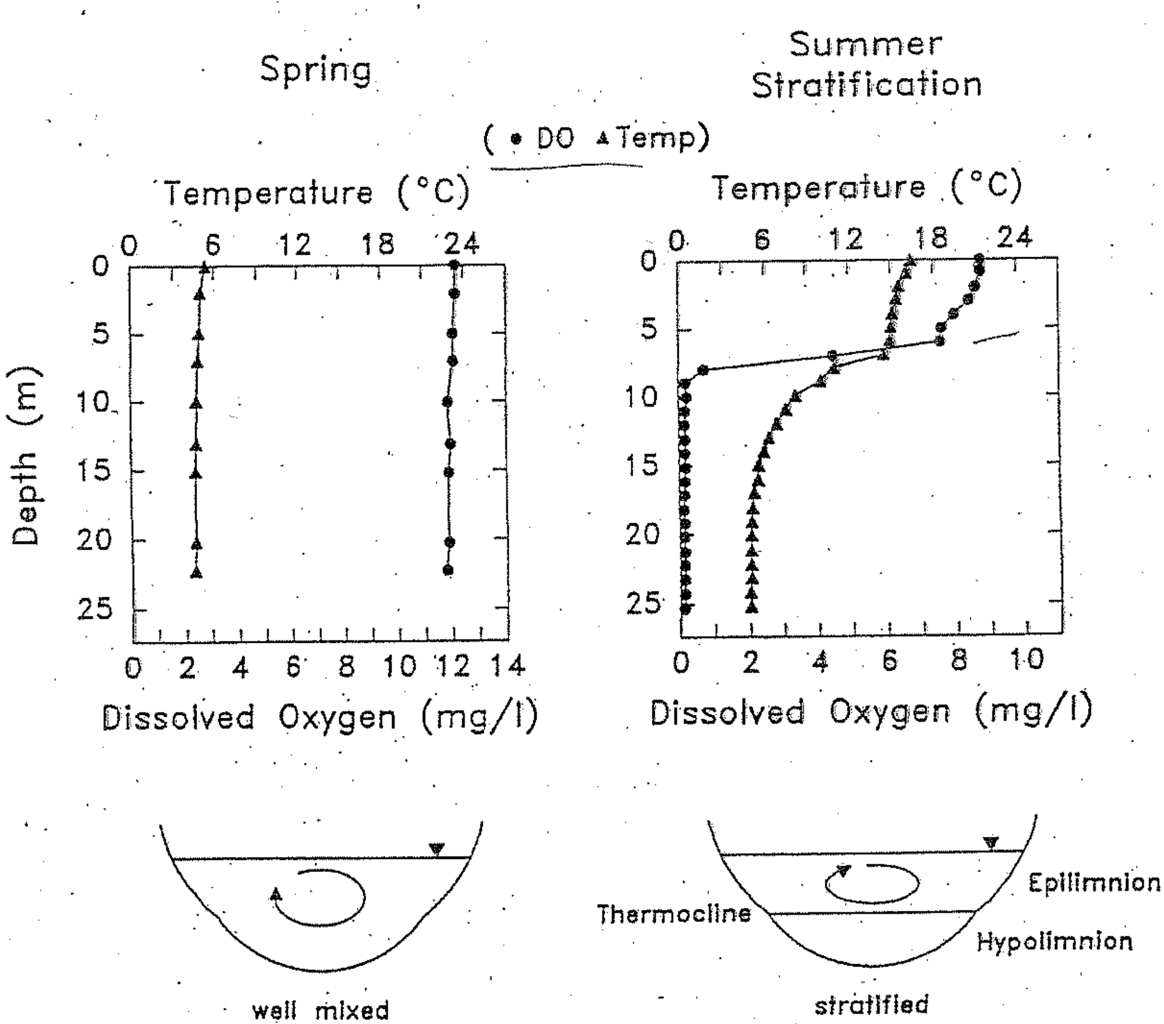
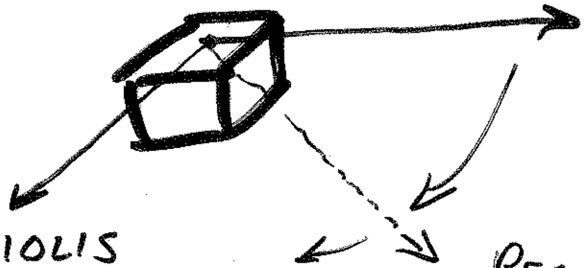



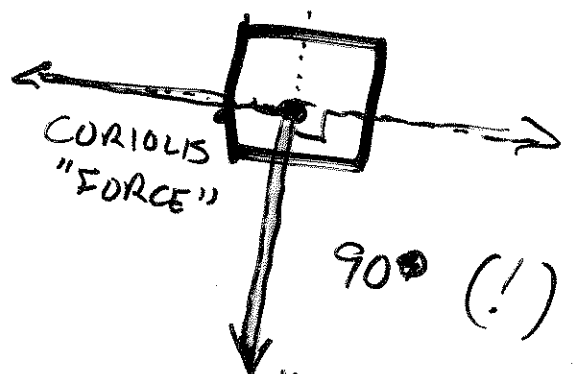

FIGURE 2-7 Measured temperature and oxygen profiles from the Upper Mystic Lake in e Massachusetts, on April 1, 1991 and September 30, 1991. (Left) the lake is unstratified an mixed during turnover, which occurs in spring and fall. (Right) during summer, this eut

# LARGE LAKES:
# "Ekman Phenomena"



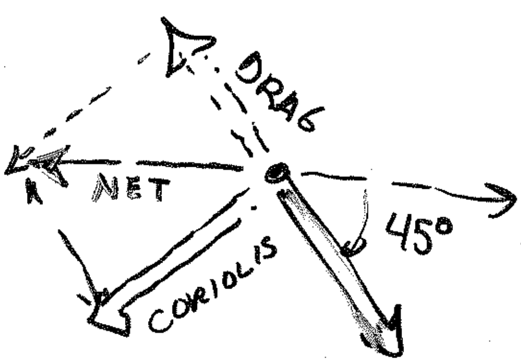
CORIOLIS REACTION
(90° "cum sole";
RT IN NORTH. HEM.)

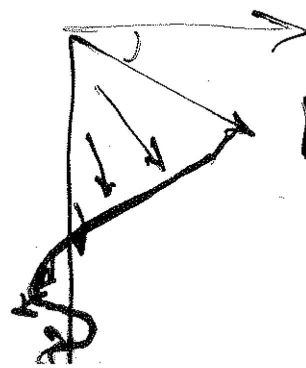
RESULTANT VELOCITY




BUT
ADD IN DRAG FROM
BELOW:

(TRUE FOR
LARGE AIR
MOTIONS
(HURRICANES))



**EKMAN SPIRAL**

# WHEN DO WE WORRY ABOUT THE CORIOLIS EFFECT?

## Coriolis UNIMPORTANT when

$$\left[\frac{\Omega_o L}{U}\right] \ll 1$$

For a given LATITUDE ($\rightarrow \Omega_o$) the relative importance depends on the ratio $\left[\frac{L}{U}\right]$

an Rewrite as:

$$\left[\frac{\Omega_o}{[U/L]}\right] \quad \left[\frac{\text{CHAR. VELOCITY}}{\text{CHAR. LENGTH}}\right] = 1 \Big/ \left[\begin{array}{c}\text{CHAR. TIME SCALE}\\ \text{OF THE FLOW}\end{array}\right] \rightarrow \left[\frac{T_{flow}}{T_{\Omega}}\right] = \left[\frac{T_{FLOW}}{10^4\,s}\right]$$

AT 45°

$$\Omega_o^{@45°} \quad \frac{2\pi}{86{,}000\,s} \sin 45° \approx 10^{-4}\,s^{-1} \Rightarrow T_{\Omega} \approx 10^4\,s$$

| Water Body | L (m) | U (m/s) | $[\Omega_o L/U]$ |
|---|---|---|---|
| Toilet | 0.1 | 1 | $10^{-5}$ |
| Stream | 10 | 1 | $10^{-3}$ |
| River | 100 | 0.1 | 0.1 ↑ |
| Lake/Coastal Zone | 10,000 | 0.1 | ↓ 10 |
| Estuary | 10,000 | 1 | 1 |
| Ocean Current | 1,000,000 | 00.1 | $10^4$ |