

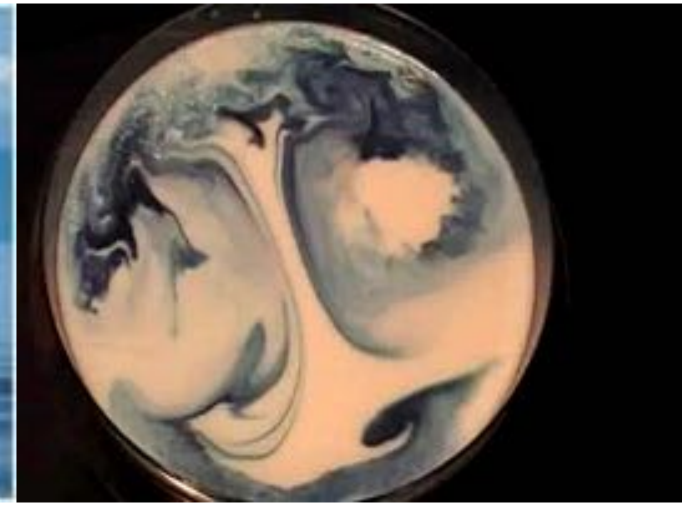

Fluid Mechanics: A few concepts

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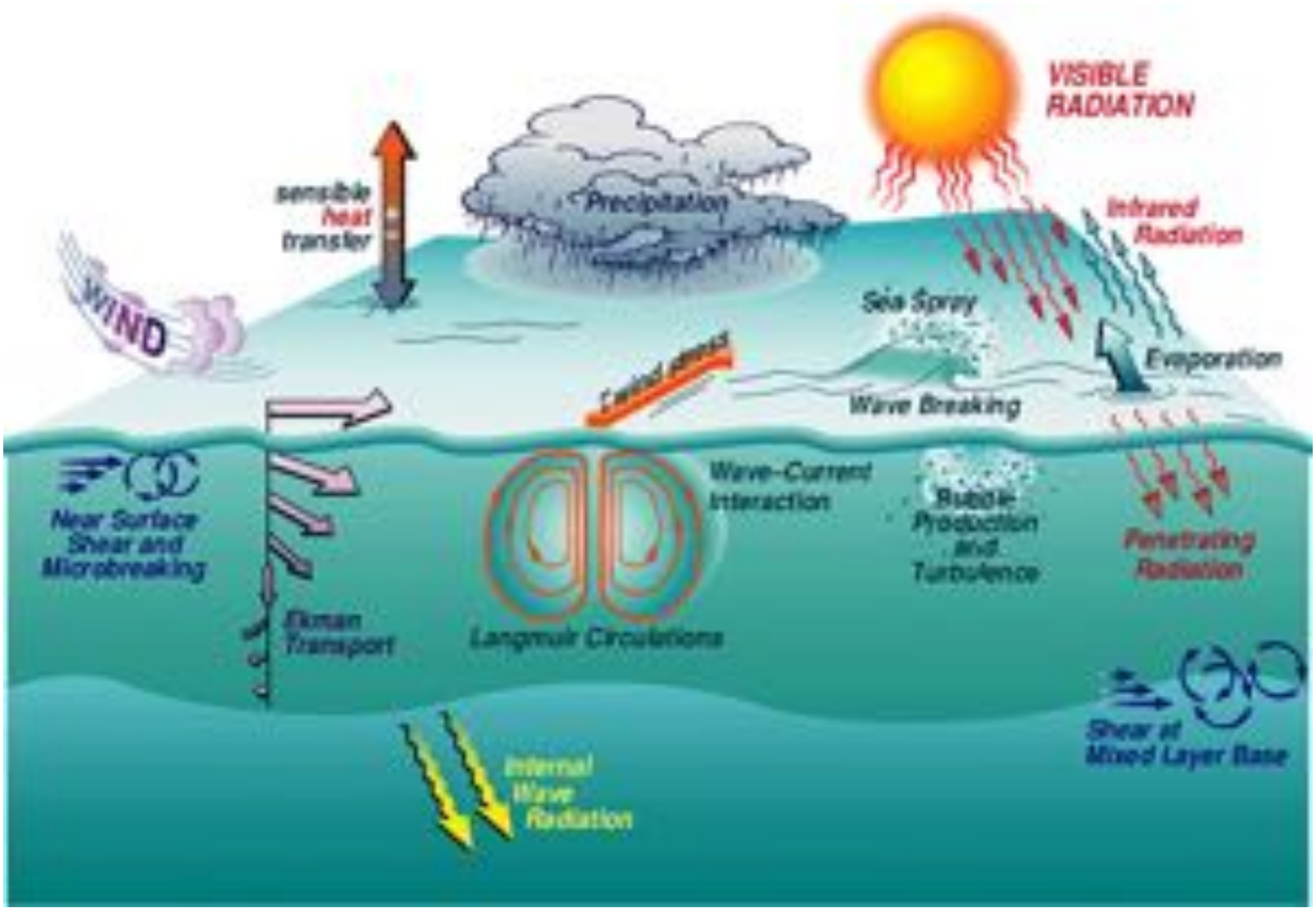
COESSING 2019



Schematic of processes that contribute to variability in the ocean surface boundary layer

[R. Weller, WHOI]

Outline

1. Diffusion versus turbulence – Mixing example
2. Laminar and turbulent flows
3. Density stratification
4. Effect of rotation

Diffusion

en.wikipedia.org

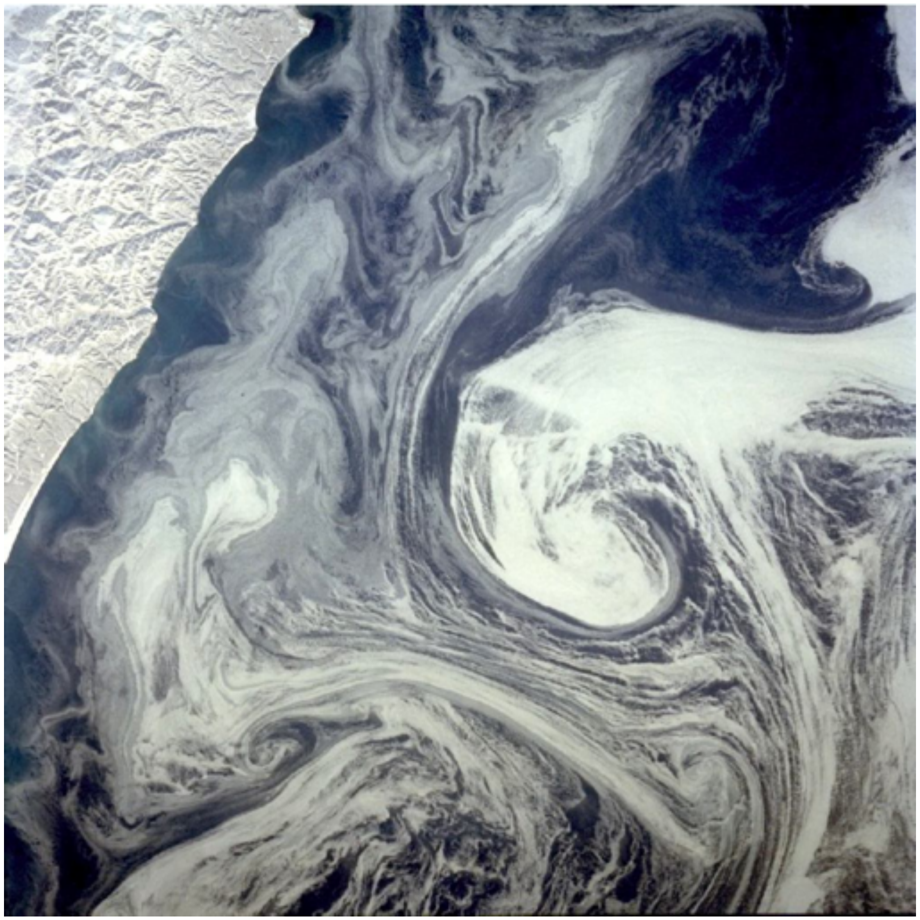
Molecular Diffusion

- Definition - Brownian motion, i.e. random movement of the diffusing particles.

- Diffusion versus stirring

- Diffusive time scale?

Take a guess assuming that
the diffusivity coefficient for the
dye in water is $10^{-9} m^2/s$.



EDDIES IN THE OYASHIO CURRENT

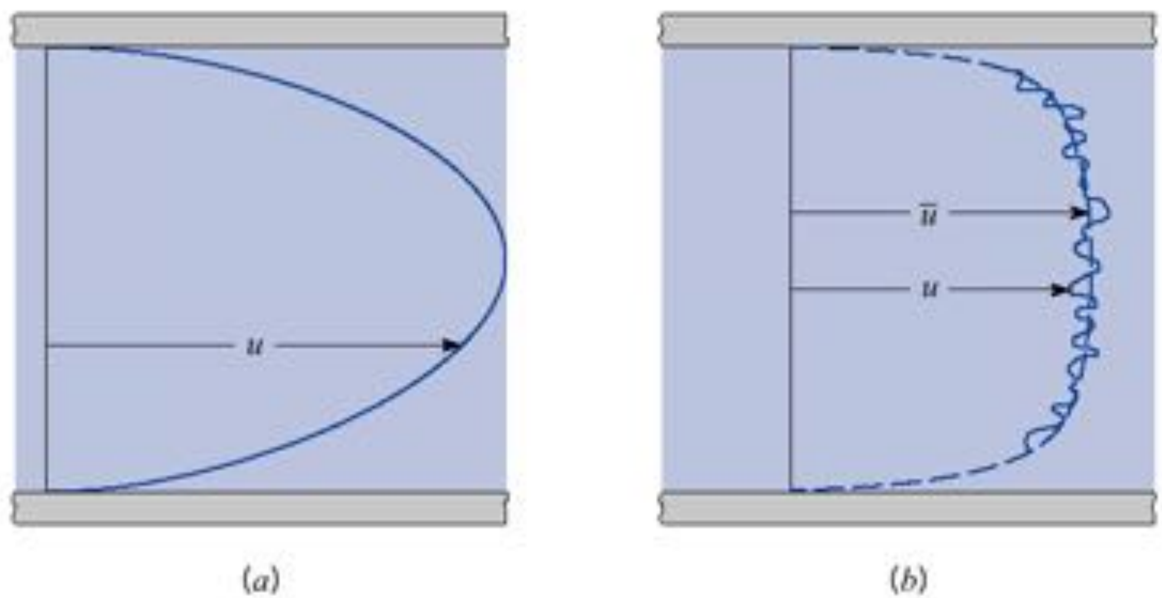
G. K. Vallis
Princeton University

The photograph from NASA shows eddies in the Oyashio Current, off the Kamchatka Peninsula in the Bering Sea, in March, 1992. The current, part of the the western boundary current of the North Pacific subpolar gyre, is baroclinically unstable and sea-ice provides flow visualization. Snow cover (white) covers the thicker ice flows just to the right of the centre of the image.



Laminar and Turbulent flows

- Example below – velocity profile in a straight pipe. Which one is the turbulent case?



- Determined by the value/range of the Reynolds number

Reynolds number

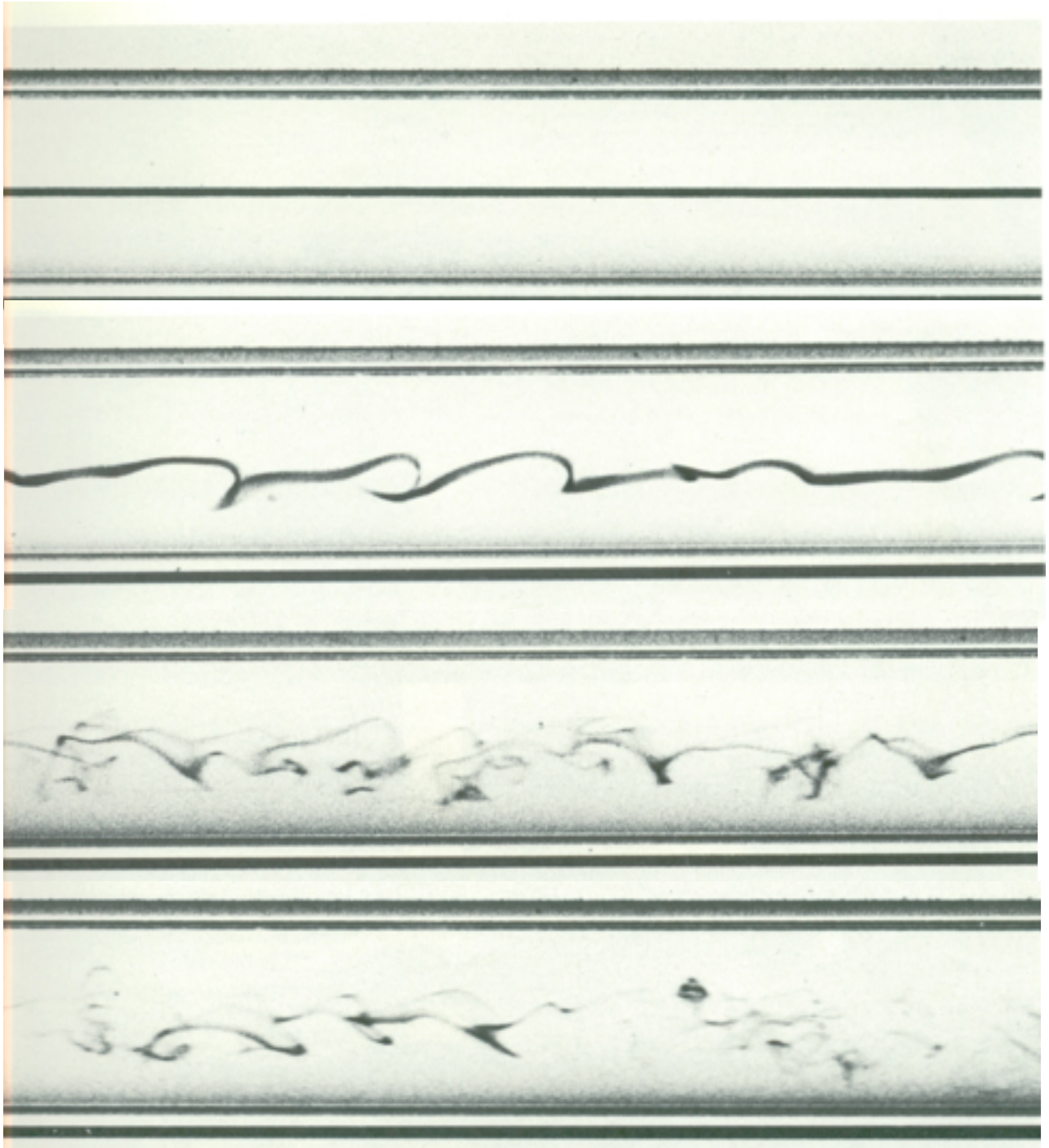
$$Re = UL/\nu$$

- U is the flow velocity (m/s), L the relevant length scale (m) and ν the kinematic viscosity (m^2/s). $\nu=\mu/\rho$, where μ is the dynamics viscosity and ρ the density.

- Determines the transition from laminar to turbulent flows

- Important in determining turbulent eddy spectrum in terms of size, velocity and rotation period. Important in predicting mixing in industrial and environmental flows.

Reynolds' experiment



Laminar

Transitional

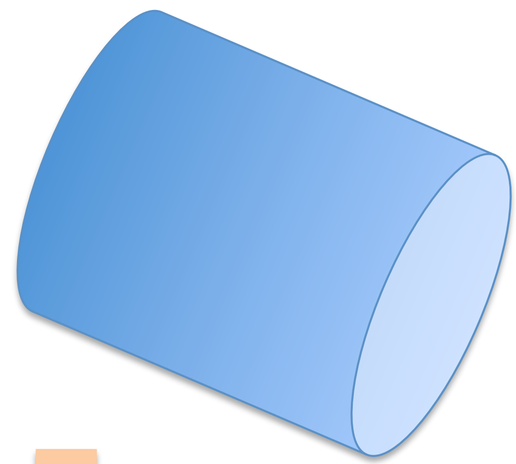
Re

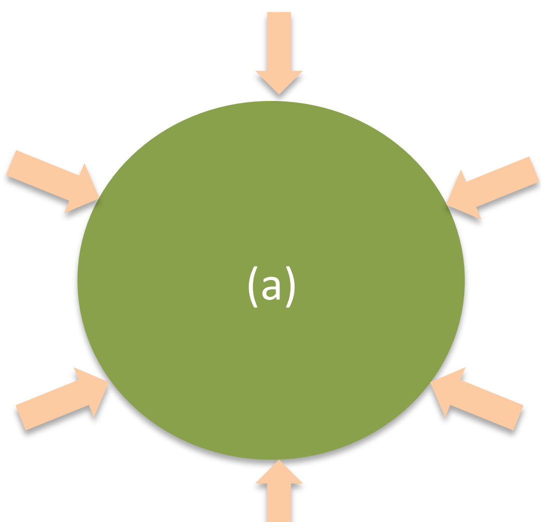
Turbulent

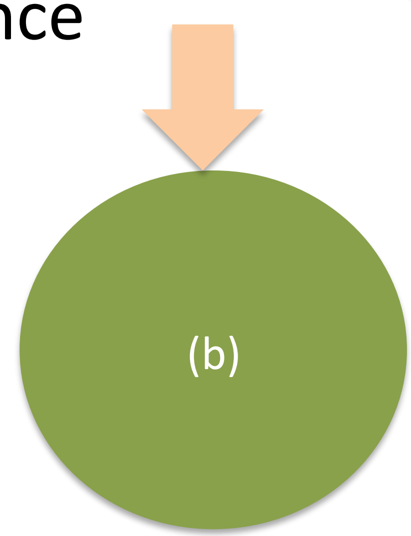
Fully turbulent

What's the most efficient configuration?

- Mixing 2 fluids thru injection.
- Choice of configuration:
  - Option 1 : (a) is better
  - Option 2: (b) is better
  - Option 3: There is no difference



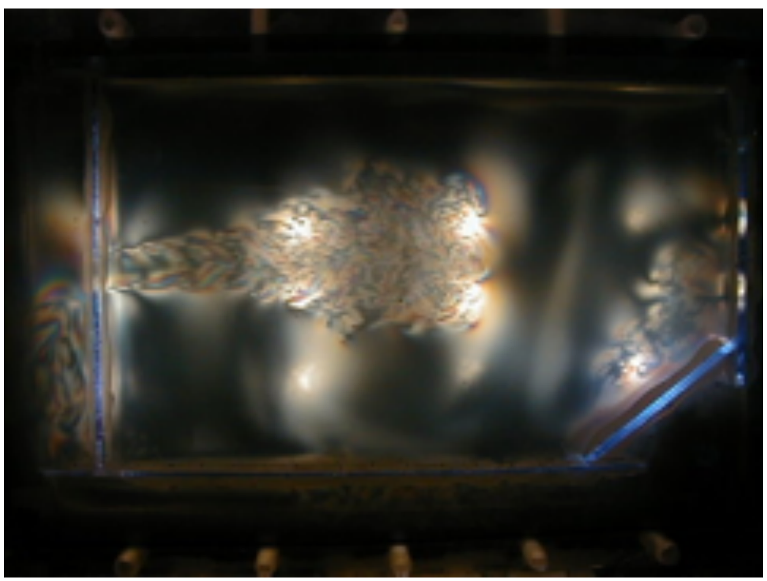




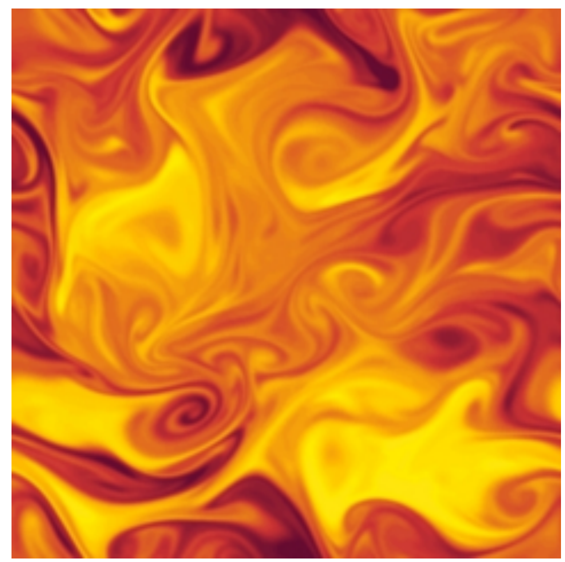
Cross-section of pipe

Definition of turbulence

- At least 2 ways:
  1. Through its properties – This gives intuition
  2. Mathematical definition – Necessary for theory and modeling



Jet in ambient fluid, V=2cm/s, 15cm horizontal field of view



Isotropic turbulence – Sc=25

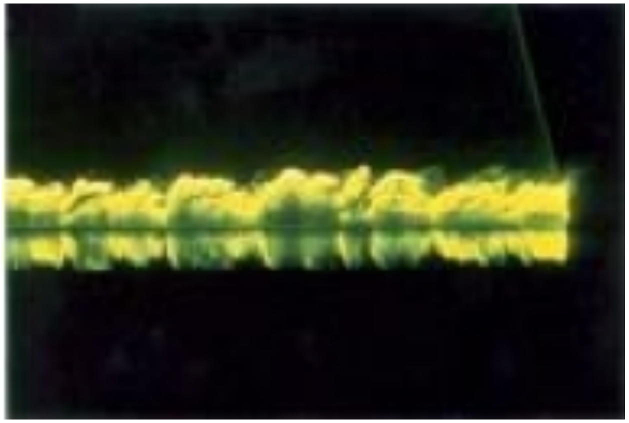
Properties of turbulence

- Flows that are described by the Navier-Stokes equations and corresponding boundary conditions. Continuum approximation and Newtonian fluid.
- Turbulent flows are highly irregular. Chaotic, random but not completely. Expected to have some structures: eddies!
- Turbulent flows are unstable. They are the results of flow instabilities.
- Turbulent flows are strongly non linear. The velocity field can be associated with random waves.
- Turbulent flows are highly vortical, i.e. characterized by a large amount of vorticity.

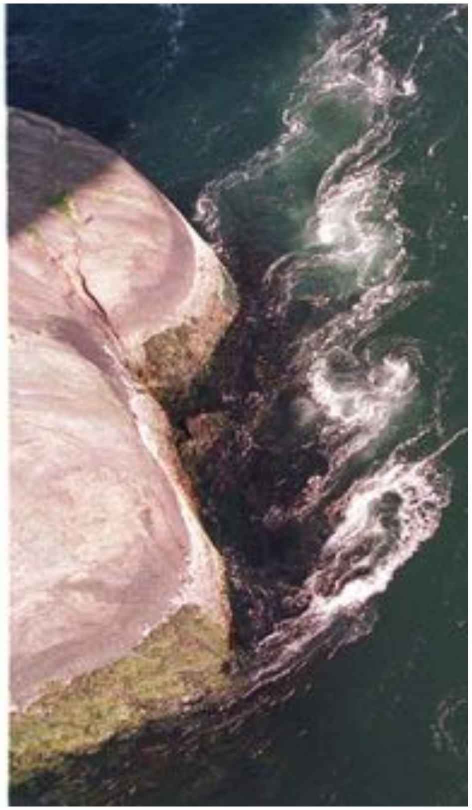
Properties cont'd

- Turbulent flows are characterized by high rates of diffusion of mass, momentum, heat, chemical species…
- Turbulent flows are highly dissipative.

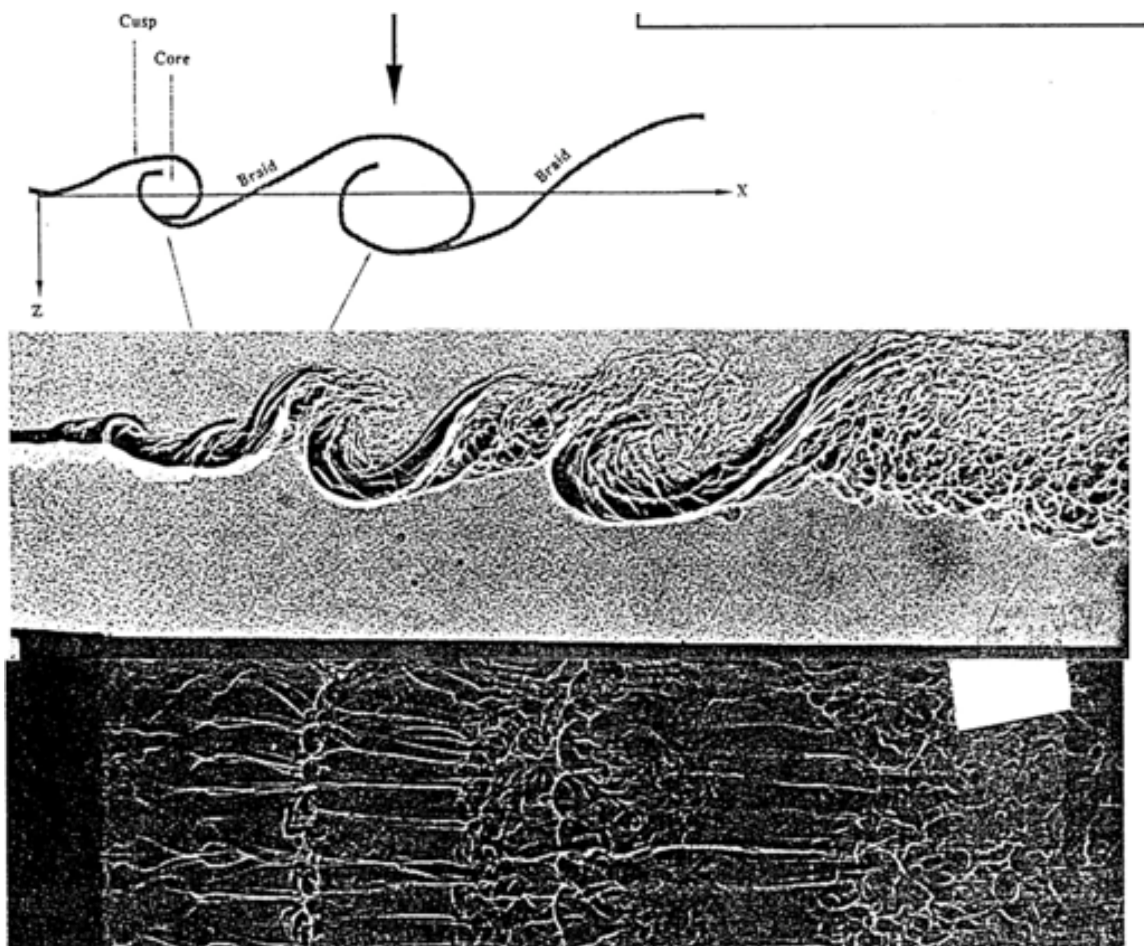
  Mechanical energy is transformed into internal energy. Need a supply of energy to sustain it.

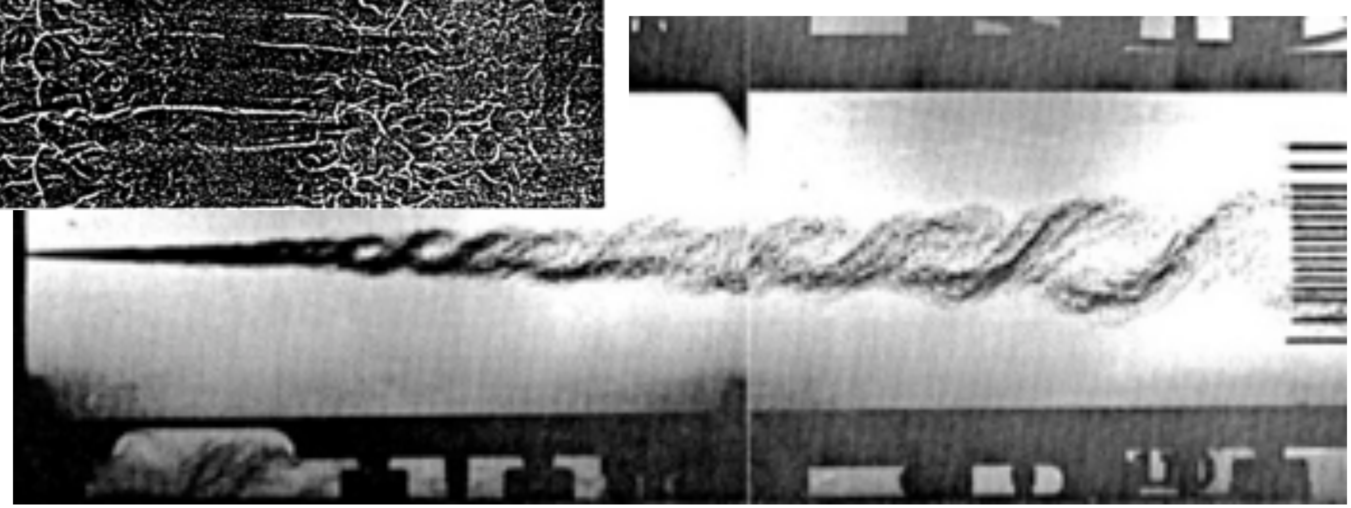


Large eddies in a turbulent boundary layer



Kolmogorov’s energy cascade theory (1941)





Navier-Stokes equations

- One of the last unresolved problems of classical physics.
- Describe all the complexity of fluid flows.

Rotation

$$\frac{D\vec{u}}{Dt} + 2\vec{\Omega} \times \vec{u} = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

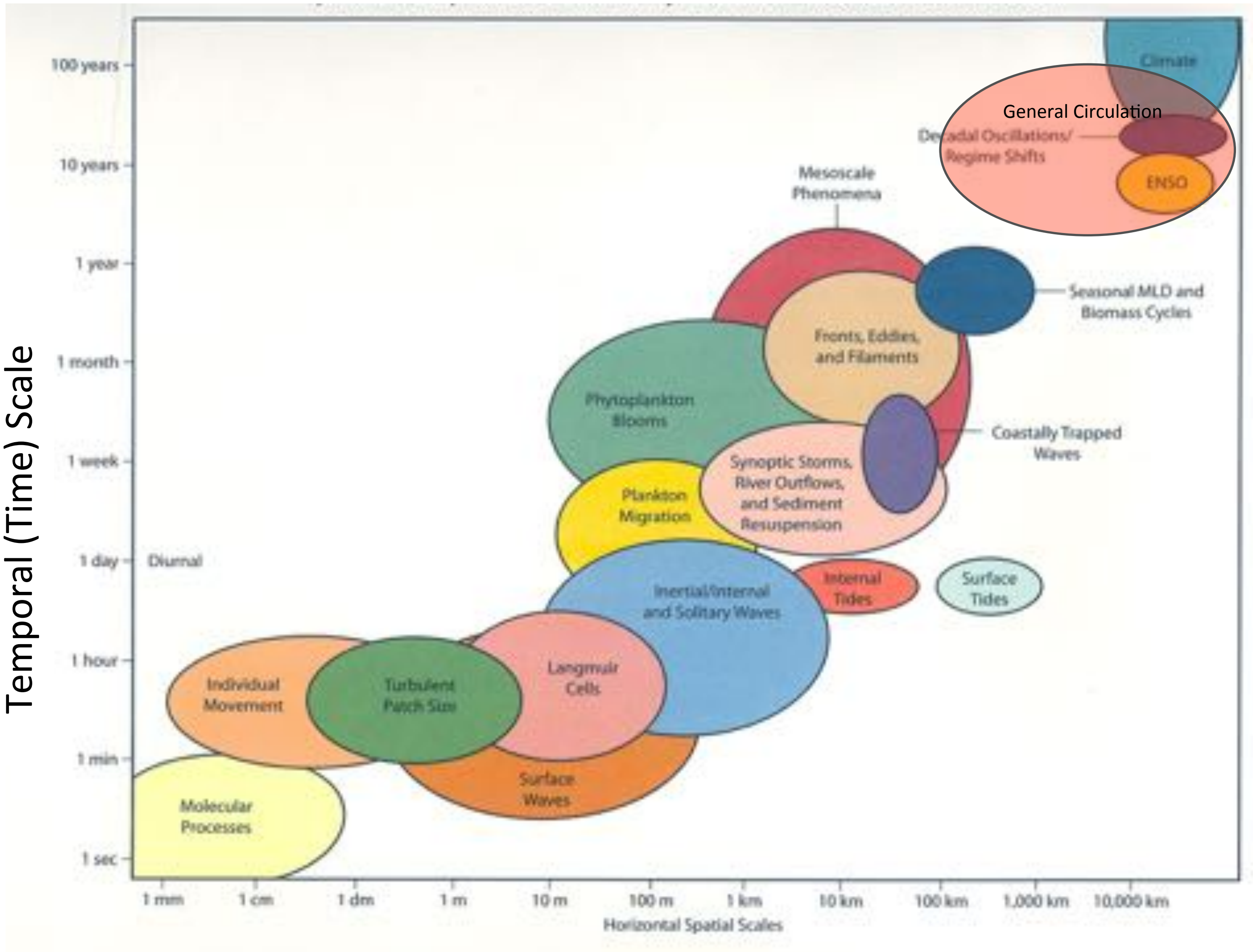
Gravity: pressure gradient and buoyancy

Friction: wind stress

Coriolis Force

$$\rho \frac{d\vec{V}}{dt} = -\nabla p + \nabla . \tau_{ij} + \rho \vec{g}$$

Temporal and spatial scales of various physical ocean processes



Temporal (Time) Scale

Horizontal Spatial Scale

Image credit: Exploring the World Ocean, inside cover

Other dimensionless parameters

- Richardson number: $Ri = \frac{(\Delta\rho/\rho)g\delta}{U^2}$
- Rossby number: $Ro = \frac{U}{Lf}$

where f is the Coriolis frequency, $f = 2\Omega \sin\theta$

Ω: planet rotation

Θ: latitude

Ocean measurements

Lagrangian -> follow the particles in the flow as a function of time. Instruments are following the ocean currents.

Eulerian -> motion of particles are both a function of time and space. Moored ADCPs for example.

A few more things….

THE OCEAN IS ALSO STRATIFIED AND THE EARTH IS ROTATING…

Temperature of seawater

Most of the ocean is very cold:

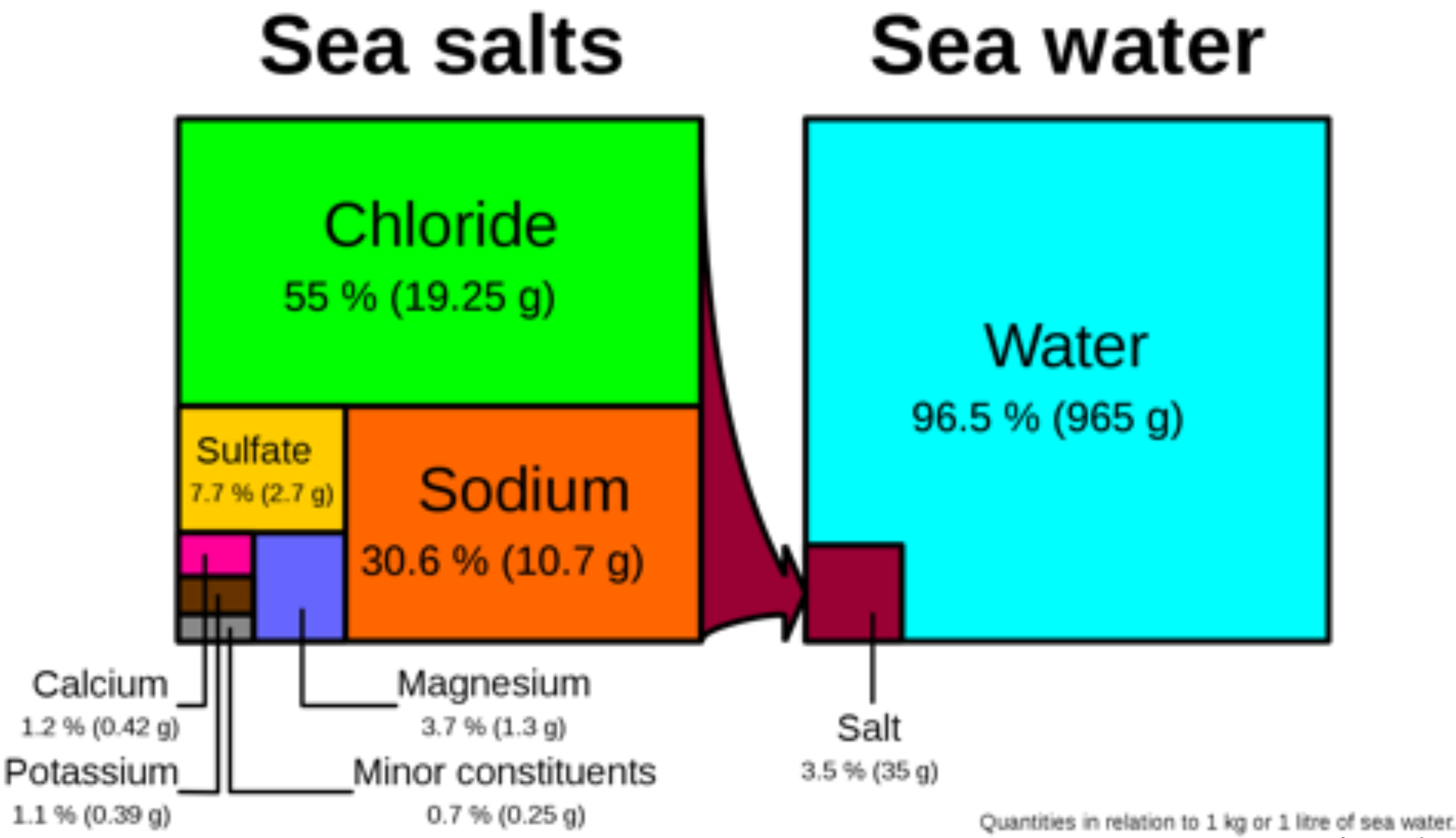
~ 4 °C

Surface waters can reach ~28 ° C

Water has a high heat capacity: It can absorb and release a lot of energy without changing temperature much.

Salinity is a measure of the

grams of dissolved salts per kilogram of seawater



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How do Temperature, Salinity and Pressure influence density (ρ)?

Seawater's density is a function of T, P and S

As Temperature ↑

ρ↓

As Salinity ↑

ρ ↑

As Pressure ↑

ρ ↑

(note: seawater is only a little compressible…6% change)

Density of seawater - why does it matter?

- Vertical variation of density determines static stability, i.e., how strongly stratified the water column is.

- Density variations determine a very important part of the horizontally varying pressure and thus the ocean circulation.

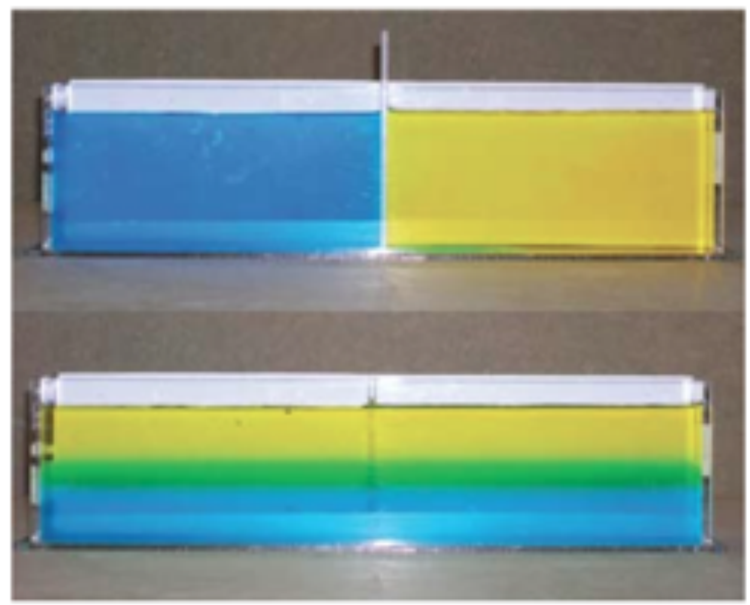


Figure 1.4. Tank before (top) and after removal of divider (bottom).

Annual mean of sea surface temperature, SST

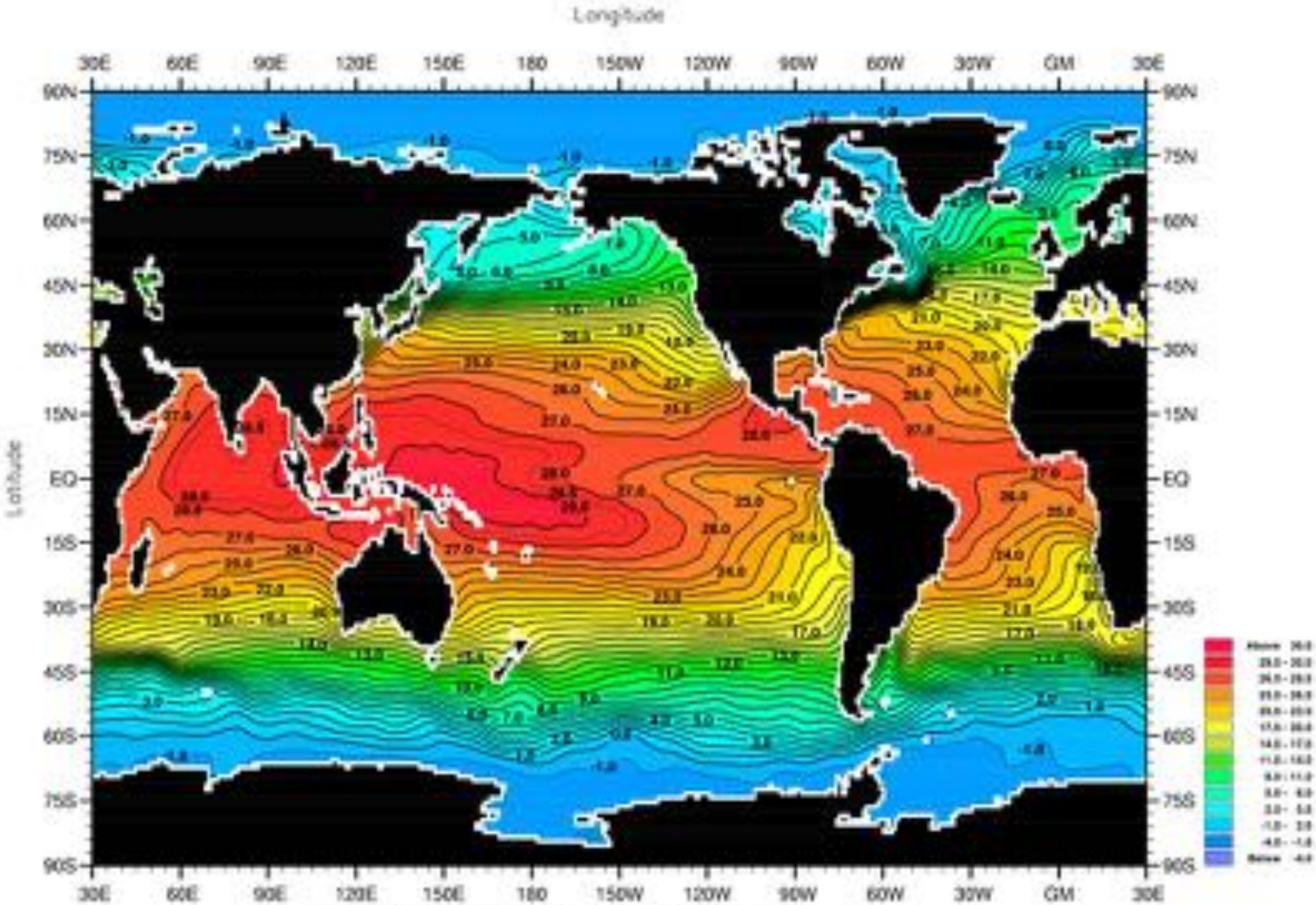


Fig. A2-1. Annual mean temperature (°C) at the surface.

Minimum Value= -1.93 Maximum Value= 29.93 Contour Interval: 1.00

World Ocean Atlas 2001
Ocean Climate Laboratory/NODC

made from about 5 million hydro casts

Salinity at the ocean surface

Low Salinity along the equator due to excess rain at the equator

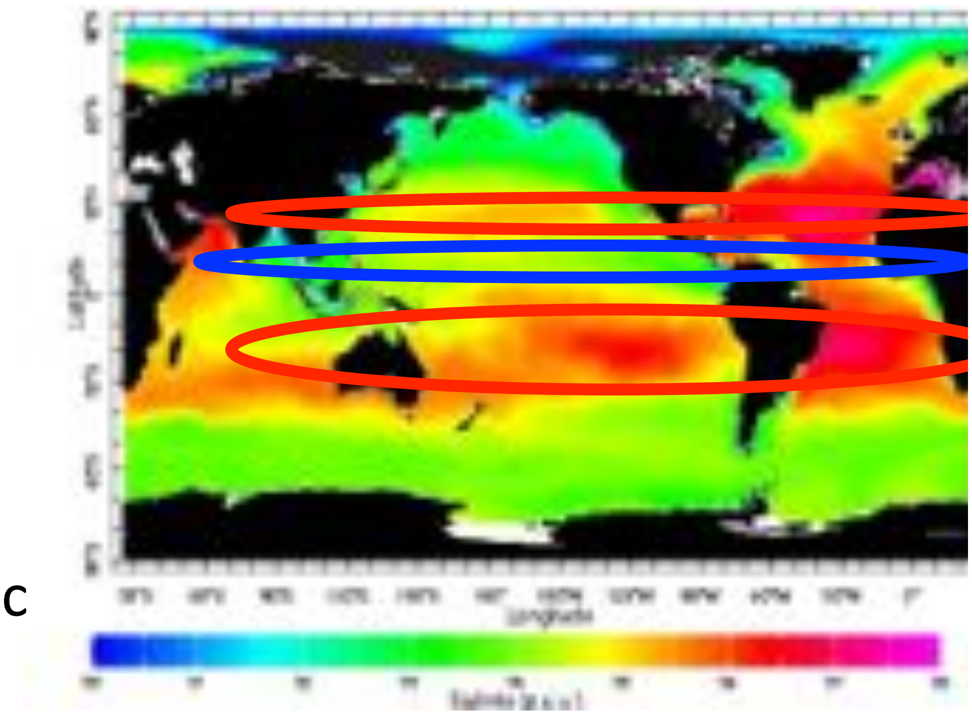
High Salinity at 30°N & 30°S due to excess evaporation

Isolated regions of low salinity near coasts. Could be: upwelling, or river input

The Atlantic is saltier than the Pacific

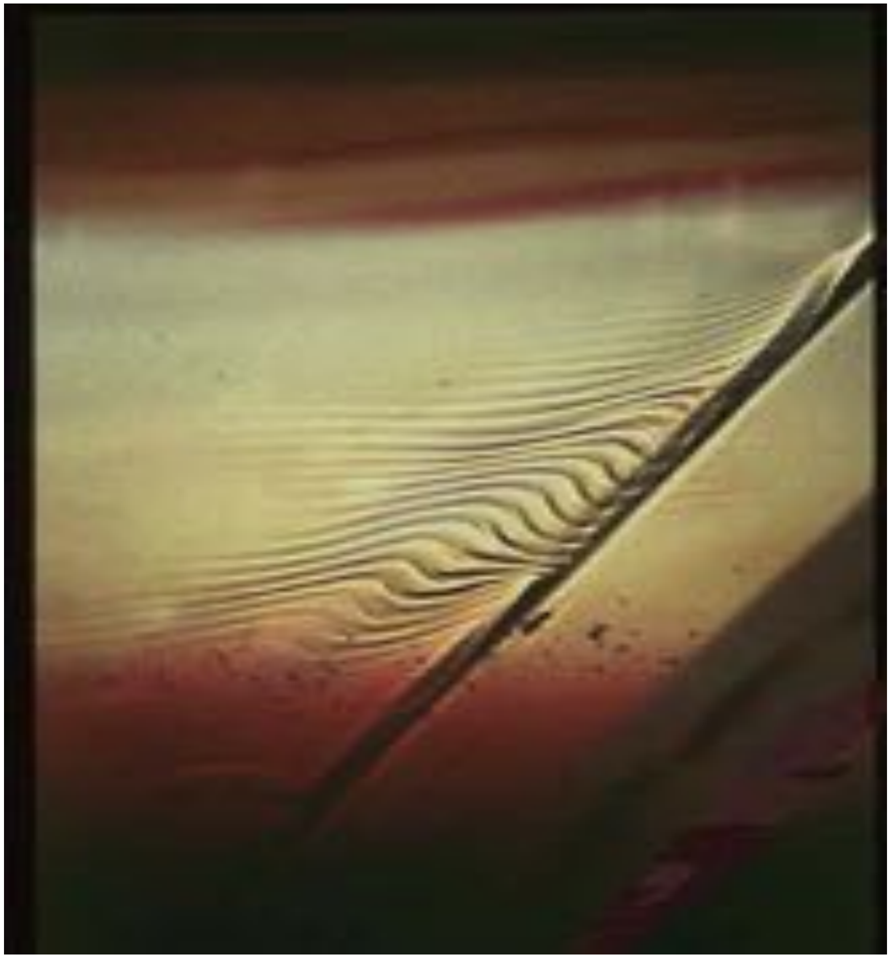
Net evaporation in the Atlantic, precipitation in the Pacific = freshwater flux

The Mediterranean is very salty (a lot of evaporation).

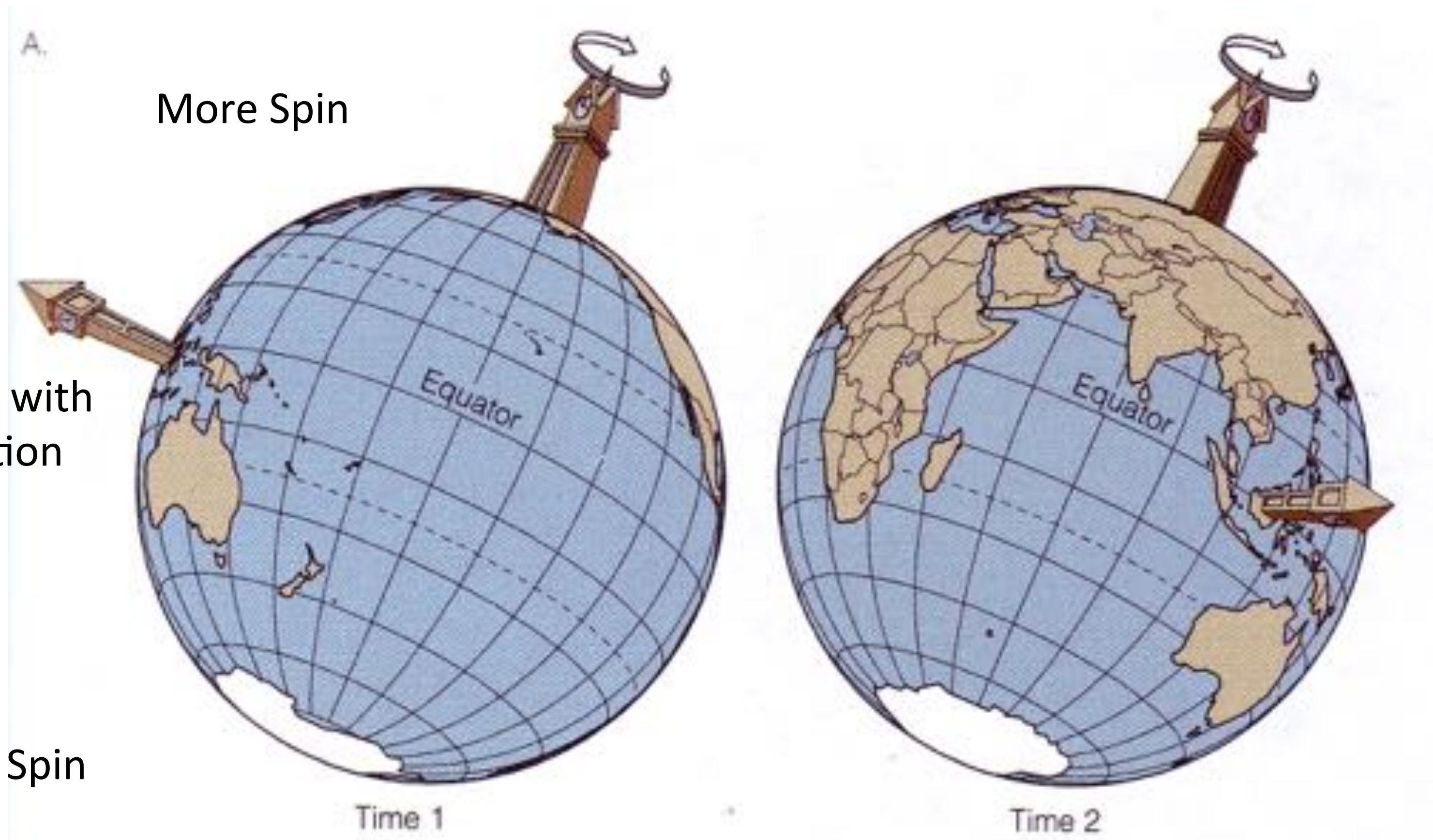


Stratification continued

Internal waves formation off a slope -> Important for sediment transport into the interior of the ocean + slope stability



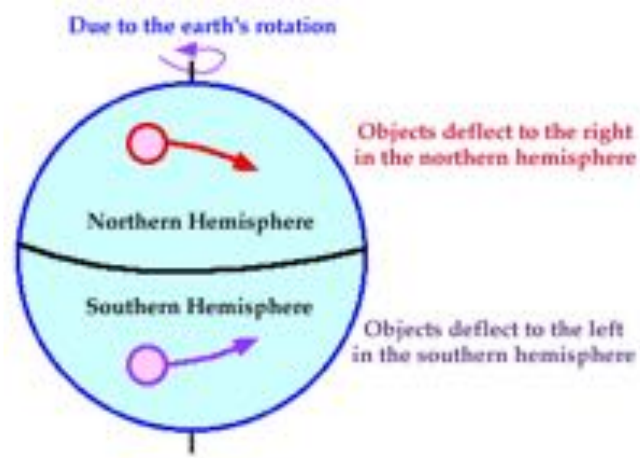
And we are on a rotating planet…



No Coriolis effect at the equator

3 rules of the Coriolis Effect

1) Any object moving horizontally on earth's surface has its trajectory deflected



2) The faster an object moves, the greater its tendency to deflect

3) The tendency to deflect is greatest at the poles and decreases to zero at the equator.

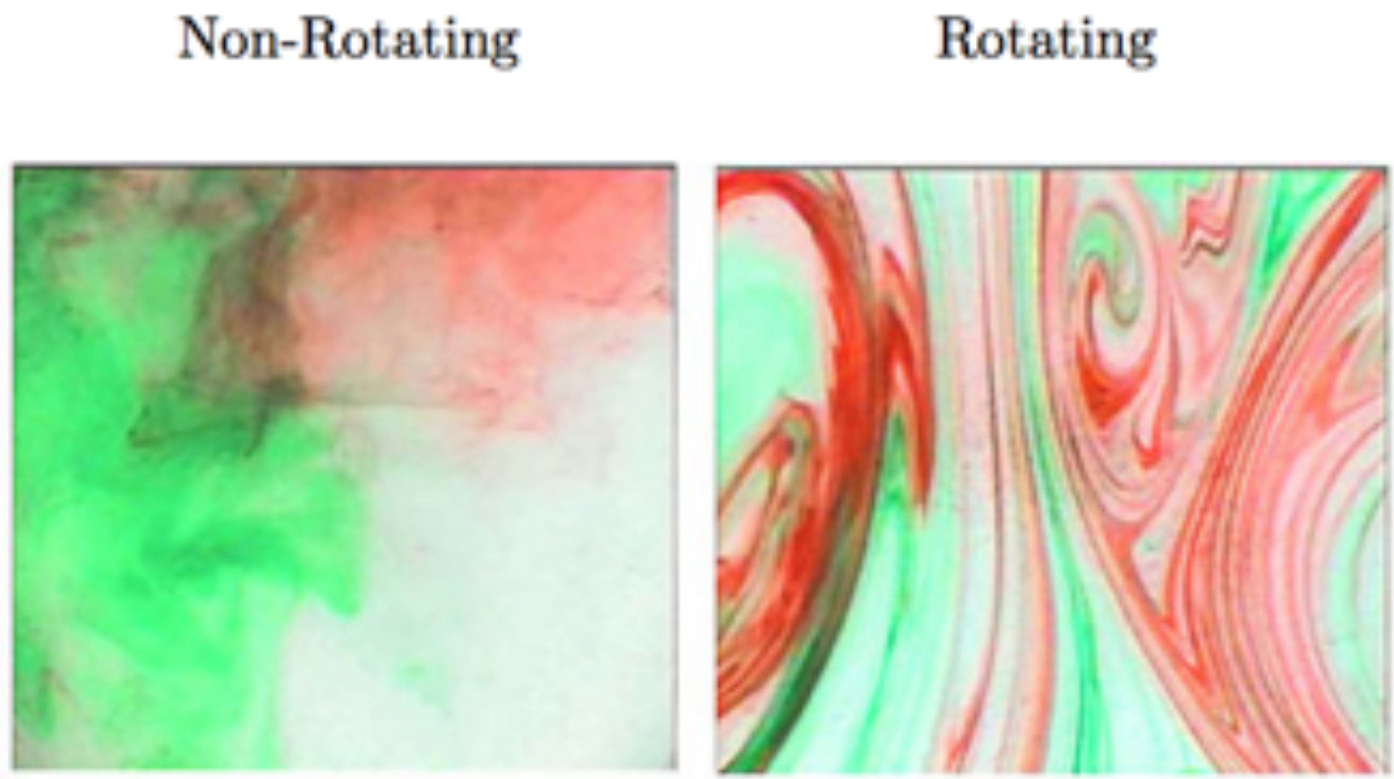
We don't notice it on land because other forces overwhelm its influence

ww2010.atmos.uiuc.edu

(from How the Ocean Works, by Mark Denny)

Impact of Rotation

- Tends to keep water columns vertically aligned



Next…

We will look at some of these physical processes in the laboratory!!