Today

I. Introduction to Physical Oceanography

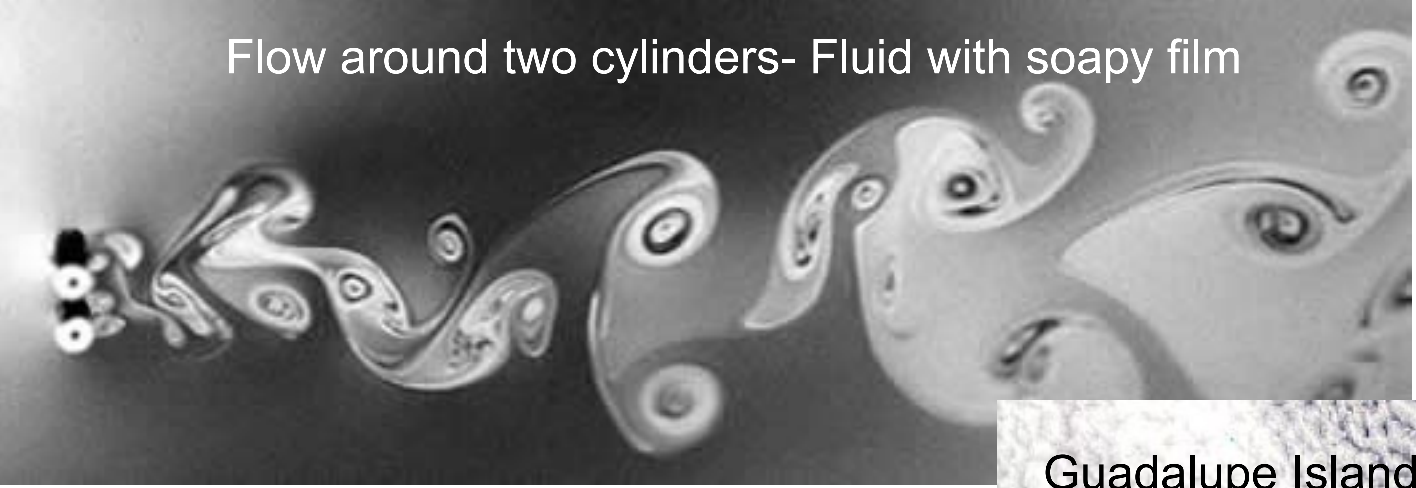
Emily Shroyer, Oregon State University

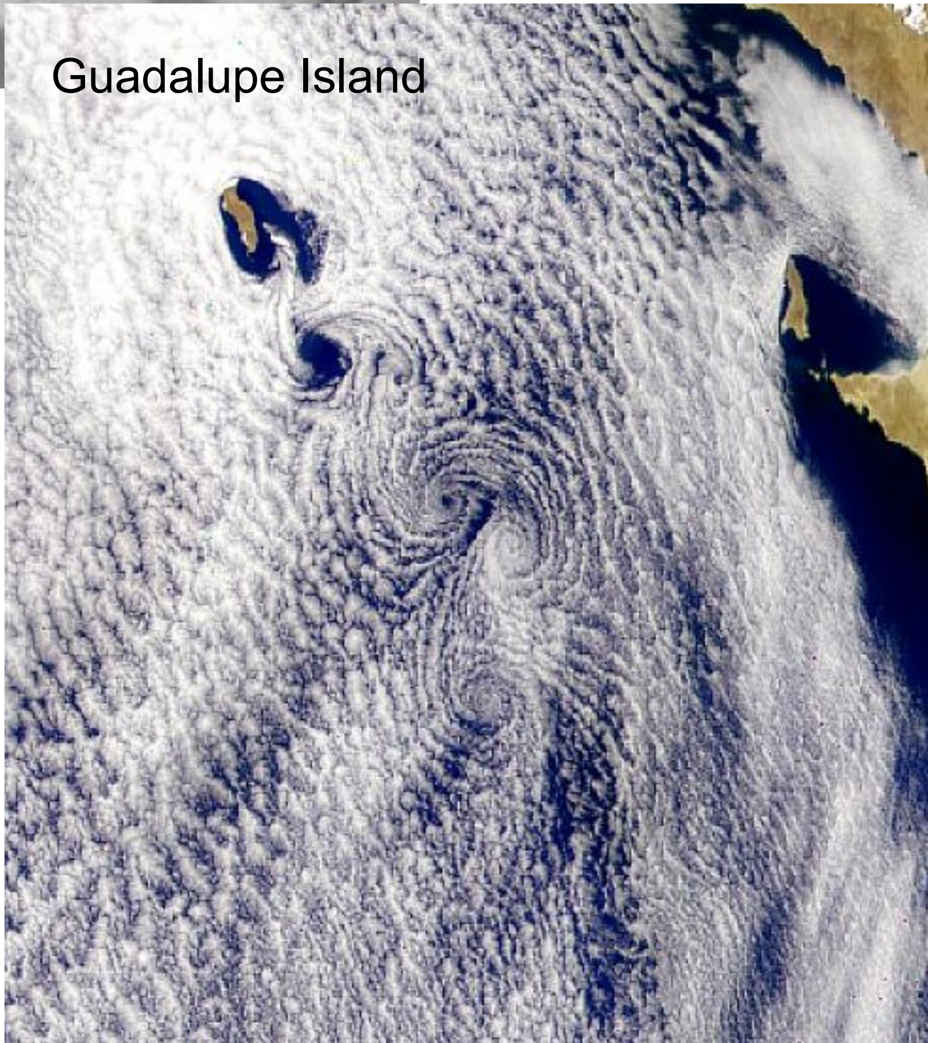
II. Turbulence and Mixing

Aline Cotel, University of Michigan

III. Estuarine Processes

Andrew Lucas, Scripps Institution of Oceanography



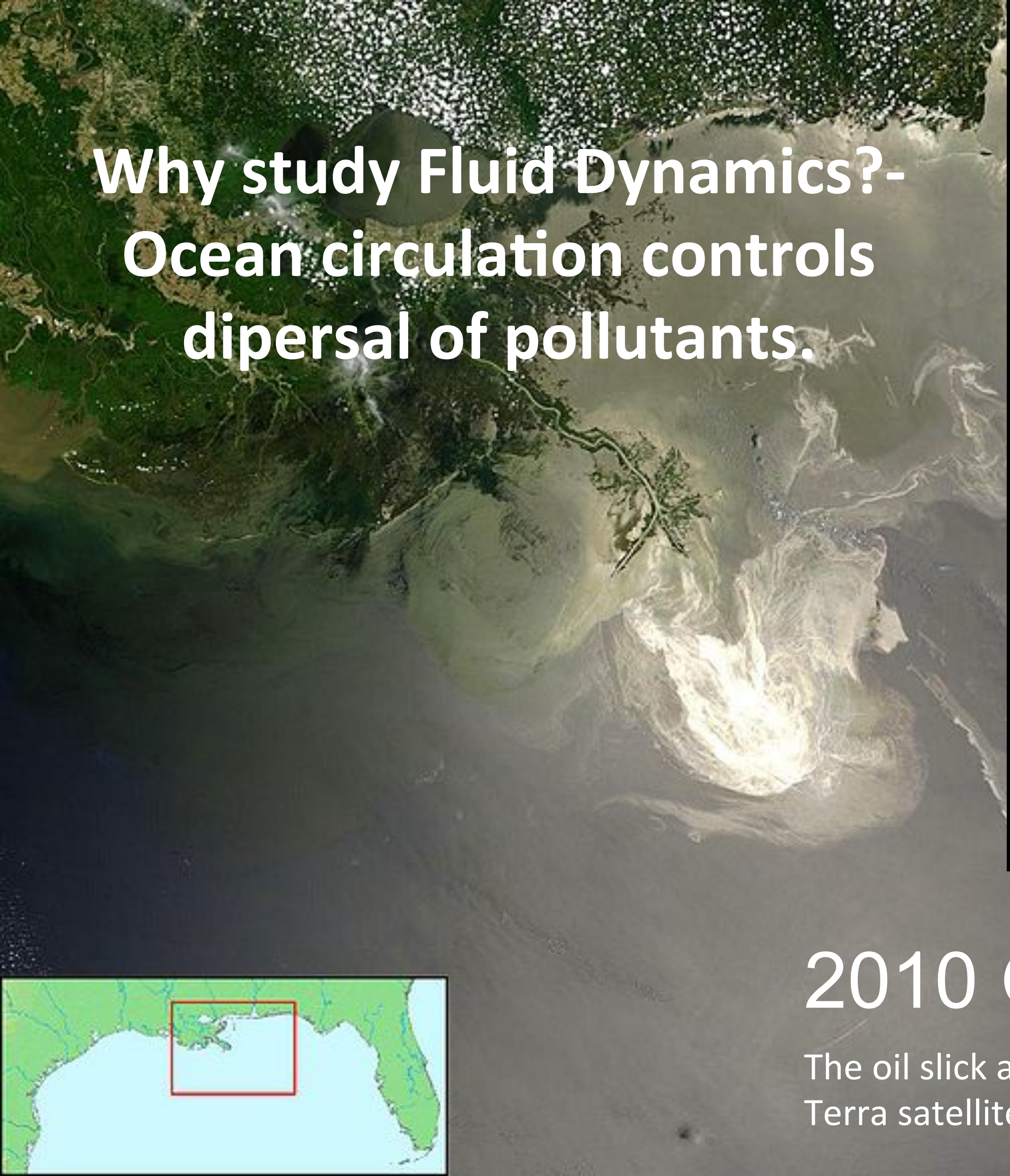


Our Approach→ basics of geophysical fluid dynamics applied to the coastal ocean (rotation, stratification, geomorphology, and applications)

Why study Fluid Dynamics?- Societal Importance
The ocean impacts our weather and climate.

In the present warming scenario, *increased* ***monsoon rainfall has been projected*** by various models. Extreme rainfall events are causing an increase in the frequency and intensity of large floods in major Indian rivers. –Huffington Post Online, 9/22/2014

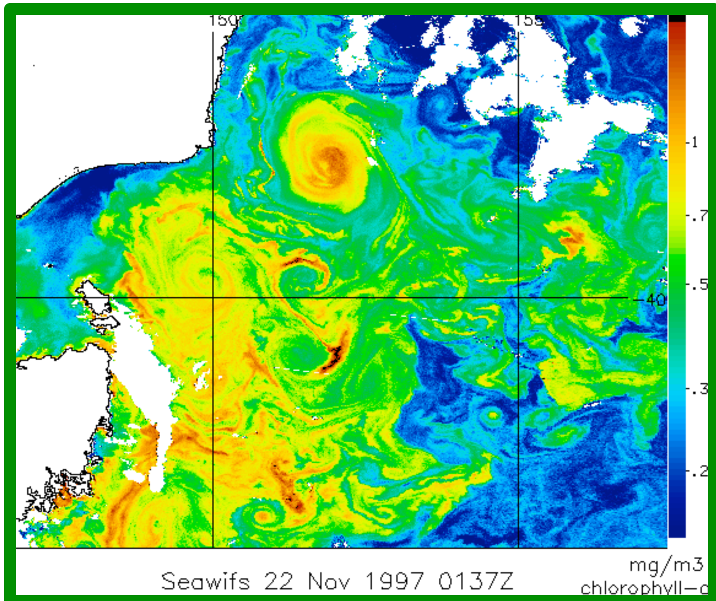
Why study Fluid Dynamics?- Ocean circulation controls dipersal of pollutants.



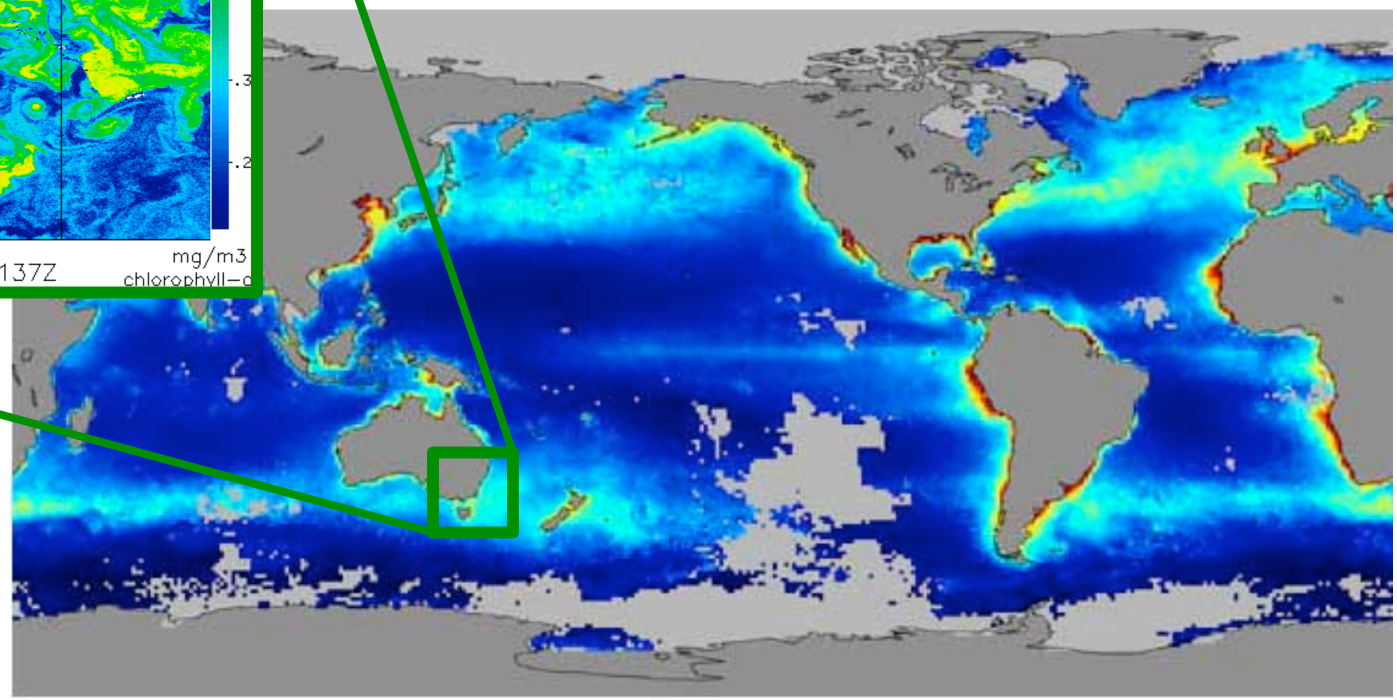
2010 Gulf Oil Spill

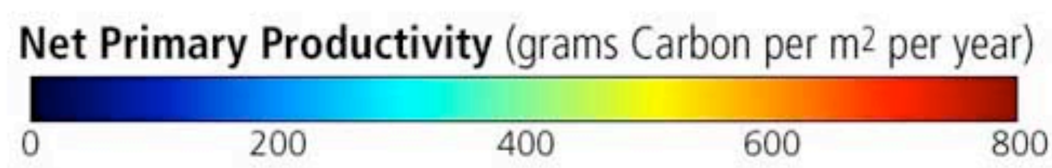
The oil slick as seen from space by NASA's Terra satellite on May 24, 2010.

Why study Fluid Dynamics?



Physical oceanography sets the for local ecosystems and ocean life

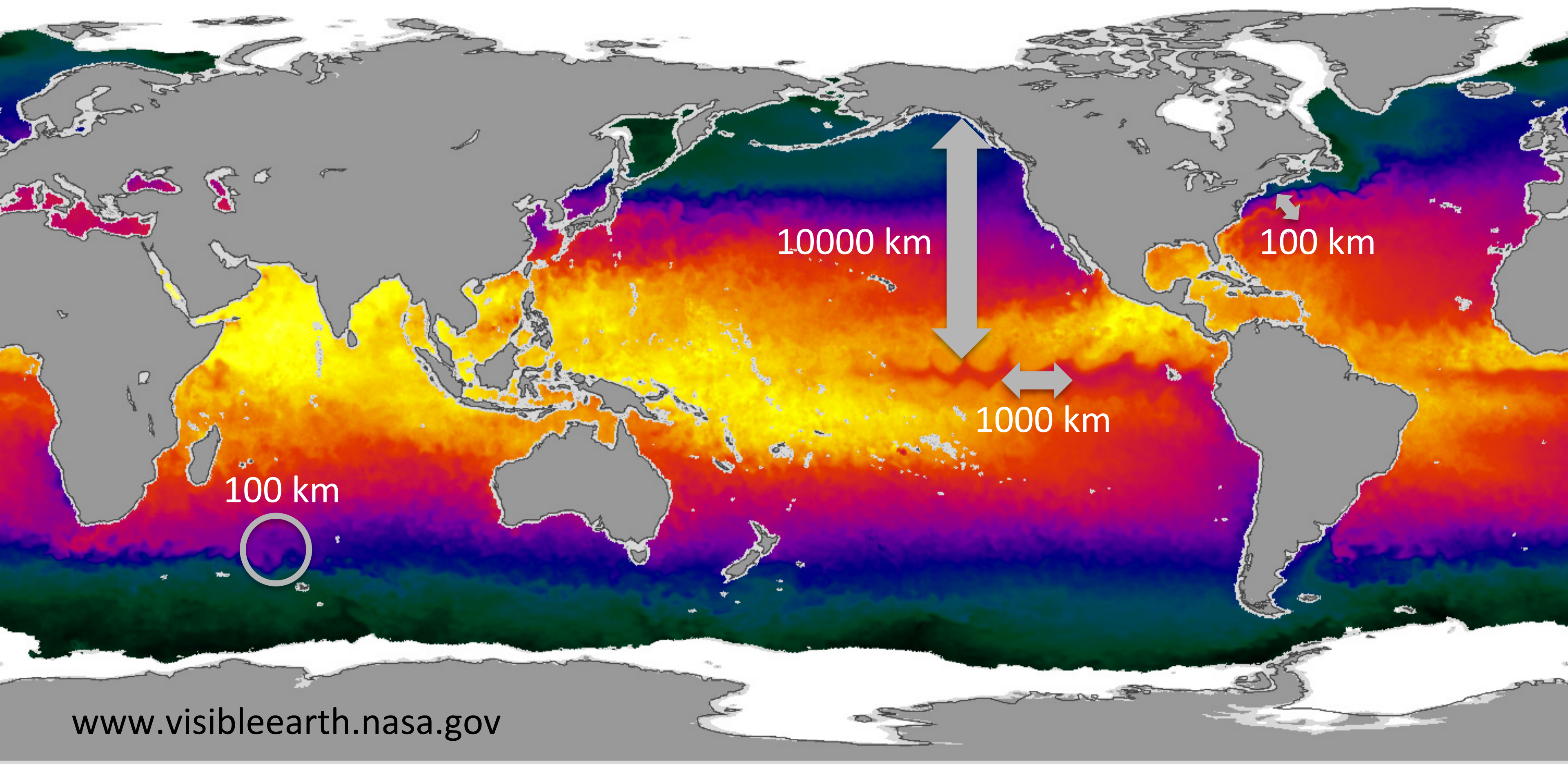




Images from
pages.jh.edy and nasa.gov

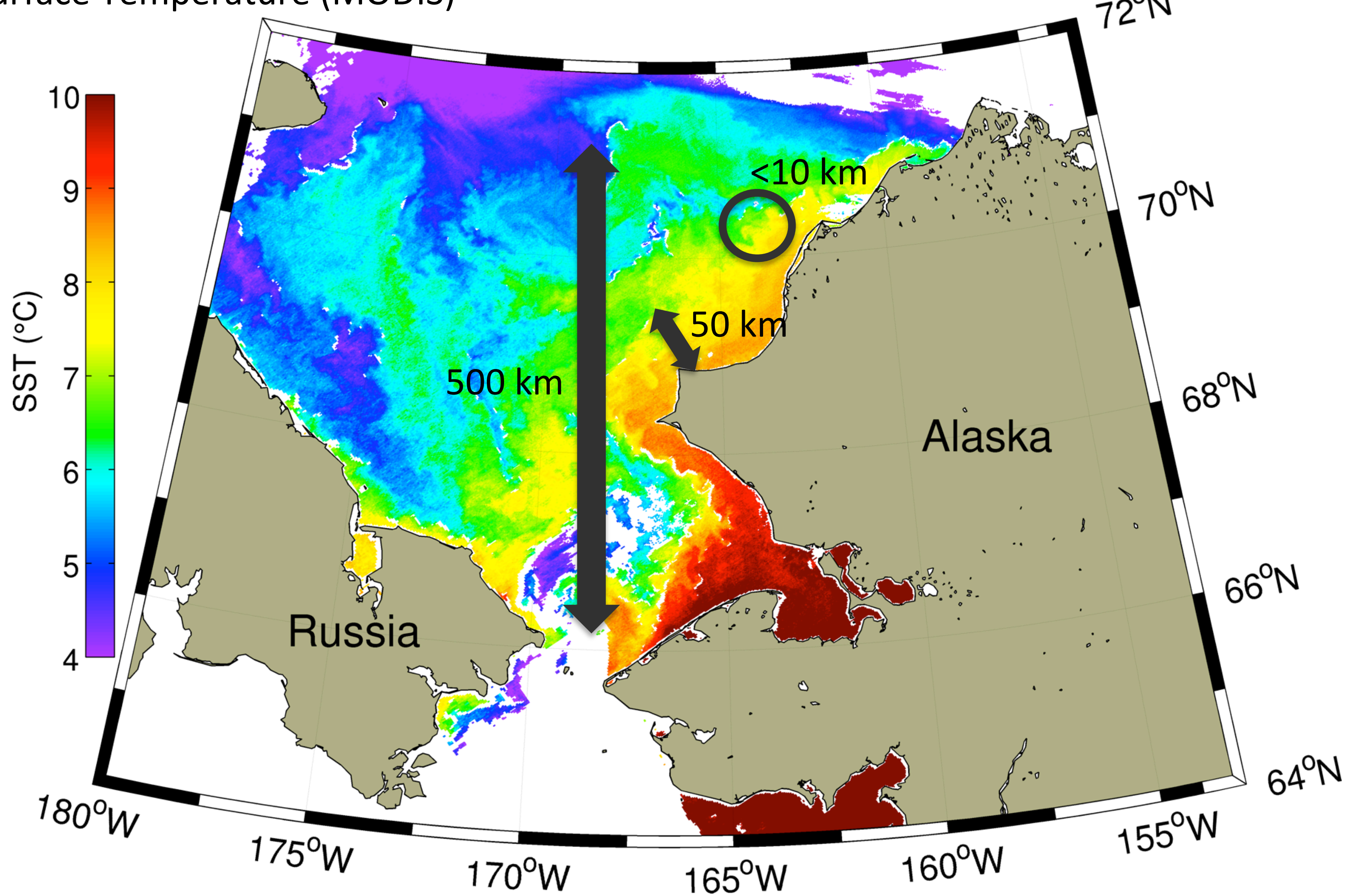
Variability in the Ocean

Sea Surface Temperature from NASA's Aqua Satellite (AMSR-E)



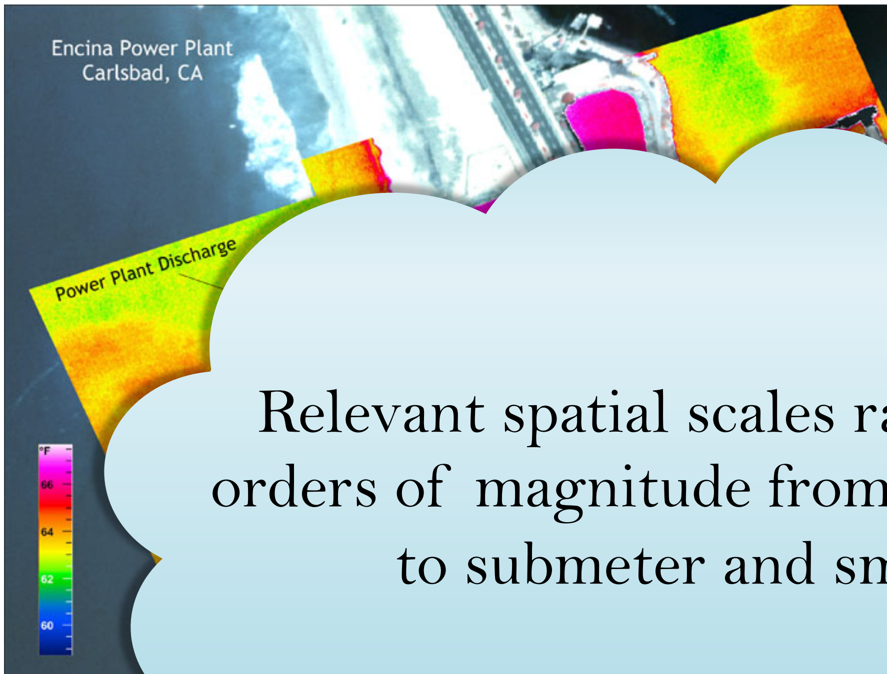
Variability in the Ocean

Sea Surface Temperature (MODIS)



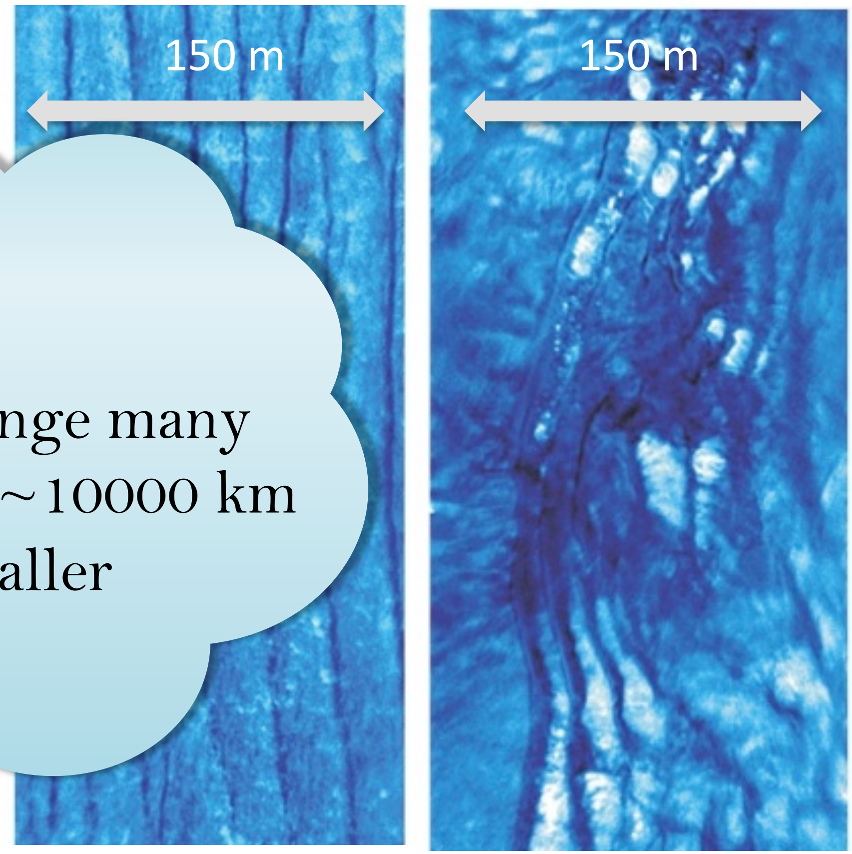
Variability in the Ocean

Sea Surface Temperature (Field Infrared Imagery)

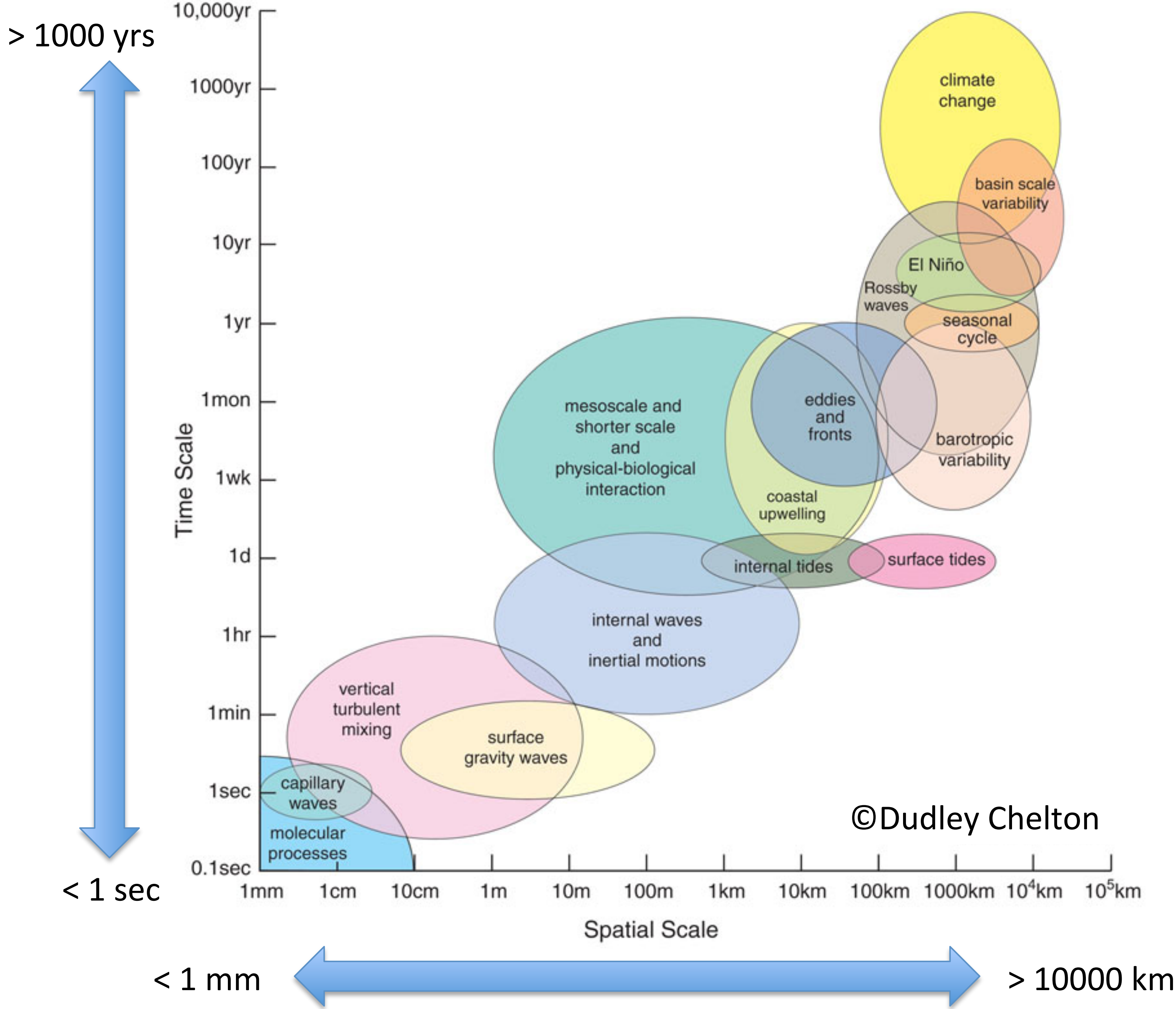


Plant Di

Relevant spatial scales range many orders of magnitude from ~10000 km to submeter and smaller



Langmuir and Internal Waves, NRL



> 1000 yrs
< 1 sec
10,000yr
1000yr
100yr
10yr
1yr
1mon
1wk
1d
1hr
1min
1sec
0.1sec
Time Scale
climate change
basin scale variability
El Niño
Rossby waves
seasonal cycle
eddies and fronts
barotropic variability
mesoscale and shorter scale and physical-biological interaction
coastal upwelling
internal tides
surface tides
internal waves and inertial motions
vertical turbulent mixing
surface gravity waves
capillary waves
molecular processes
©Dudley Chelton
1mm
1cm
10cm
1m
10m
100m
1km
10km
100km
1000km
10^4km
10^5km
Spatial Scale
< 1 mm
> 10000 km

From Merriam-Webster

Fluid (noun) : a *substance* (as a liquid or gas) tending to flow or *conform to* the outline of *its container*

need to describe both the *mass* and *volume* when dealing with fluids

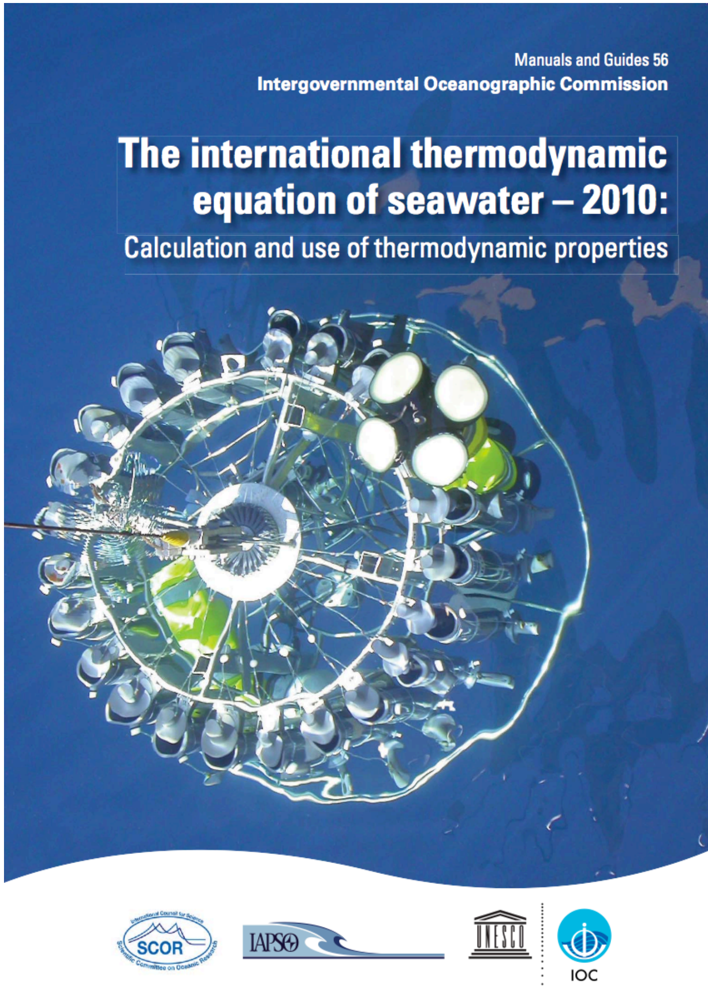
Enter→ density (ρ) = mass per unit volume

= M/V

What factors effect density in the ocean?

The *Equation of State* relates density to ocean state variables

- We don't measure density of seawater directly, but instead compute it using known values of temperature (T), salinity (S), pressure (P) and the **equation of state of seawater**.
- Equation of state of seawater is a **nonlinear** function of T, S, P.
- Equation of state of seawater was derived empirically in the laboratory and is a long, complex polynomial.



How do T, S, and P 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)

Processes that increase (decrease) temperature

- Incoming (outgoing) radiation→
  shortwave & longwave
- Contact with warmer (cooler) gas/fluids →
  sensible
- Condensation (evaporation) →
  latent
- Mixing with warmer (cooler) gas/fluids
- Increasing (decreasing) pressure

Salinity in the Ocean- Salinity is grams of salt per kilogram of seawater. The units are gm/kg.

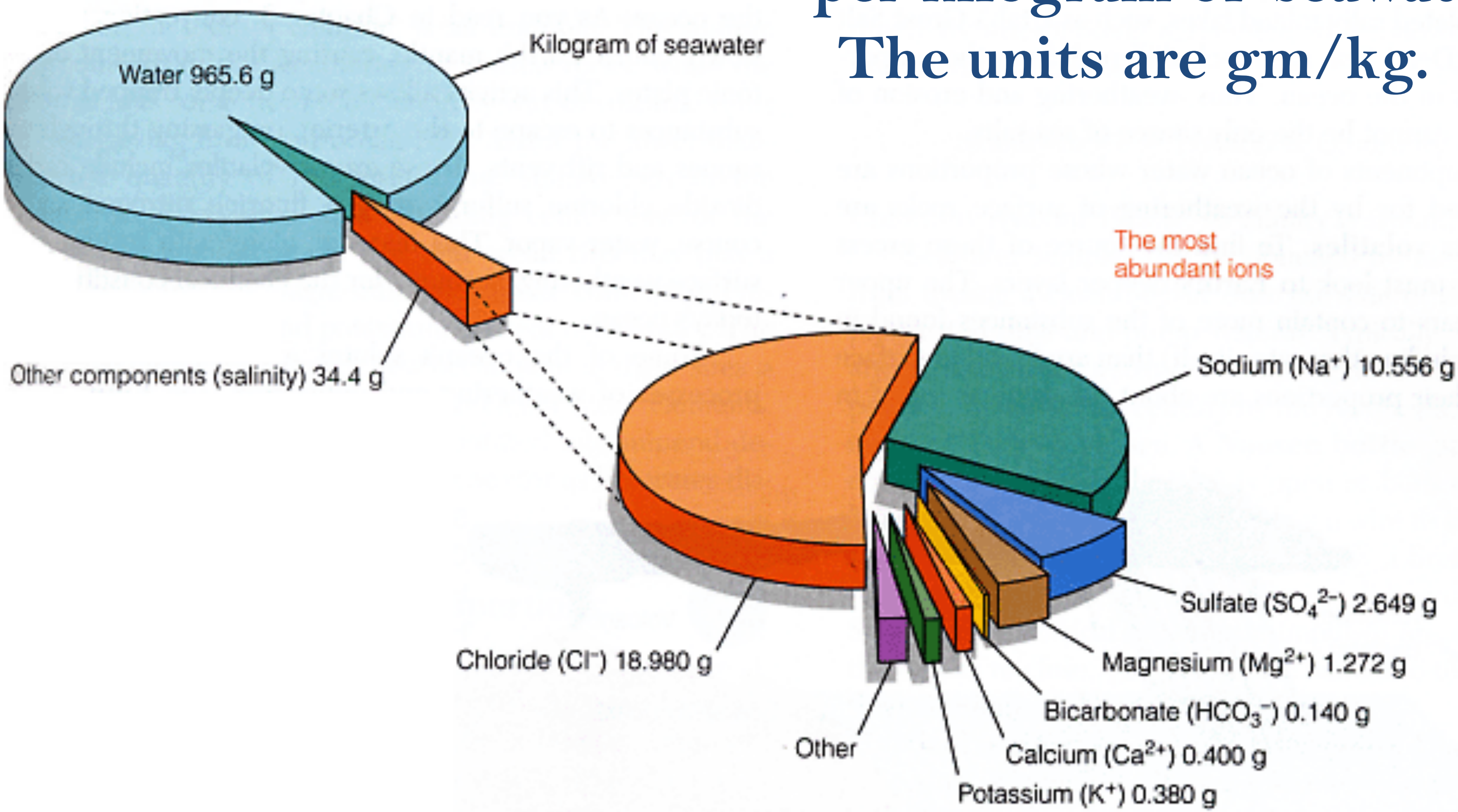
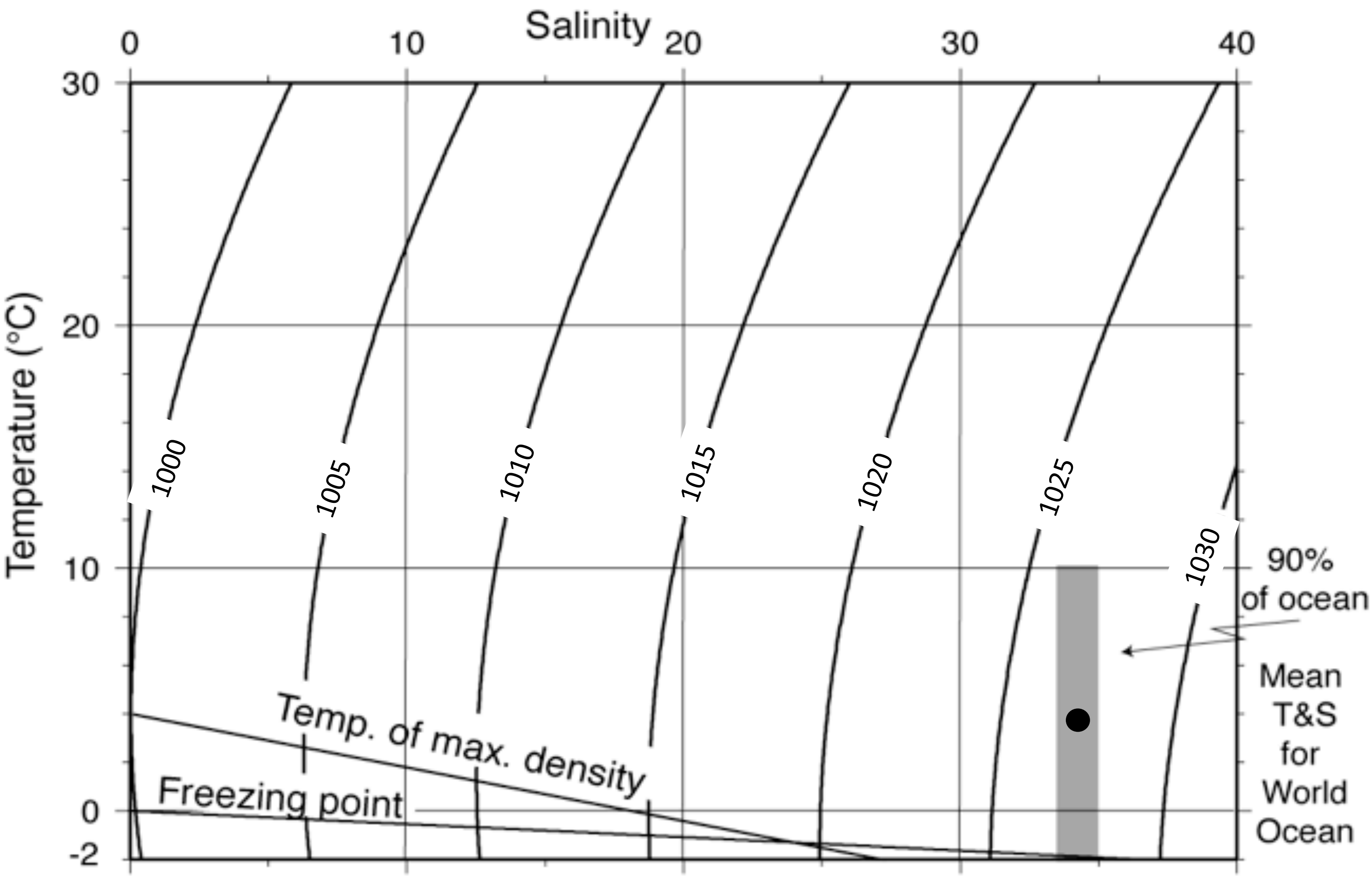


Figure 7.3 A diagrammatic representation of the most abundant components of a kilogram of seawater at 35‰ salinity. Note that the specific ions are represented in grams per kilogram, equivalent to parts per thousand (‰).

Density is a function temperature, salinity, (and pressure)



Density is a function temperature, salinity, (and pressure)

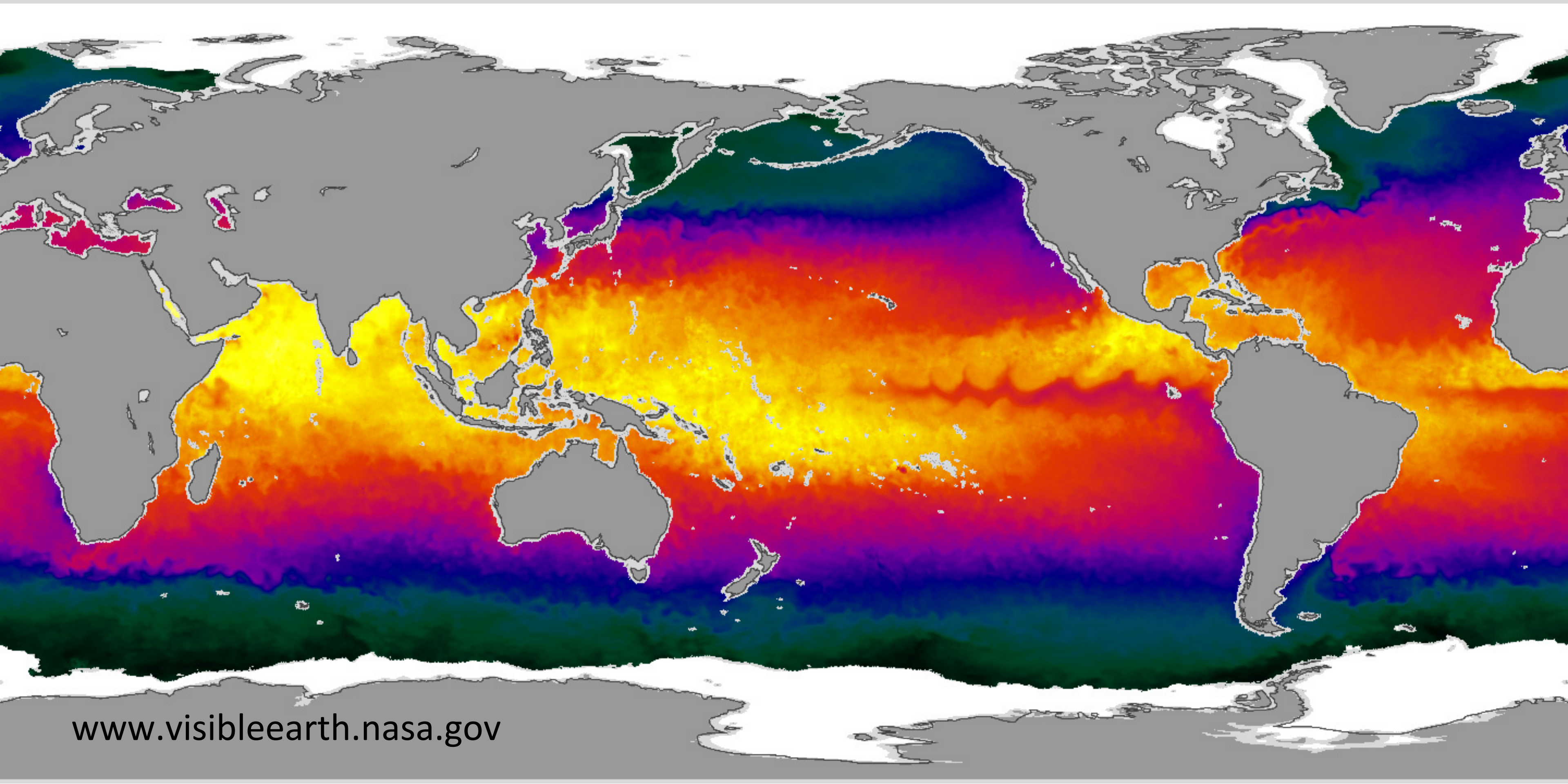
It is often useful to use a simplified equation to express the incremental *change in density* ρ due to incremental *changes* in T, S *and* p:

$$\Delta\rho = \bar{a}\Delta T + \bar{b}\Delta S + \bar{k}\Delta p$$

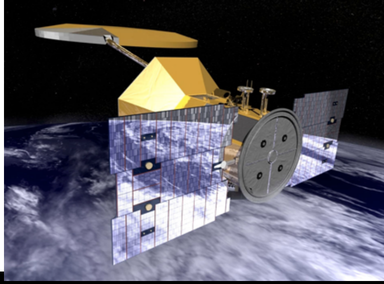
where *a*, *b* and *k* are forms of the *thermal expansion*, *saline contraction* and *compressibility coefficients*, respectively

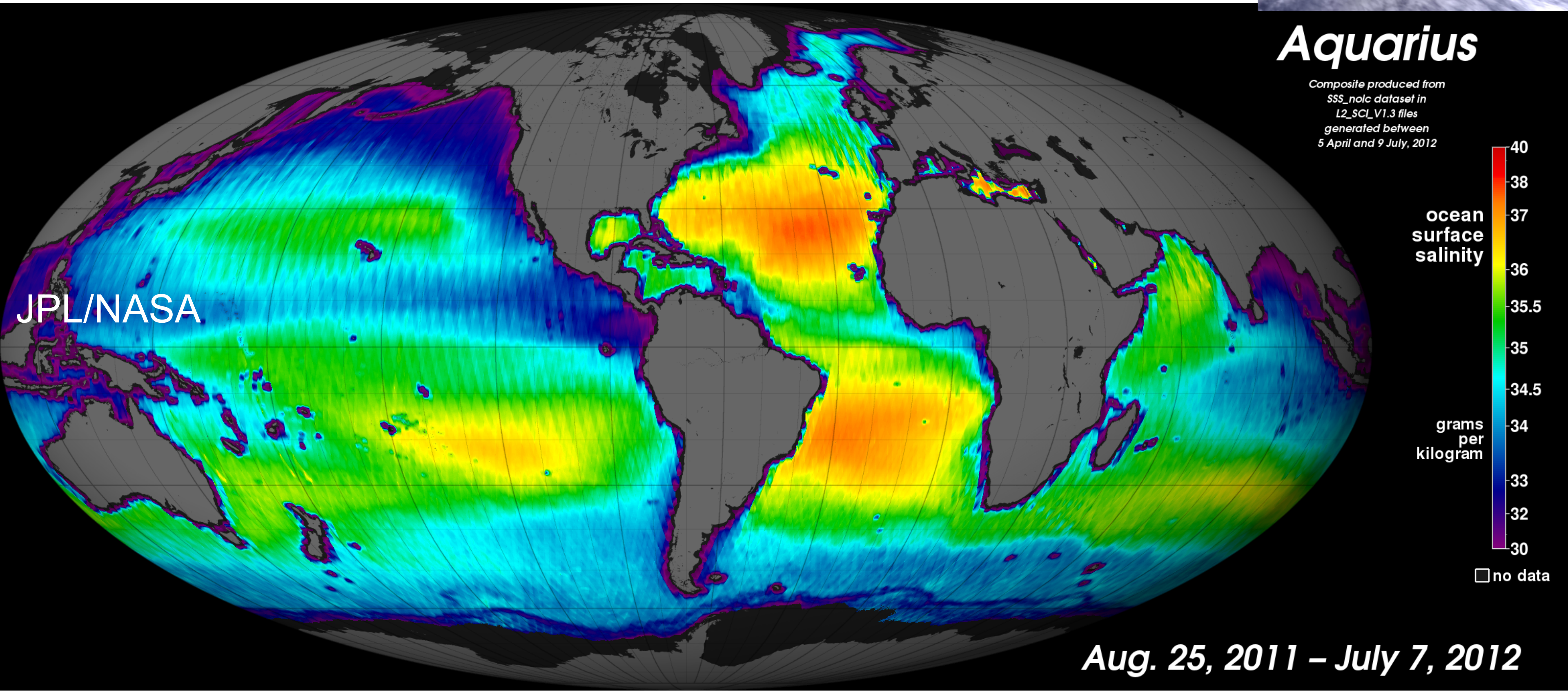
Surface Temperature- Net warming at low latitudes and cooling at high latitudes.

Sea Surface Temperature from NASA's Aqua Satellite (AMSR-E)



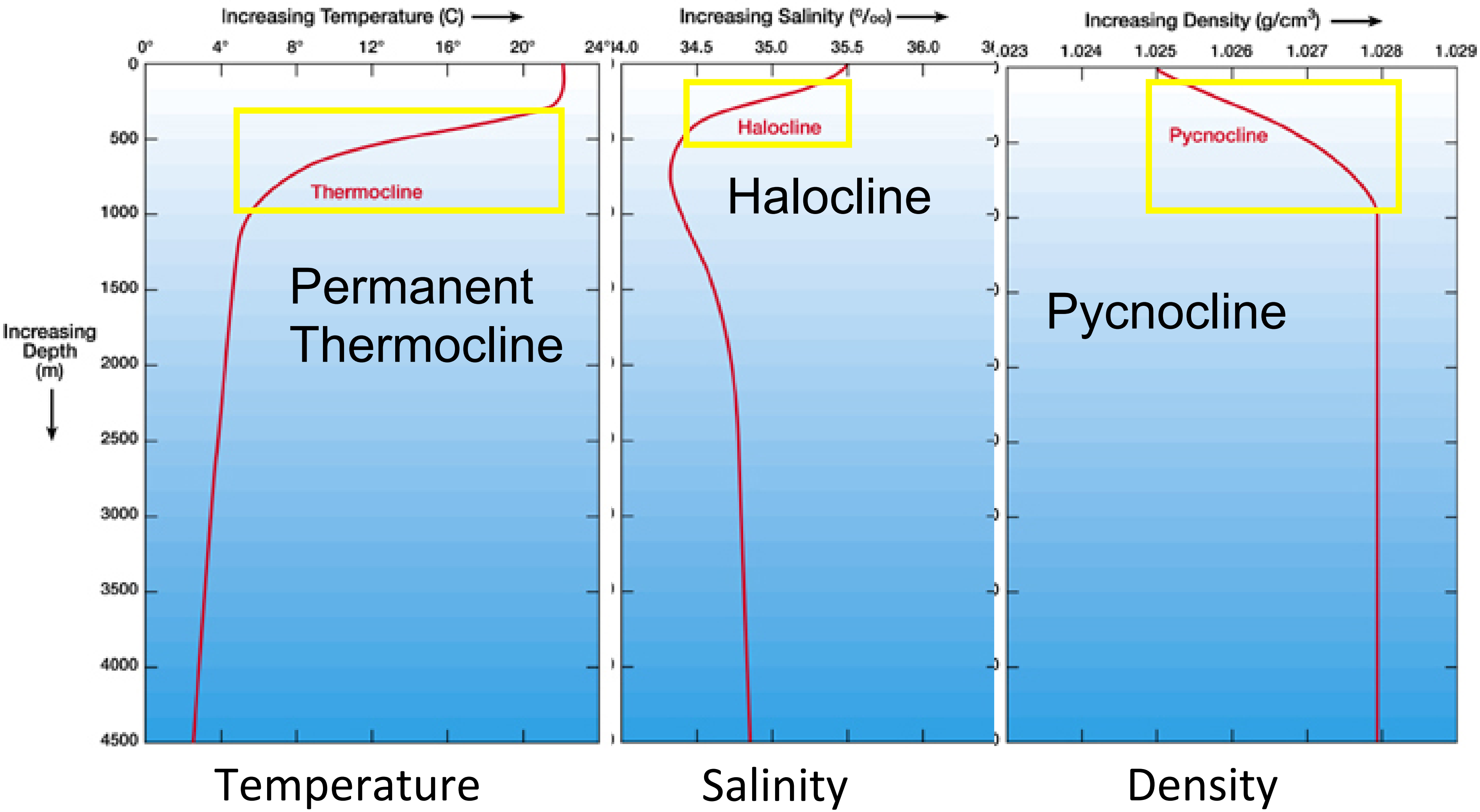
Surface Salinity using the Aquarius Satellite





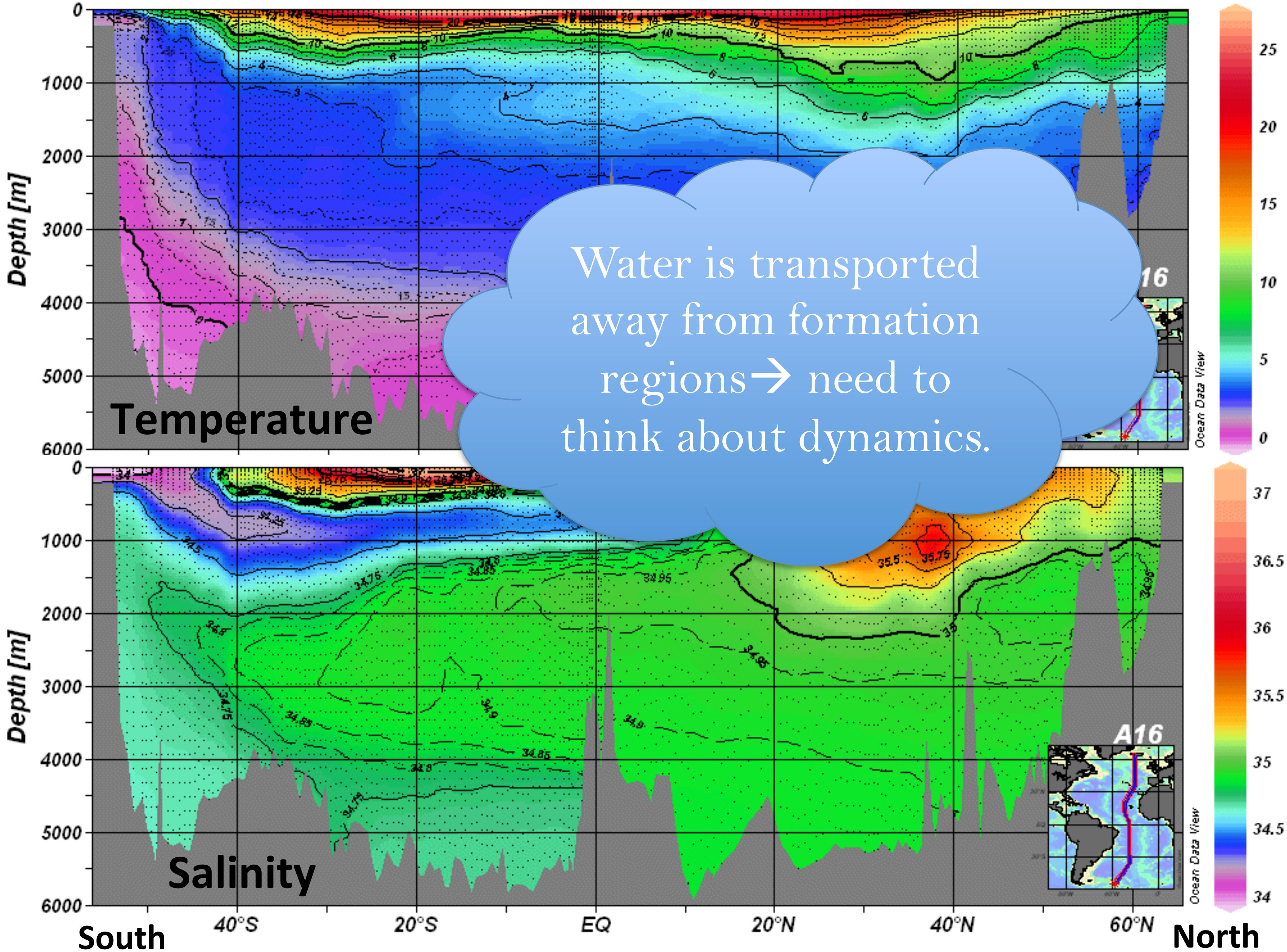
Where precipitation exceeds evaporation and river input is low, salinity is increased and vice versa. Note: coastal variations are not evident on this coarse scale map.

Ocean properties change with depth. (The ocean is stratified.)



Credit: eWOCE

Vertical distributions: typical north-south sections



Water is transported away from formation regions→ need to think about dynamics.

Newton's 2nd Law recast for fluids (the Navier - Stokes equation)

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

acceleration local+ advective

Coriolis

pressure gradient

buoyancy

Other (friction, tidal, wind, etc.)

ROTATION

STRATFICATION

where (**u**=[u,v,w]) are velocity components,
Ω is the earth's rotation rate,
p is the pressure, ρ the density, and g gravity.

Rotation

Two people are standing on a rotating merry-go-round.

One person throws a ball to the other.

1. What does the ball's path look like from above in the “non-rotating" frame?

2. What does the ball's path look like to the people on the merry-go-round?

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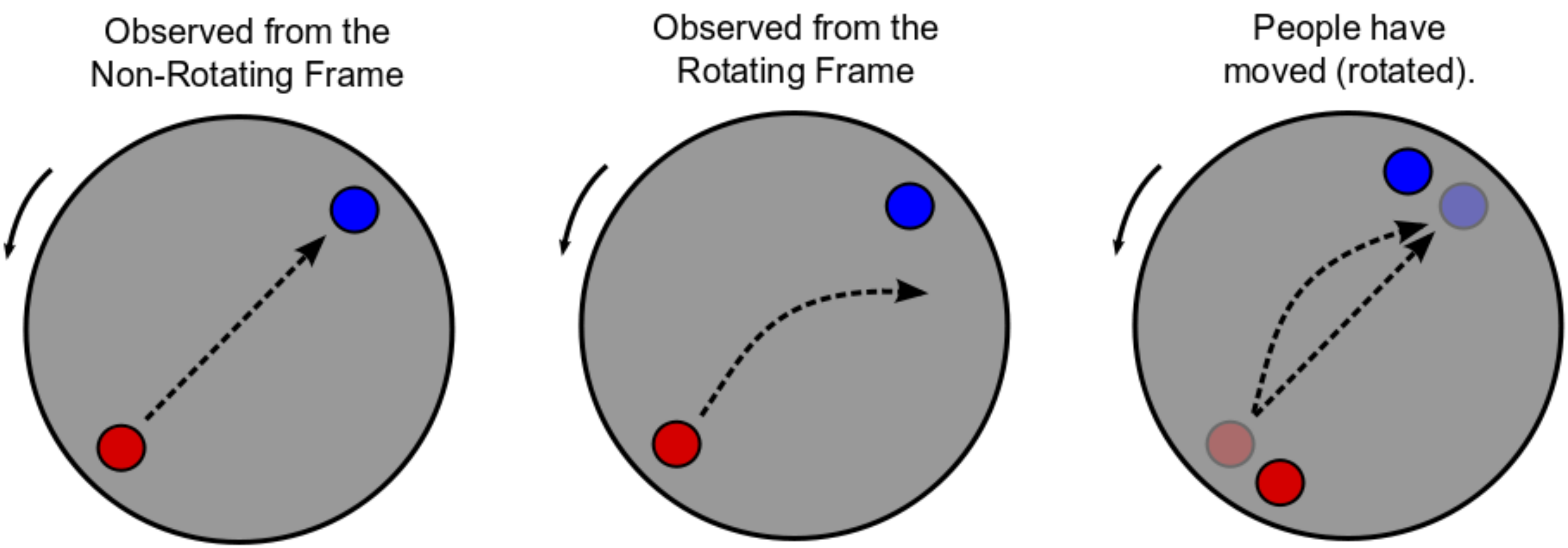


Rotation

The Coriolis effect-

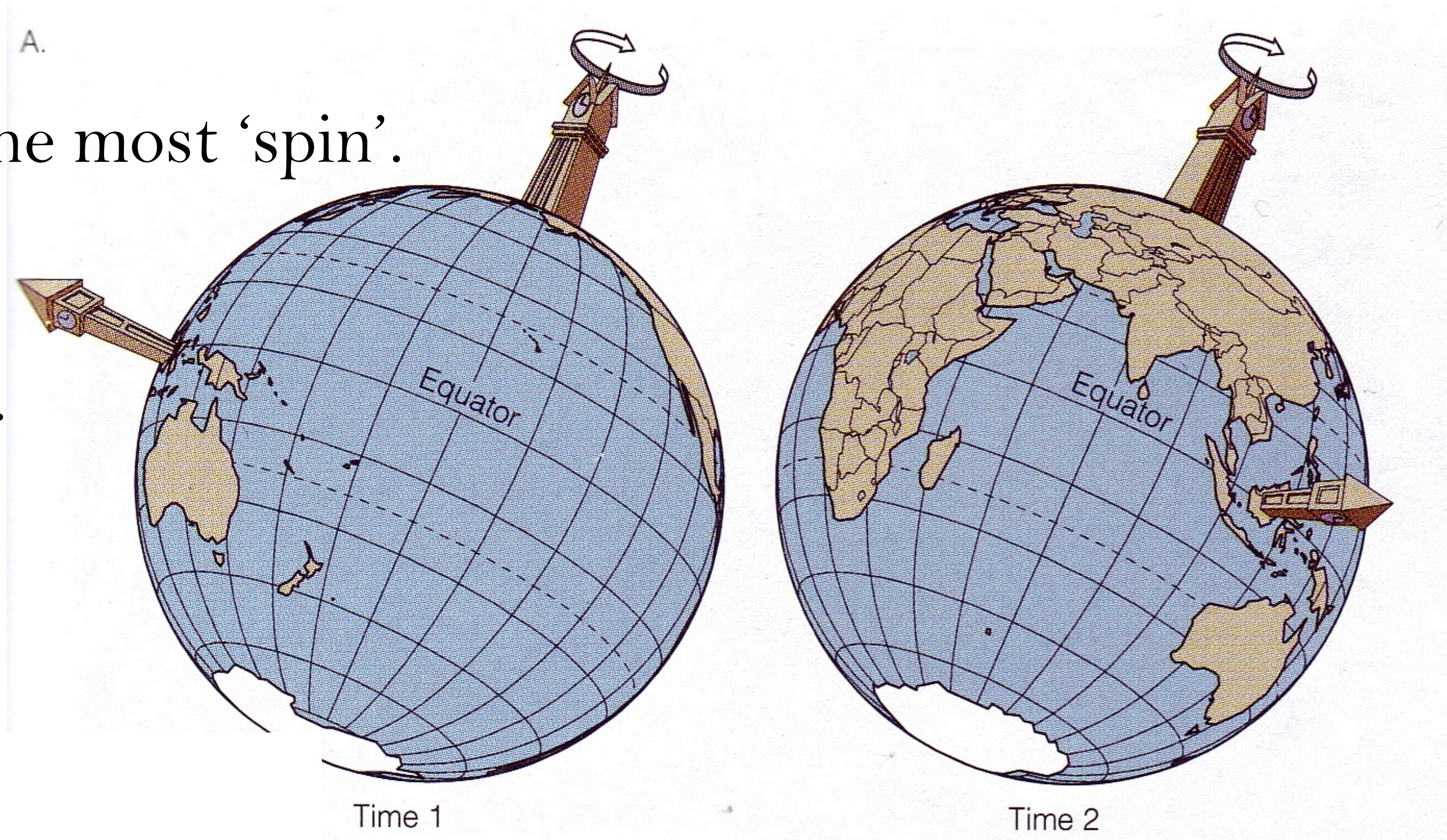
an apparent deflection of moving objects from a straight path when they are viewed from a rotating frame of reference

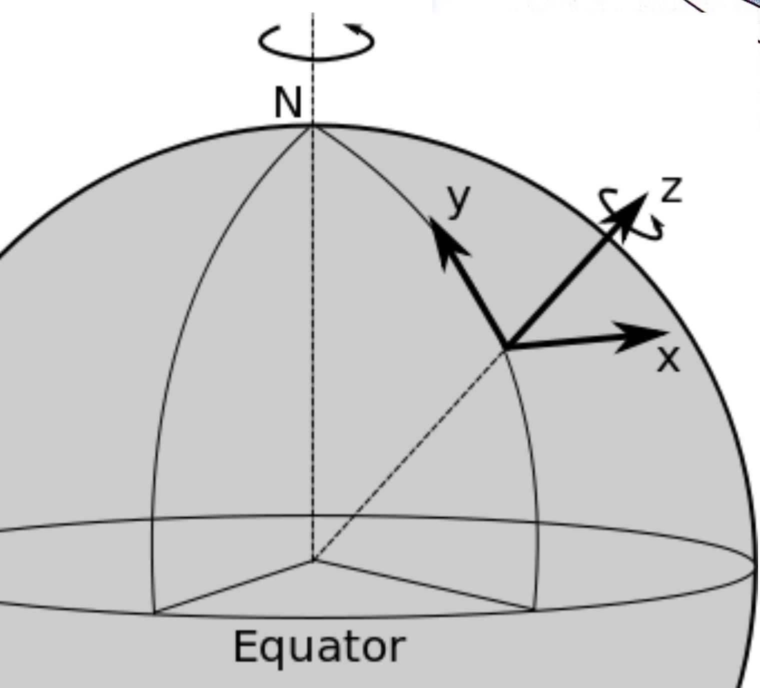
Movie

Check out
J. Price, 2004, A Coriolis Tutorial
available online.

Poles have the most 'spin'.

Equator has
no 'spin'.





The Coriolis Parameter

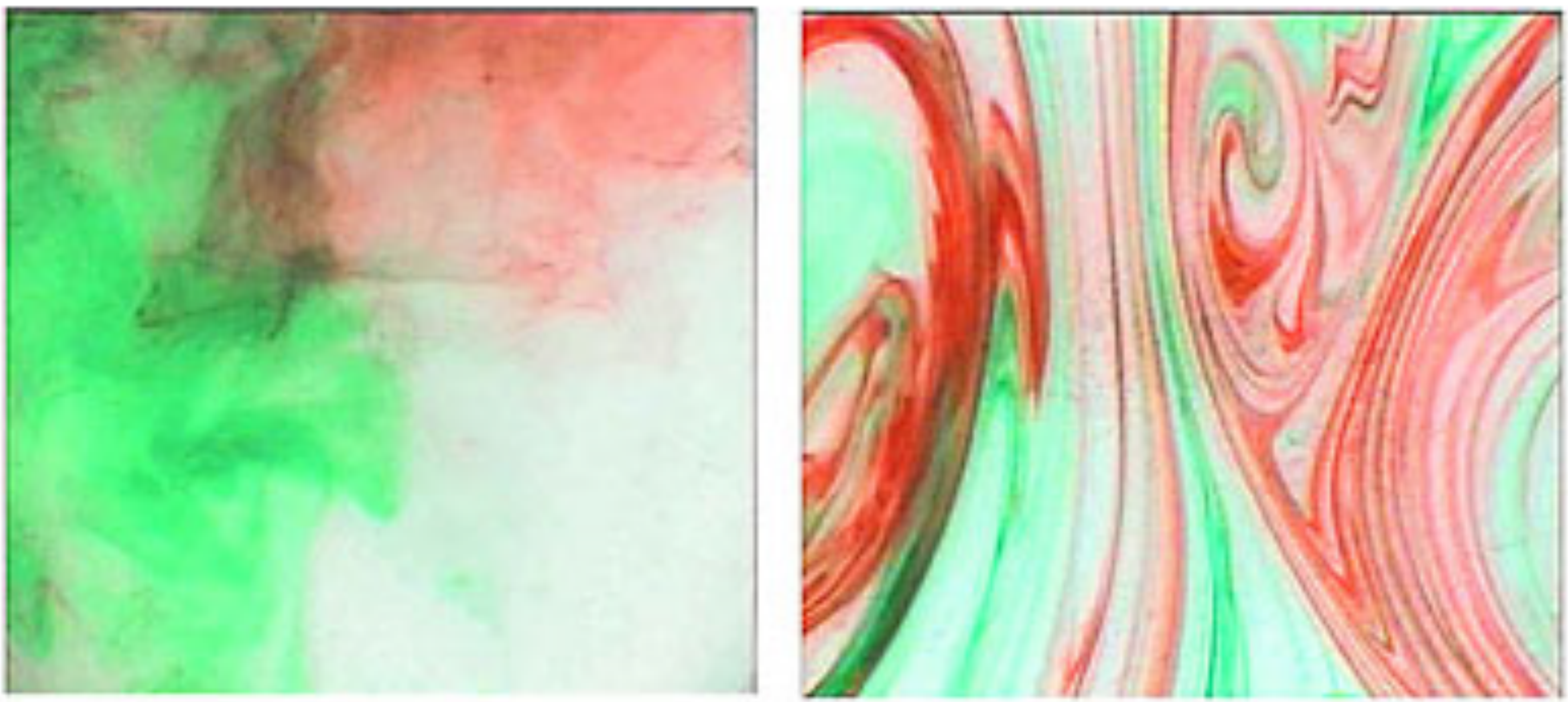
$$f = 2\Omega \sin \phi$$

The Coriolis Force

1. Any object moving horizontally on earth's surface has its trajectory deflected: to the right in the northern hemisphere, to the left in the southern hemisphere.
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.

Rotation- Restricts Motion Horizontally

Non-Rotating | Rotating



Weather in a Tank, http://paoc.mit.edu/labweb/lab1/taylorclip.mpg

Stratification- Restricts Motion Vertically

(1) Horizontal density contrasts lead to pressure gradients that drive flow

(2) Vertical density contrasts inhibit mixing (a stratified fluid is hard to mix)

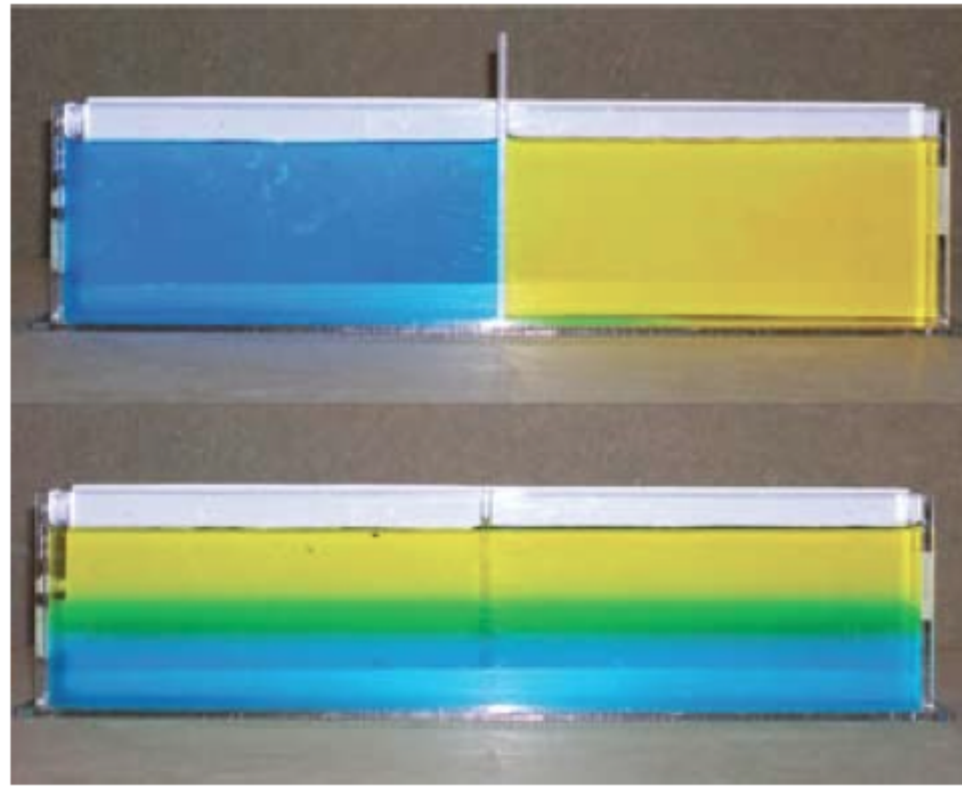
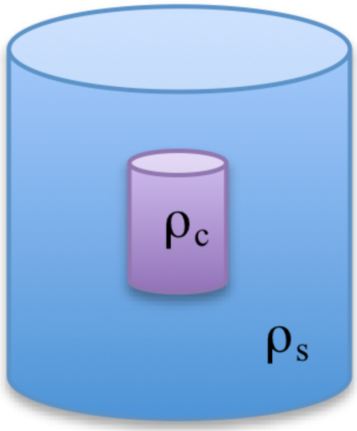


Figure 1.4. Tank before (top) and after removal of divider (bottom).

Archimedes' Principle



If $\rho_c > \rho_s$, then parcel sinks.

If $\rho_c < \rho_s$, then parcel rises.

Archimedes principle states that the **buoyant force (upward) on a submersed object is equal to the weight of the water displaced by the object.**

Note: Changing density of parcel (ρ_c) does **not** affect F_b !

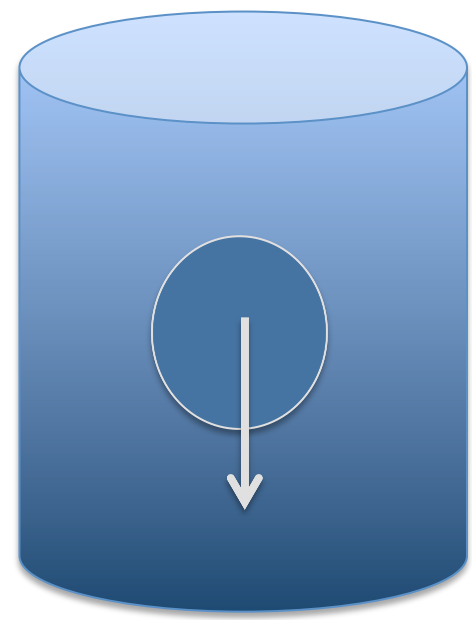
$$F_{parcel} = F_b - F_g = (\rho_s - \rho_c)AHg$$

Stratified layers in the ocean oscillate like a spring when they are displaced. The frequency, *N*, of the oscillator is given by

$$N^2 = \left[-\frac{1}{\rho_0} \frac{\partial \rho}{\partial z} \right] g \quad [\text{radians/s}]^2$$

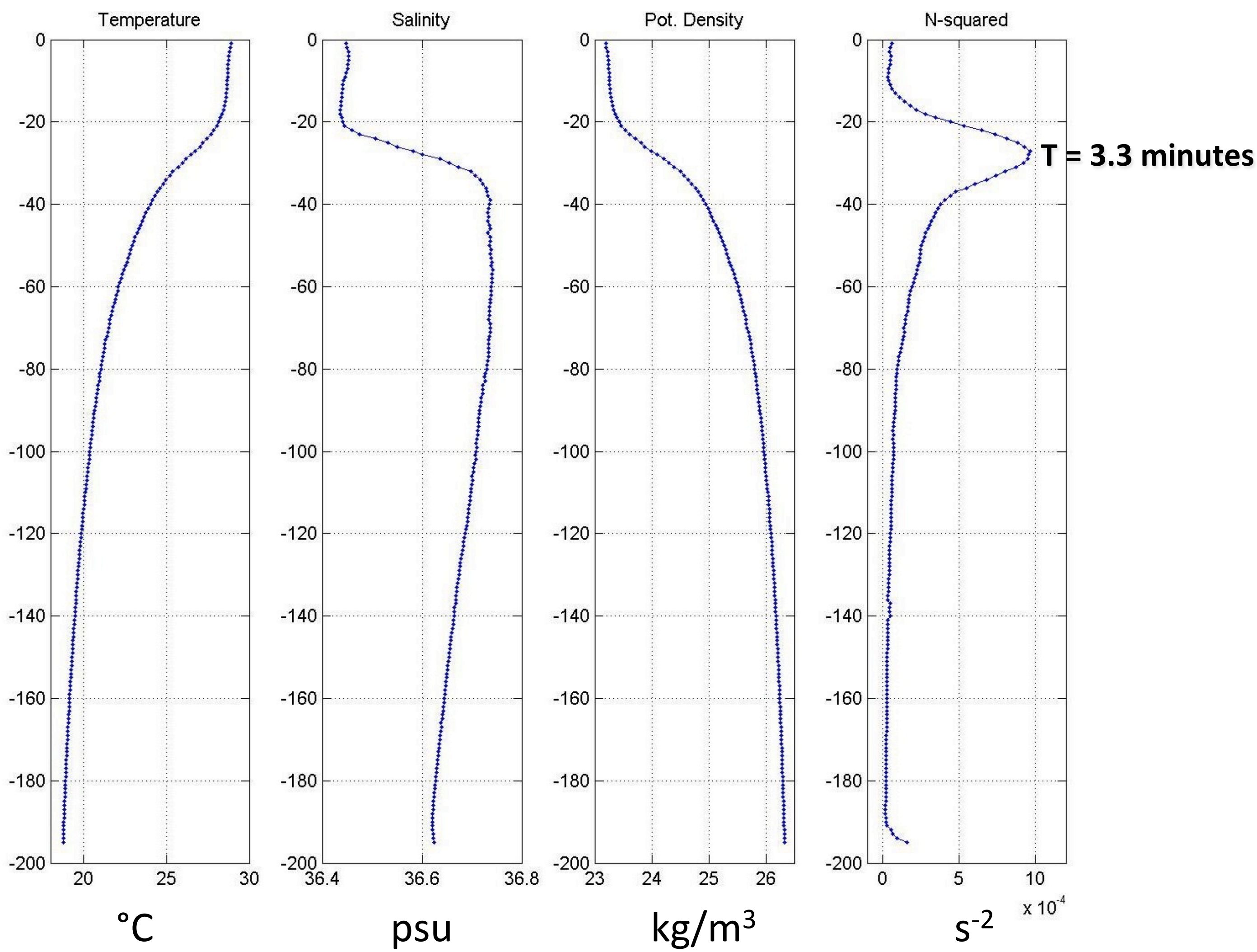
N is known as the buoyancy, Väisälä, or Brünt-Väisälä frequency. The period of oscillation is given by

$$\tau = \frac{2\pi}{N} \quad [s]$$

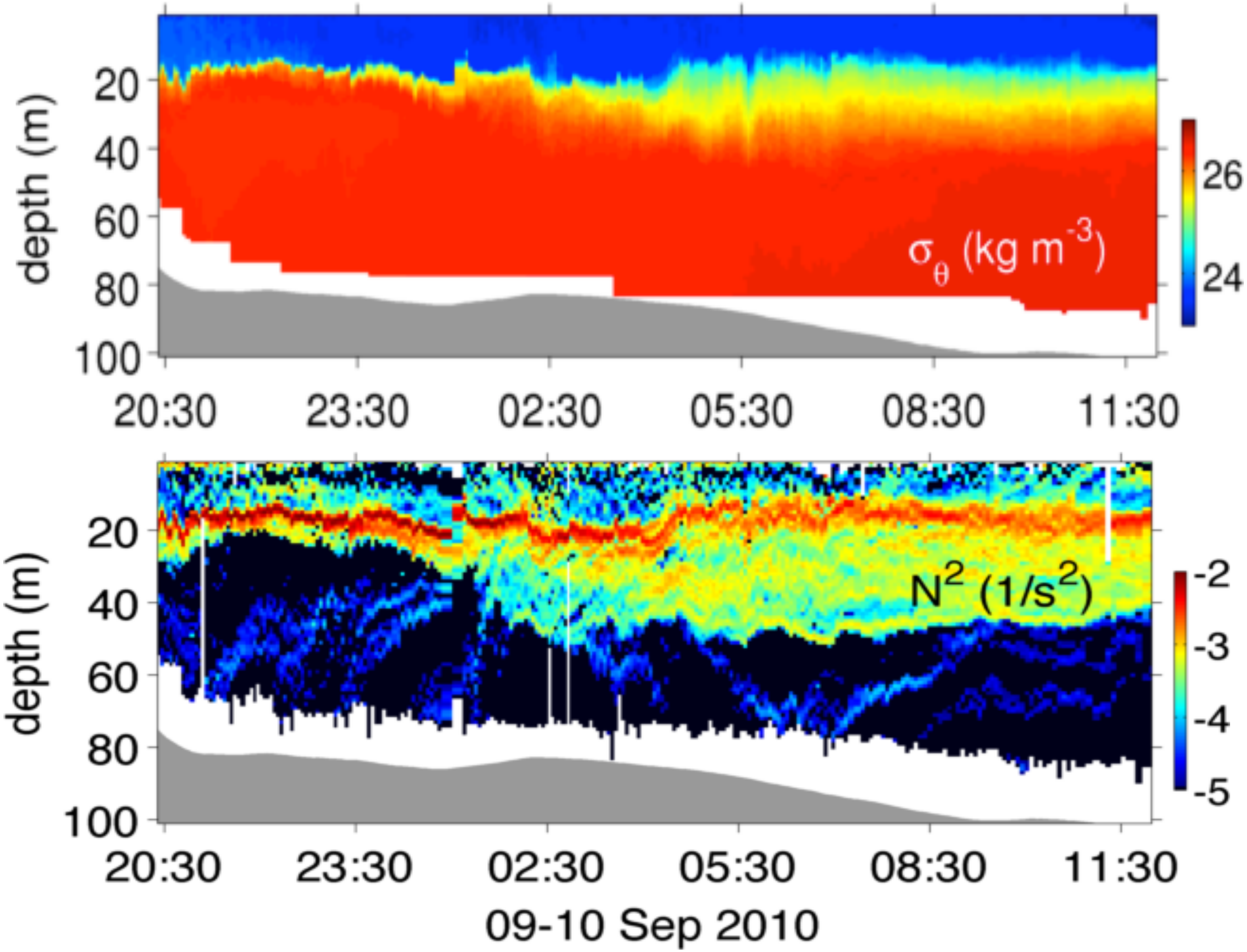


A high *N* (short τ) indicates a strong restoring force or a high stratification.

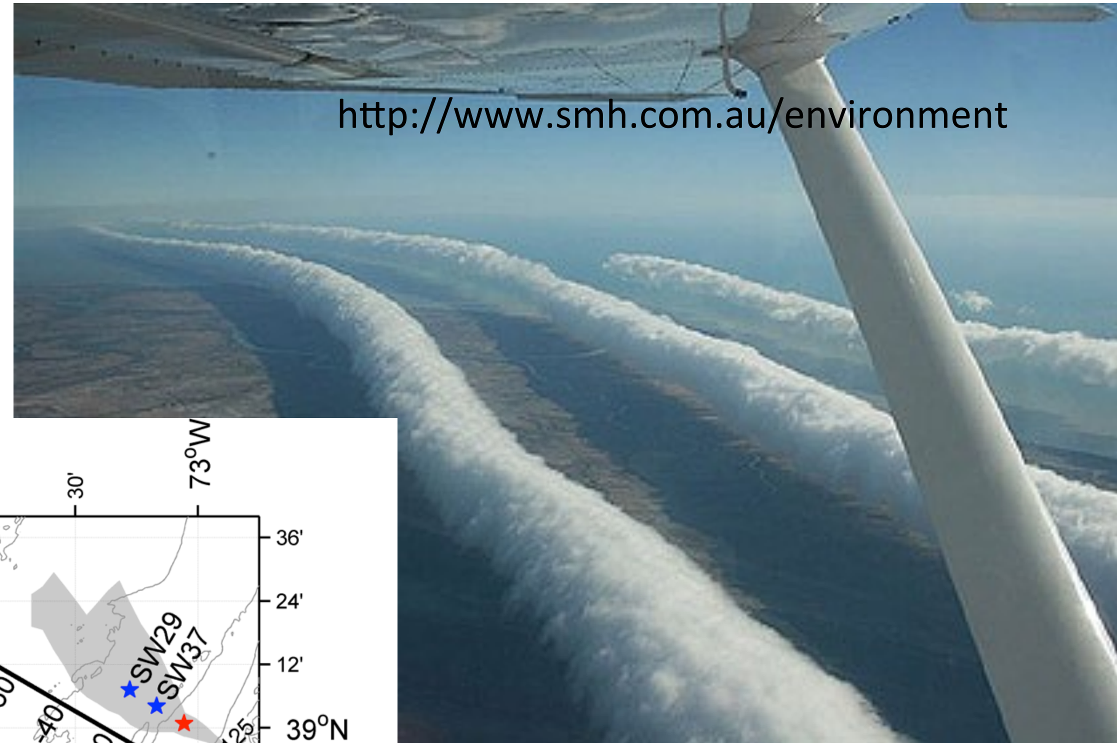
Observed open ocean buoyancy frequency measured by gliders

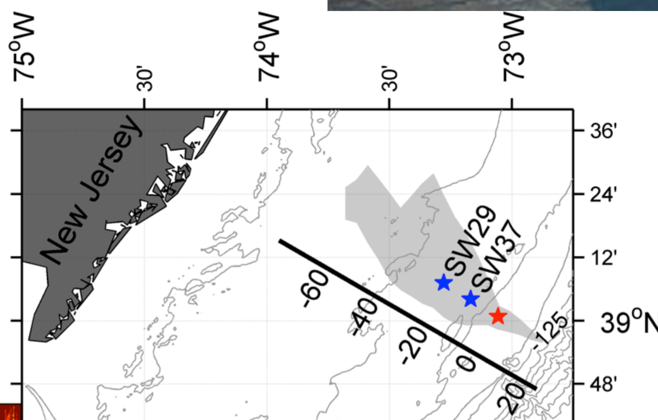


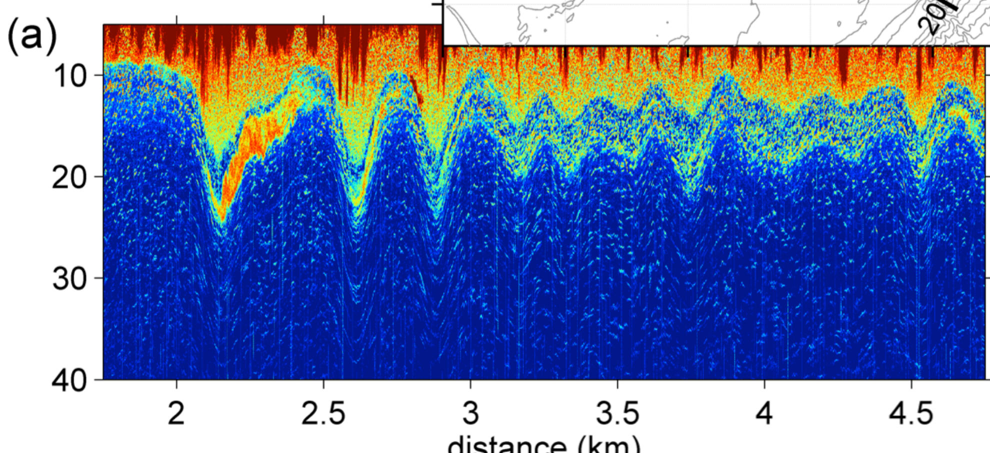
Example Density and N^2 from the Coastal Ocean



Internal Waves in the Atmosphere and Ocean…







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