Introduction to Observational Physical Oceanography 12.808

Class 3, 11 September 2008

Seawater its properties and their distribution

these slides are available online at

http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class3_11Sep08.ppt

http://www.whoi.edu/science/PO/people/jprice/class/miscart/Class3_11Sep08.pdf

Class 3

Seawater its properties and their distribution

- temperature
- salinity

Class 2

- pressure
- density (equations of state)
- potential temperature/density
- static stability

Class 3

- T/S diagrams
- water types and masses

Class 4

Pressure:

What is pressure?

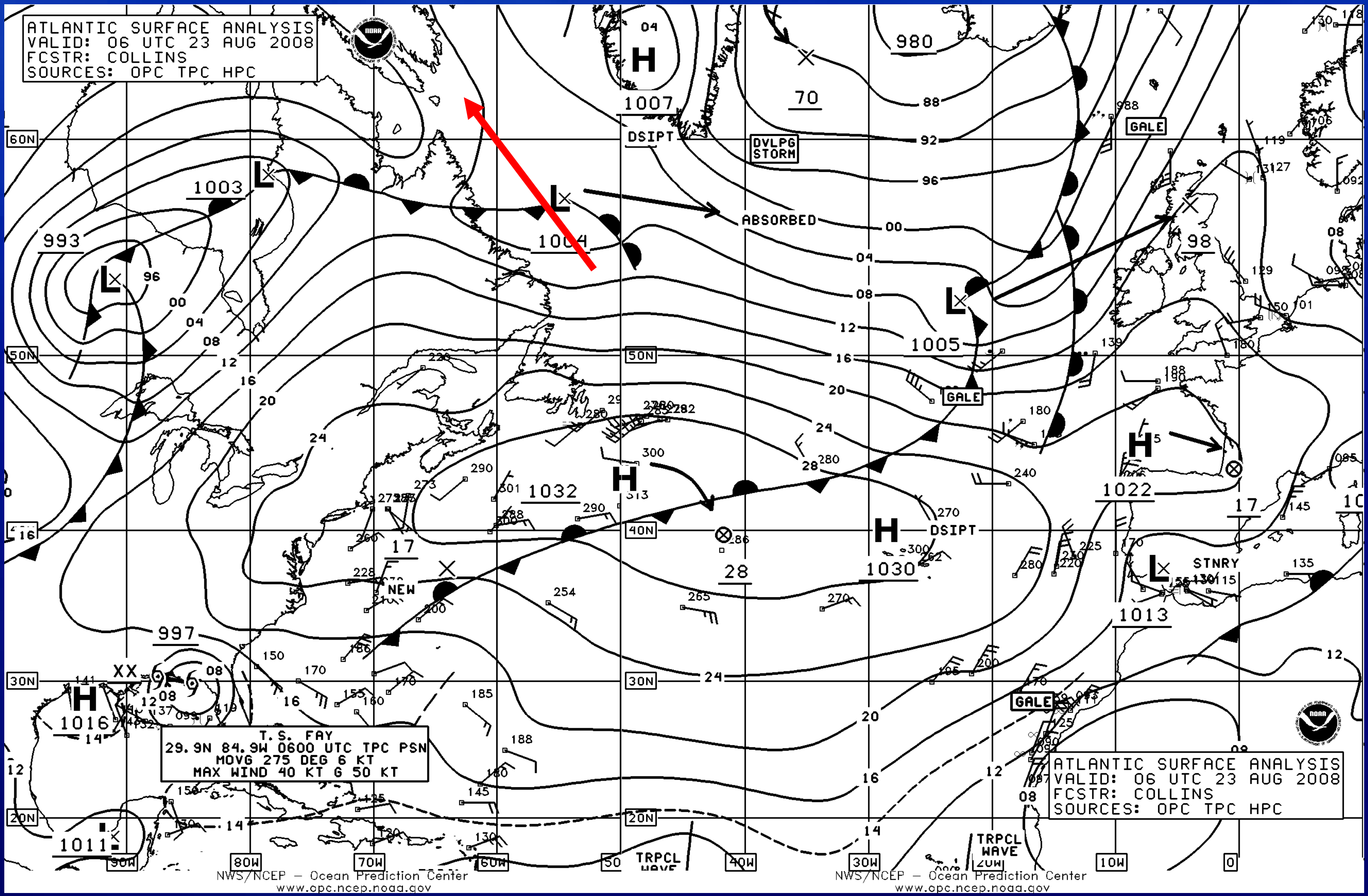
Pressure is the normal force per unit area exerted by water (or air in the atmosphere) on either side of the unit area

Units: [Force] = kg m/ s^2 = N (Newton)
[Pressure] = [Force/Area] = kg/ (m s^2) = N/m^2 = 1 Pascal (Pa)

1 bar = 10^5 Pa (atmospheric pressure)
1 dbar = 10^4 Pa (ocean pressure)

A pressure force is the result of spatial pressure gradients. These are typically decomposed into vertical and horizontal components.

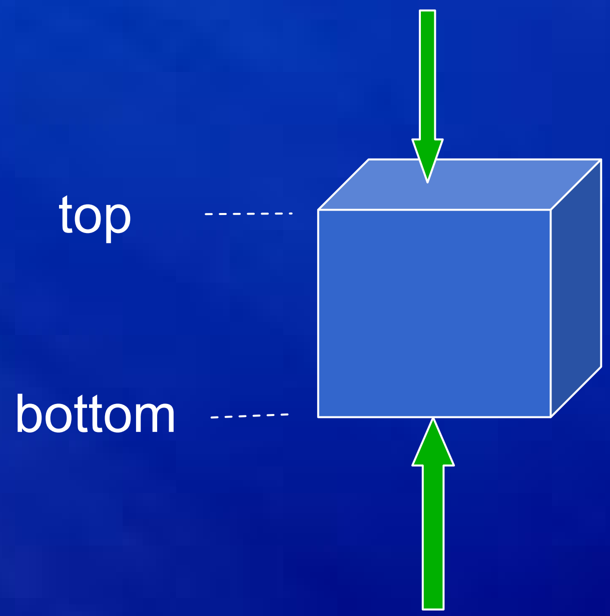
Sea Level Pressure over the North Atlantic: the Horizontal component and its link to dynamics



Vertical Pressure Force

Vertical pressure force =

-A x (pressure (top) – pressure (bottom))



If pressure (top) = pressure (bottom)
then Fz = vertical pressure force = 0

When is fluid parcel in equilibrium in the vertical?

Force 1 - Vertical pressure force =

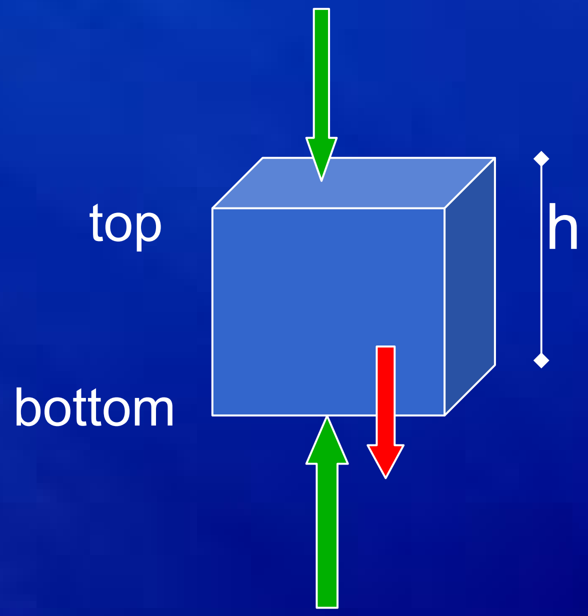
-A x (pressure (top) – pressure (bottom))

= - A x (P (top) - P(bottom))

Force 2 – Gravity = - A h ρ g

Equilibrium = sum of forces = 0

$$P(\text{bottom}) - P(\text{top}) - h\,\rho\,g = 0$$



As h -> 0 $\boxed{dP/dz = -\rho\, g}$

The fluid is in

Hydrostatic balance

Depth

Depth is the third coordinate, besides latitude and longitude which identifies a location in the ocean (i.e. a point)

Thus each observation in the ocean is associated with a depth as well as a horizontal position.

Measuring depth (from the surface) of a measurements is problematic (e.g. wire angle) – instead we measure pressure and use hydrostatic balance to determine depth.

Pressure as a vertical coordinate

Density of seawater varies little and the hydrostatic relation provides a simple relation between pressure and depth

Pressure change over 1 m;

$\Delta P = -\rho\, g\, \Delta z = -1025*9.8\ \mathrm{kg\ m^{-1}\ sec^{-2}} = 10^4\ \mathrm{Nt\ m^{-2}} = 1\ \mathrm{dbar}$

In practice – the pressure versus depth relationship is a function of density and latitude (both g and density vary with latitude)

For most purposes – we use an empirical relationship between pressure, depth and latitude:

P = sw_pres(depth, latitude)
depth = sw_dpth(P, latitude)

Remember to pay attention to the units!

Density:

What is density?

density is mass per volume, ρ (kg/m^3)

Density of fresh water at 0 C, atm. pressure = 1000 (kg/m^3)

Range in the density of seawater = $1020 < \rho < 1060$ kg/m3

hence we use sigma $\sigma = \rho - 1000$

e.g. $\rho = 1027 \Rightarrow \sigma = 27$

Why does density 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.

How do we measure density?

Density is a complex function of S, T and P. It is not measured directly but instead computed using known values of T,S, P and the equation of state of sea water.

This was derived empirically in the laboratory and is a long, complex polynomial.

$$\rho_w = 999.842594 + 6.793952 \times 10^{-2}t - 9.095290 \times 10^{-3}t^2 + 1.001685 \times 10^{-4}t^3 - 1.120083 \times 10^{-6}t^4 + 6.536332 \times 10^{-9}t^5. \qquad (A3.1)$$

Second, the density at one standard atmosphere (effectively $p = 0$) is given by

$$\rho(S, t, 0) = \rho_w + S(0.824493 - 4.0899 \times 10^{-3}t + 7.6438 \times 10^{-5}t^2 - 8.2467 \times 10^{-7}t^3 + 5.3875 \times 10^{-9}t^4) + S^{3/2}(-5.72466 \times 10^{-3} + 1.0227 \times 10^{-4}t - 1.6546 \times 10^{-6}t^2) + 4.8314 \times 10^{-4}S^2. \qquad (A3.2)$$

Finally, the density at pressure p is given by

$$\rho(S, t, p) = \rho(S, t, 0)/(1 - p/K(S, t, p)), \qquad (A3.3)$$

where K is the secant bulk modulus. The pure water value K_w is given by

$$K_w = 19652.21 + 148.4206t - 2.327105t^2 + 1.360477 \times 10^{-2}t^3 - 5.155288 \times 10^{-5}t^4. \qquad (A3.4)$$

The value at one standard atmosphere ($p = 0$) is given by

$$K(S, t, 0) = K_w + S(54.6746 - 0.603459t + 1.09987 \times 10^{-2}t^2 - 6.1670 \times 10^{-5}t^3) + S^{3/2}(7.944 \times 10^{-2} + 1.6483 \times 10^{-2}t - 5.3009 \times 10^{-4}t^2) \qquad (A3.5)$$

and the value at pressure p by

$$K(S, t, p) = K(S, t, 0) + p(3.239908 + 1.43713 \times 10^{-3}t + 1.16092 \times 10^{-4}t^2 - 5.77905 \times 10^{-7}t^3) + pS(2.2838 \times 10^{-3} - 1.0981 \times 10^{-5}t - 1.6078 \times 10^{-6}t^2) + 1.91075 \times 10^{-4}pS^{3/2} + p^2(8.50935 \times 10^{-5} - 6.12293 \times 10^{-6}t + 5.2787 \times 10^{-8}t^2) + p^2S(-9.9348 \times 10^{-7} + 2.0816 \times 10^{-8}t + 9.1697 \times 10^{-10}t^2). \qquad (A3.6)$$

Gill, 1982

How do we measure density?

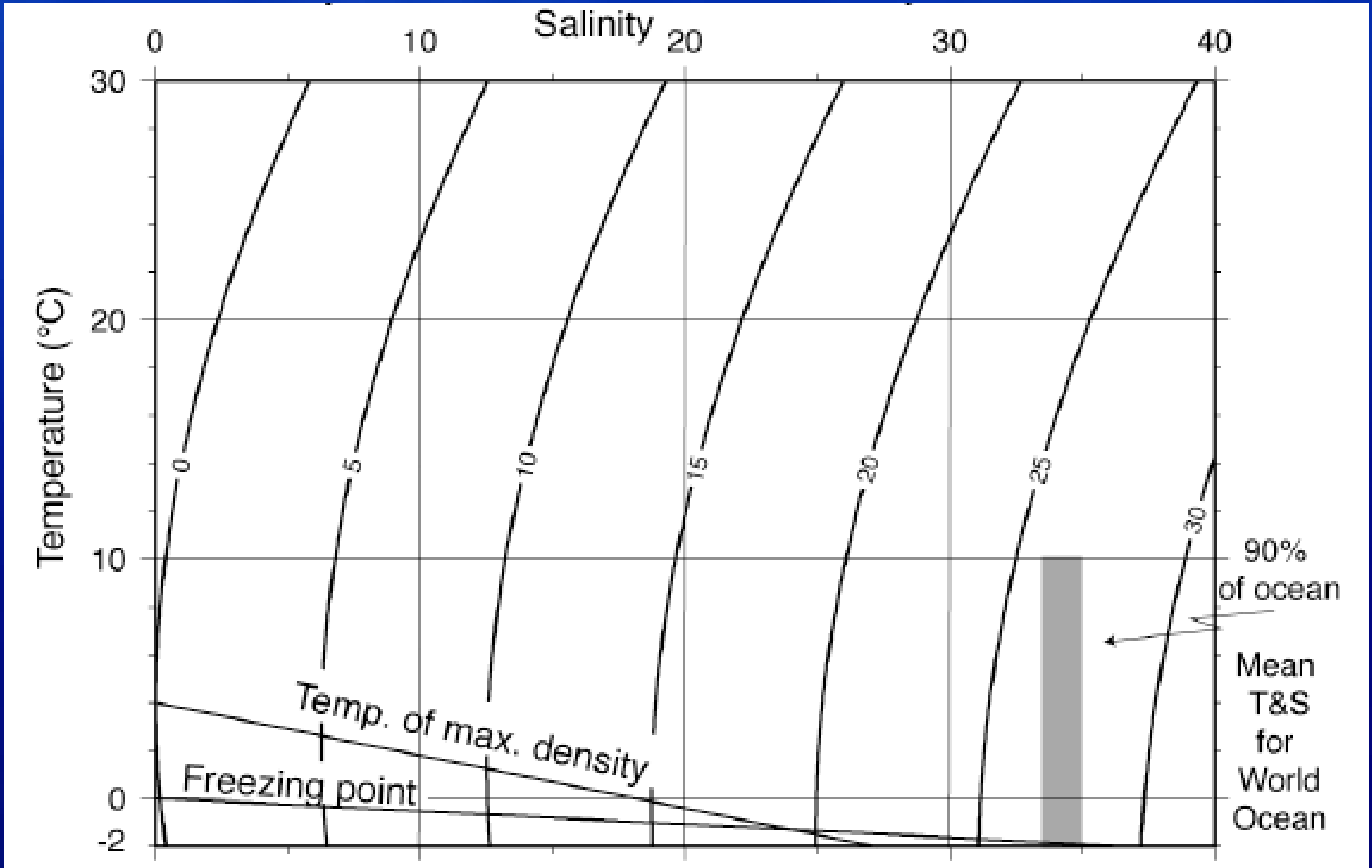
with a calculator and a lot of patience….

In practice we use numerical code to compute density once T, S and P are known.

e.g. density = ρ = sw_dens(S, T, P)

where sw_dens is a Matlab script in the seawater directory.
for this script, S is non-d (psu), T is degrees C, P is in dbars

How sigma varies as a function of T and S



From ETP05

Effect of pressure on temperature and density

Let's take a parcel of sea water in the deep ocean with
S=35, T = 1 C, d = 5000m, sigma = 51 kg/m3

Let's move it to the surface without allowing it to exchange heat or mass with its surrounding (e.g. an insulated balloon).

What happens?

1) It expands as pressure decreases (sea water is slightly compressible)

2) It cools (internal energy decreases as the parcel expands)

3) Salinity does not change (mass of salt/mass of water is constant)

D = 0m, T = 0.58 C, S = 35, sigma = 28 kg/m3

Effect of pressure on temperature and density

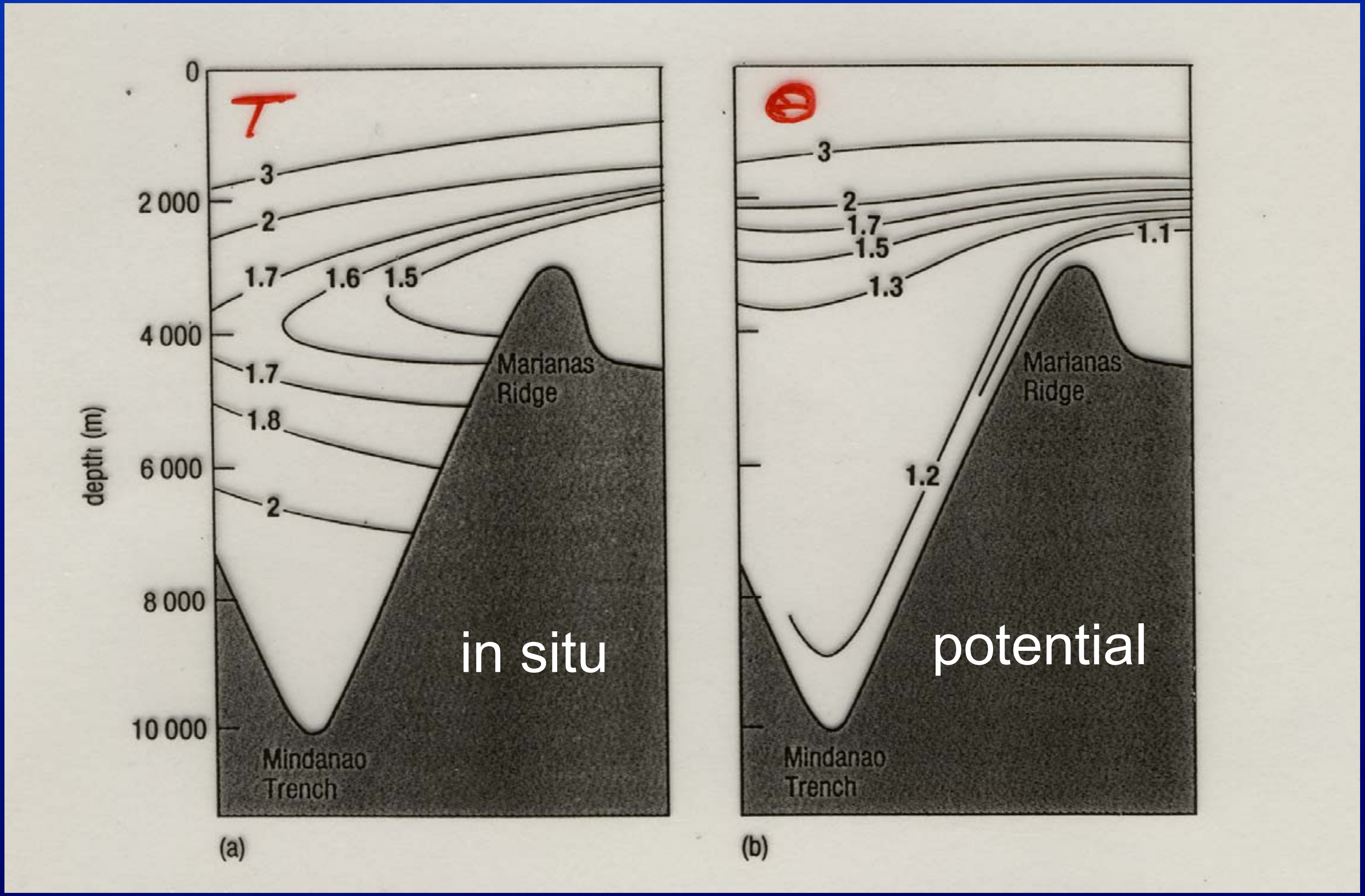
In order to compare parcels at different depths (pressures) we want to distinguish between the change due to pressure and those which reflect intrinsic properties in the fluid:

We do this by defining

in situ property (T or sigma)
- the property a parcel has at the D/P at which it is found (this is what an instrument would measure)

potential property (θ or sigma-theta - σ_θ)
- the property a parcel has at some reference pressure if moved there adiabatically (insulated ballon)

Temperature in situ and potential temperature in the Mindanao trench



Potential temperature

is defined with respect to a reference pressure (Pref – often 0 = the sea-surface) and is the temperature that parcel would have if moved adiabatically from its in situ pressure to Pref.

θ= sw_ptmp(S, T, P, Pref) where S, T, P are in situ values

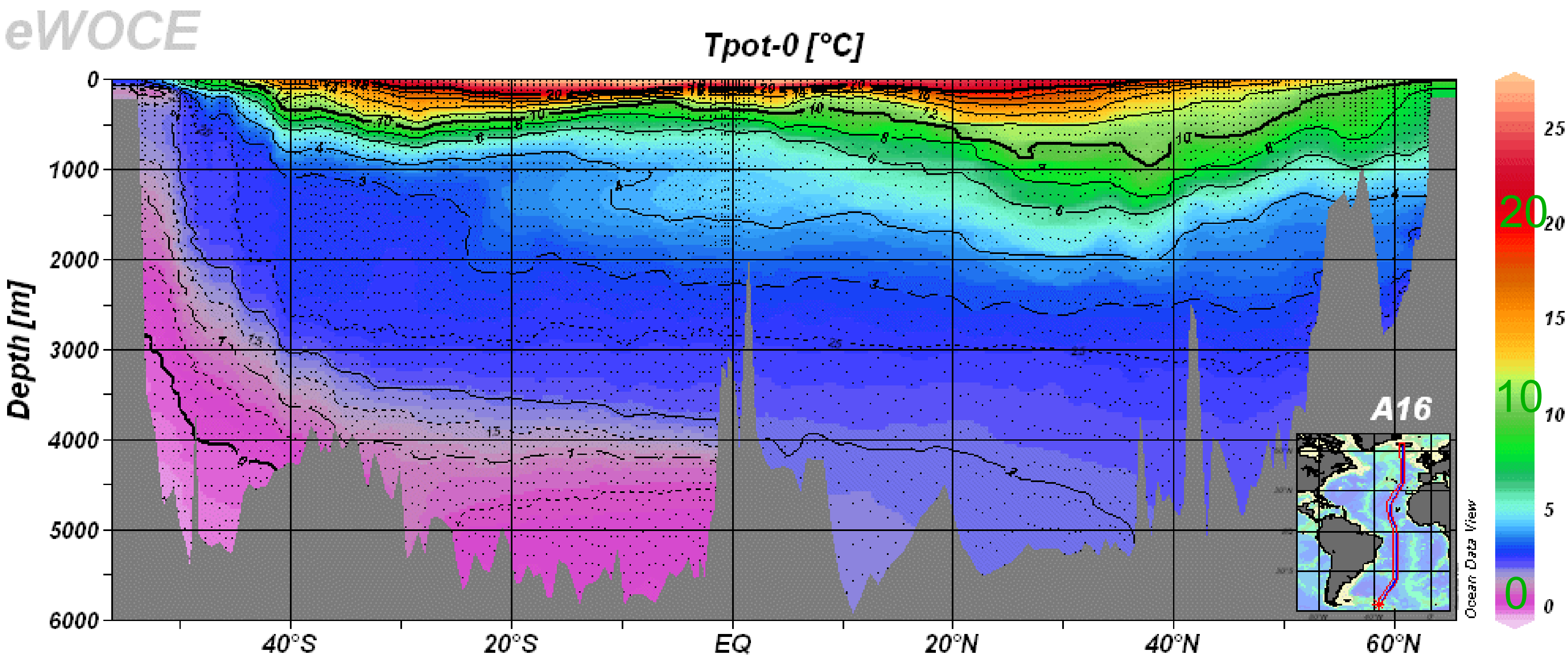
(adiabatic lapse rate, dT/dz:
ocean~ -0.1 C/km; atmos dT/dz~-10 C/ km)

Potential density

is the density that the water parcel would have if taken adiabatically to P = Pref (again often the sea-surface Pref = 0)

pden = sw_pden(S,T,P,Pref)

a north to south section (z, y) of Potential Temperature, C



Potential temperature is conserved under change of depth, and so makes a good tracer of water movement.

e-woce gallery

Static Stability

Measure of the stability of a water parcel with respect to vertical displacements – or equivalently of how much energy it takes to mix some portion of the water column in the vertical.

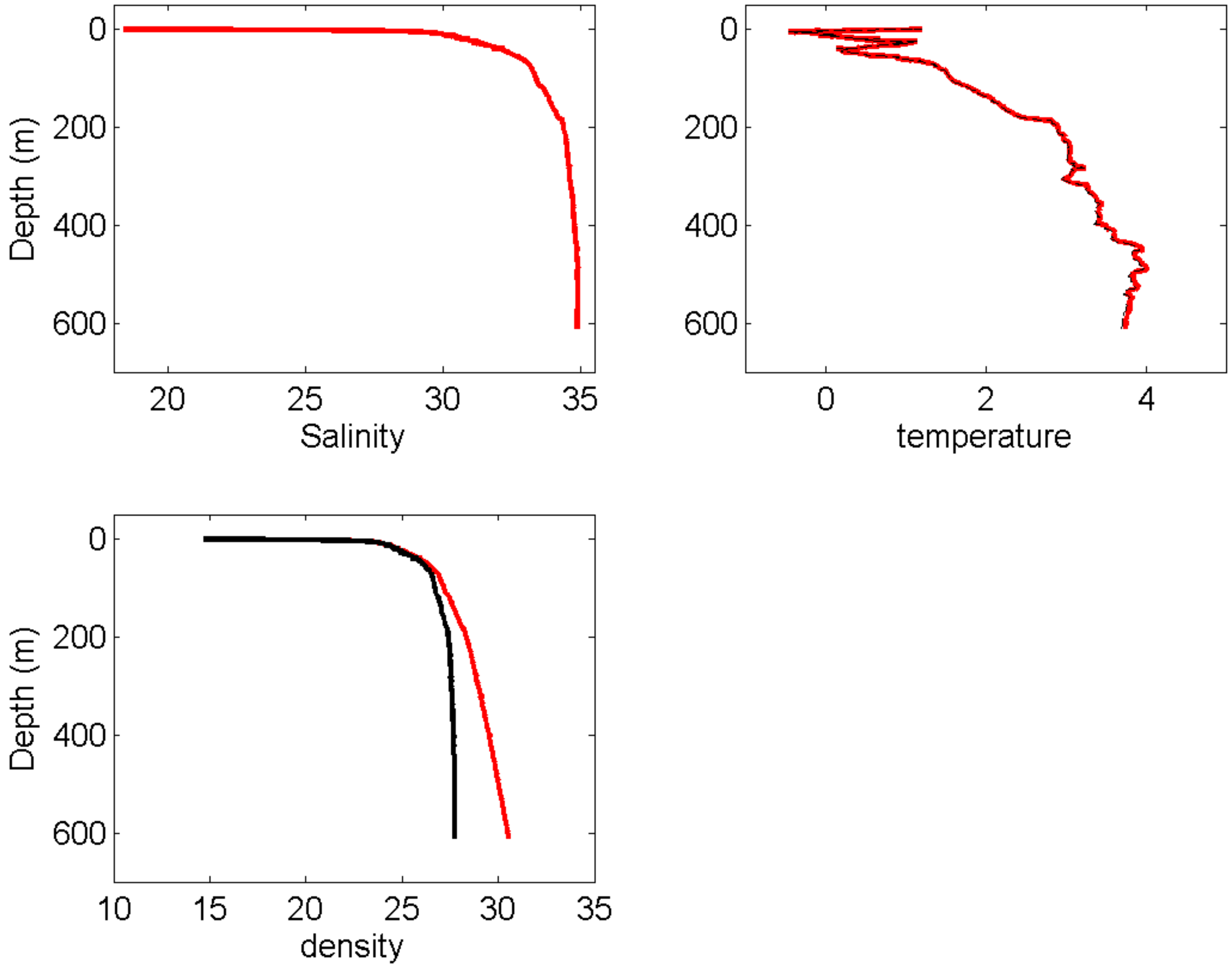
Static Stability = Stratification

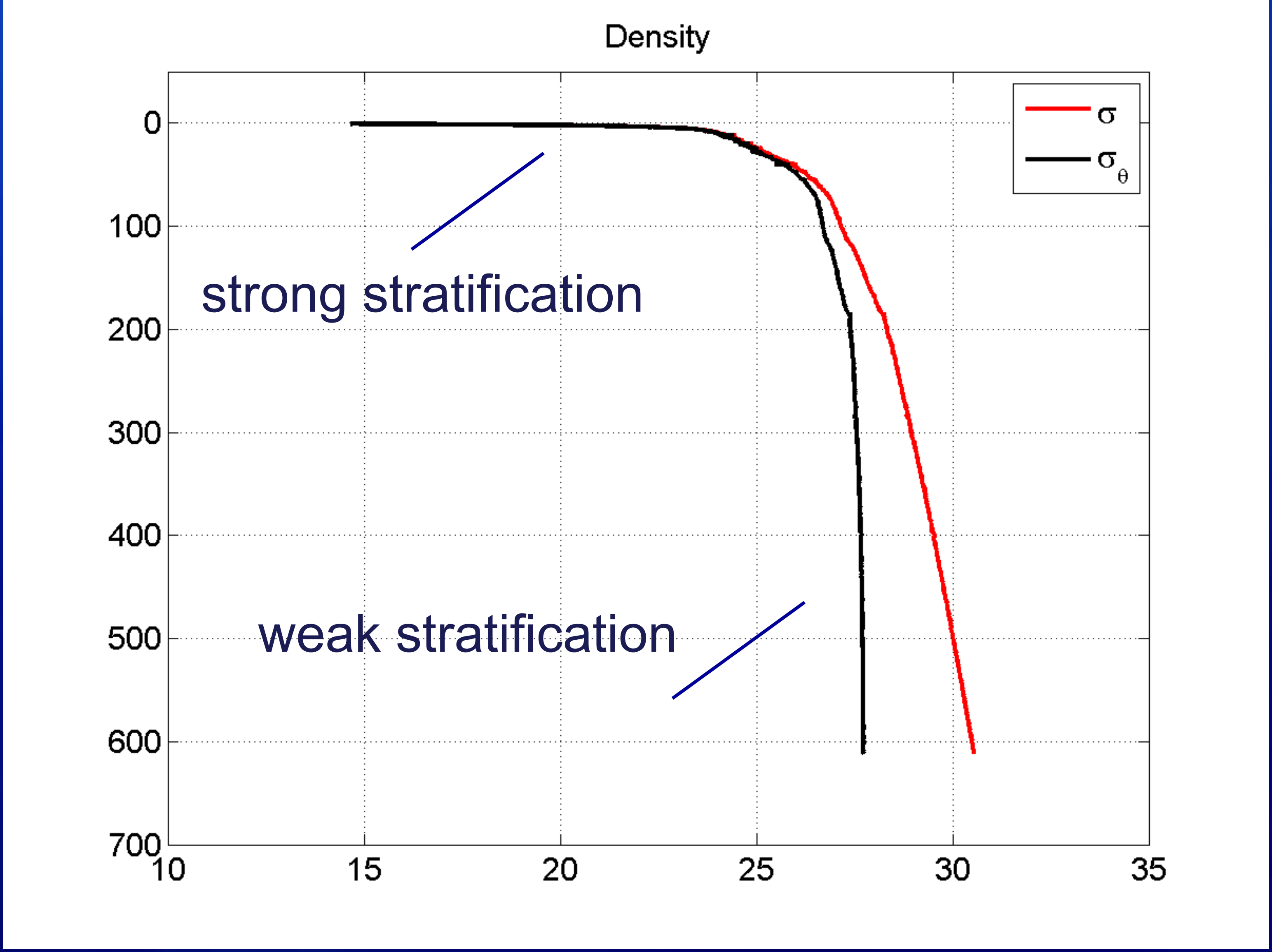
This a very important concept in the ocean:

i) Very stable water columns are difficult to mix so that, for example, if the nutrients are in the lower portion of the water column they are difficult to bring up to the surface

ii) Weakly stable water columns are easy to overturn allowing for the vertical mixing of properties, dissolved substances etc and, for example, the sequestration of CO_2 in the ocean.

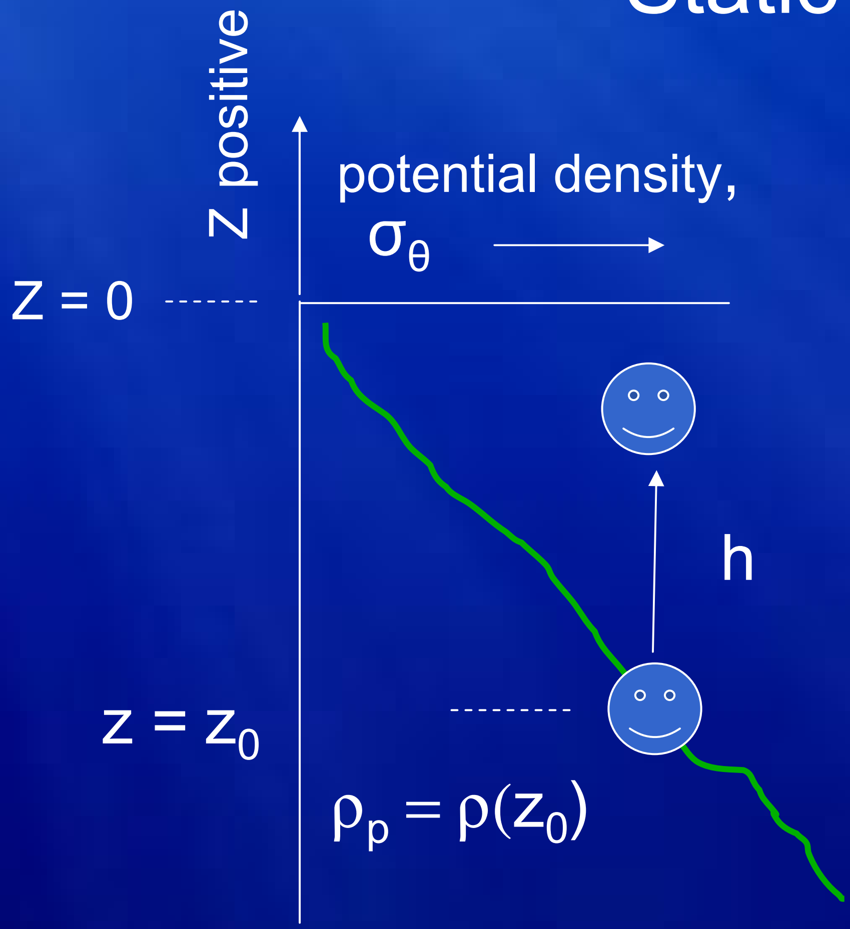
S, T, θ, σ, σ_θ from a Greenland Fjord





Density
0
100
200
300
400
500
600
700
10
15
20
25
30
35
σ
σθ
strong stratification
weak stratification

Static Stability



Consider a parcel displaced up e.g. by a wave or turbulence

at the new depth $z = z_0 + h$, it will have a different density from its surroundings:

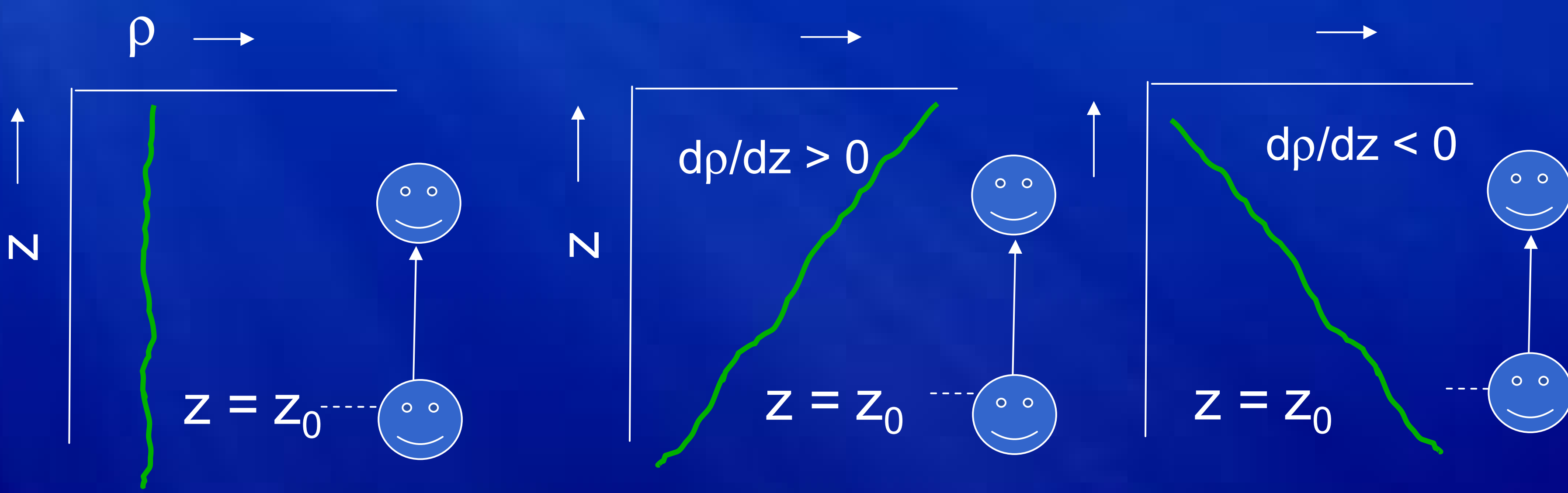
$$\delta\sigma_\theta = \sigma_\theta(z_0) - \sigma_\theta(z_0 + h)$$

$$= -d\sigma_\theta /dz \; h$$

If it is denser than its surroundings it will want to sink, if it is lighter it will want to rise.

Static Stability

$d\rho/dz > 0$



$d\rho/dz = 0 \Rightarrow N = 0.$
neutral stability
Typical in boundary layers.

$d\rho/dz > 0 \Rightarrow N^2 < 0.$
unstable

Buoyancy

this acceleration of the parcel at $z_0 + h$ =

$$-g\ \delta\sigma_\theta/\rho_0 = (g/\rho_0)\ d\sigma_\theta/dz\ h.$$

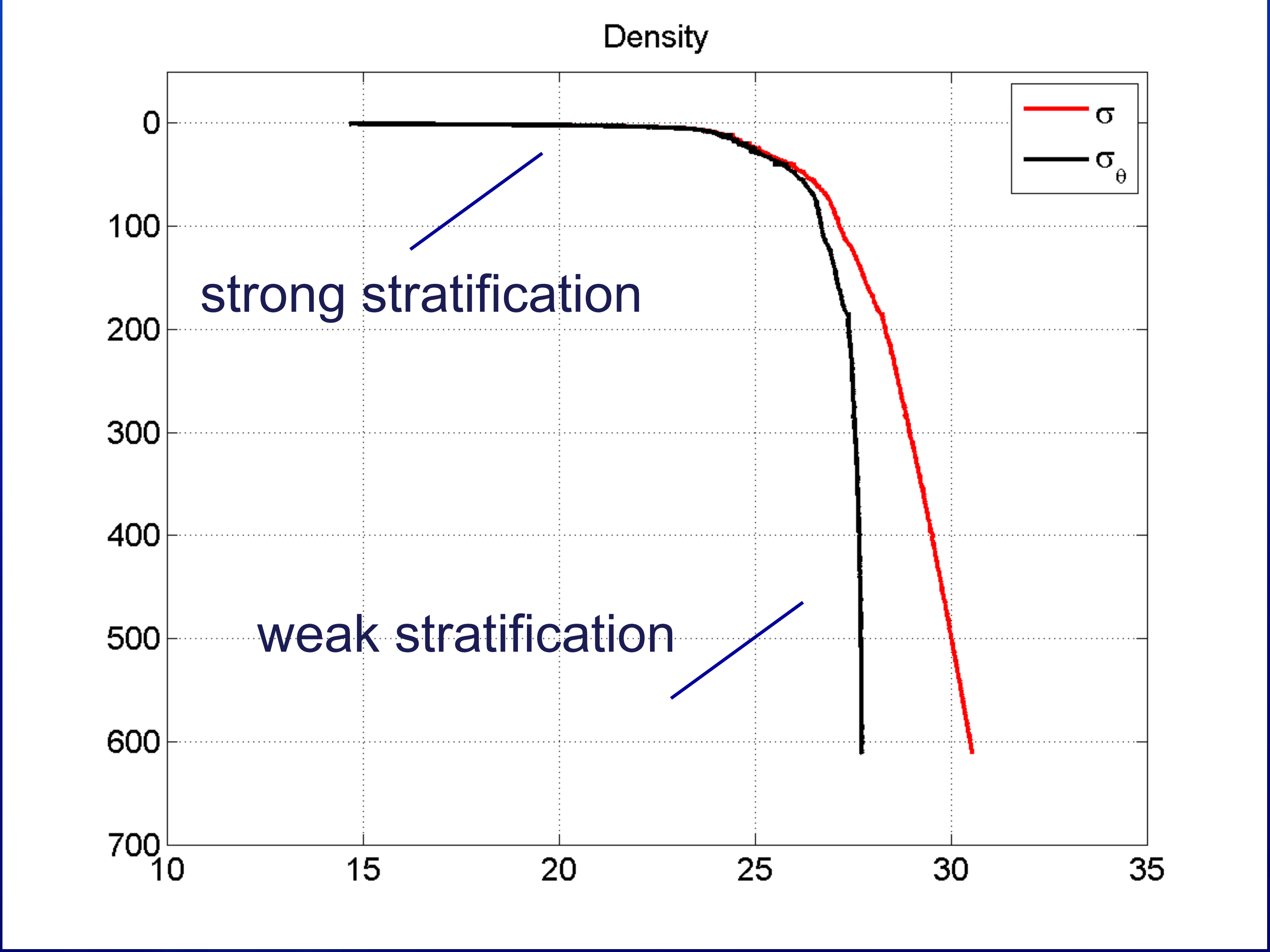
$b = -g\delta\sigma_\theta/\rho_0$ [$m\ s^{-2}$] is known as buoyancy

We define the stability in terms of :

$N = \mathrm{sqrt}(-(g/\rho_0)\ d\sigma_\theta\ /dz)$

the Brunt-Vaisala frequency or buoyancy frequency, units are radians/second.

It is a measure of the frequency with which a parcel will oscillate about its equilibrium position, if displaced, and in the absence of friction.



Density
σ
σθ
strong stratification
weak stratification
0
100
200
300
400
500
600
700
10
15
20
25
30
35

Home Work #2, due in one week, Sep 18th.

You need
pacific.mat – profile data for one station in the pacific
Seawater routines: sw_ptmp; sw_dens; sw_pden; sw_dpth

2.1) Compute depth from pressure for the profile; plot pressure versus depth

2.2) Compute potential temperature for the profile for a reference pressure of of 0 and a reference pressure of 1000 dbars

2.3) Compute density for the profile from the temperature, salinity and pressure data. Define sigma = density – 1000.

2.4) Compute potential density for the profile for a reference pressure of 0 and of 1000 dbars. Define sigmatheta = pot. density - 1000

2.5) Plot the following as a function of depth

i) Salinity
ii) Temperature, potential temperature ref. to 0 and to 1000 dbars
iii) Sigma, sigmatheta ref to 0 and ref to 1000 dbars