Density of Sea Water $\rho$

- Definition: mass of substance per unit volume
  - Grams per cm$^3$ (=cc, =ml)
- $\rho$ of pure water at 4°C = 1.0 g/cm$^3$
- Salts make water more dense
  - Salinity = grams salts per kilogram water
    - = parts per thousand or %
    - 1 g/kg = 0.1 %
  - In 35 g/kg seawater (at 4°C) density = 1.028
- Temperature also affects density
  - Warm water expands, density decreases
  - Cold water contracts, density increases

T-S Diagrams

- T&S have opposite effects on $\rho$
  - $\uparrow T = \downarrow \rho$
  - $\downarrow S = \downarrow \rho$
  - but $\uparrow T = \uparrow \rho$

T-S Diagrams

- Density is calculated from T & S
  - Uses a complex formula
  - Results printed in tables
  - Easier to use is a T-S diagram
  - Isopycnals = lines of constant density
  - Density increases from upper left to lower right

T-S Diagrams

- Many combinations of T&S give the same $\rho$
  - $\rho=1.025$
    - T=18, S=35
    - T=15, S=33.9
    - T=10, S=32.5
  - Changes in T&S counteract
**T-S Diagrams**

- Small changes in $\rho$ very important
  - Most salinities
    $34.5 < S < 35.5$
  - Most temps
    $3^\circ < T < 20^\circ C$
  - Most densities
    $1.025 < \rho < 1.028$

**Density of Sea Water**

- Sigma-t ($\sigma_t$) is an abbreviation or shorthand for density.
  - $(\rho-1) * 1000$.  
  - $\rho=1.025$, $\sigma_t=25.0$; $\rho=1.028$, $\sigma_t=28.0$
- Used because small differences in density have important effects on water movement.

**Determining Density**

- T-S diagram a graphical display of $\sigma_t$ values
  - Read directly from T & S
  - Simpler than solving the formulas
  - Today instruments are programmed to make calculations automatically

**Example #1**

- $T = 15^\circ C$
- $S = 35$ g/kg
- $\sigma_t = ?$
  - $26$
- $\rho = ?$
  - $1.026$ g/cm$^3$
Oceanography 101, Richard Strickland
Lecture 19 © 2006 University of Washington

Determining Density

• Example #2
  - $T = 20^\circ C$
  - $S = 32 \text{ g/kg}$
  - $\sigma_t =$ ?
    - 22.5
  - $\rho =$ ?
    - 1.0225 g/cm$^3$

• Example #3
  - $T = 5^\circ C$
  - $S = 32 \text{ g/kg}$
  - $\sigma_t =$ ?
    - 25.3
  - $\rho =$ ?
    - 1.0253 g/cm$^3$

• Rank the examples in order of increasing density
  - #2 $\sigma_t = 22.5$
    - $\rho = 1.0225 \text{ g/cm}^3$
  - #3 $\sigma_t = 25.3$
    - $\rho = 1.0253 \text{ g/cm}^3$
  - #1 $\sigma_t = 26.0$
    - $\rho = 1.026 \text{ g/cm}^3$

• Rank the examples in order of increasing density
  - #2 $\sigma_t = 22.5$
    - $T$ @ same $S$
      - $\uparrow \rho$
  - #3 $\sigma_t = 25.3$
    - $S$ overcomes $T$
      - $\uparrow \rho$
  - #1 $\sigma_t = 26.0$
Vertical Stratification

- Water column
  - Hypothetical vertical section of water from surface to bottom
    - Square cross-section

Vertical Stability

- Stability of stratified water column
  - Depends on relative density of layers
    - Less dense water atop more dense water = stable
      - It will persist until disturbed

- Stable stratification resists disturbance
  - tends to return to original state

Examples: Stability

- Thermal—Lake Washington
  - Surface warms in summer
    - Warm (lower-density) water lies atop cool (higher-density) water
  - Thermocline: boundary between layers of different temperature
    - Rapid change in temperature with depth

- Density stratification
  - Warmer water floats & cooler water sinks (constant salinity)
  - Fresher water floats & saltier water sinks (constant temperature)
Examples: Stability

- Haline—Puget Sound
  - River runoff meets sea water at the river mouths
  - Fresh or brackish (low-salinity) water lies atop higher-salinity water
  - Halocline: boundary between layers of different salinity
  - Rapid change in salinity with depth

- Rapid change in salinity with depth

Vertical Stability

- In general, the oceans are stable
  - Greater density difference between layers = stronger stability

- If not, they would move until stable
  - Vertical instability occurs in certain situations in the oceans

- Neutral stability = unstratified
  - Density is same at all levels

- In general, T has greater effects than S
  - Some important exceptions
  - Puget Sound, Mediterranean

Examples: Stability

- Pycnocline
  - Boundary between 2 layers of different density
  - If there is a thermocline or halocline, there is also a pycnocline.

- Mixed layer
  - Layer above the pycnocline
  - Homogenized by wind mixing
  - Nearly uniform properties over depth

Instability

- Instability of stratified water column
  - More dense water atop less dense
  - Initiates rather than resists motion
  - Dense water sinks, less dense water floats
Examples: Instability

- Thermal—Polar seas in winter
  - Strong cooling
  - Dense water at the surface
  - Sinks below warmer water beneath
  - Major factor in global density-driven ocean currents

- Haline—Polar seas in winter
  - Sea ice freezing & “brine exclusion”
  - Sea ice is almost pure fresh water
  - Salt remains in sea water, raising salinity & density
  - Sinks below less-saline water beneath.

Examples: Instability

- Haline—Mediterranean
  - Evaporation in desert climate
  - Creates high-salinity surface layer
  - Denser than the lower-salinity water beneath, and so it sinks.

Stratifying processes

- What external natural processes enhance stratification?
  - Anything that changes density
    - Heating & cooling
    - Freshwater runoff
    - Evaporation & precipitation
    - Freezing & melting of sea ice

Stabilizing processes

- What external natural processes enhance vertical stability?
  - Surface solar heating (T)
  - Freshwater runoff (S)
  - Rain (S)
  - Melting of sea ice (S)
Destabilizing processes

- What external natural processes enhance vertical instability?
  - Surface cooling (T)
  - Sea ice formation (T & S)
  - Surface evaporation (S)
  - Sea-floor heating (T)

Destratifying forces

- What external natural processes break down vertical stratification?
  - Forces that move water rather than exchanging heat or fresh water
  - Wind mixing
  - Fast, turbulent currents (esp. over or around bathymetric barriers)
  - Instability-induced convection

The Real Ocean

- Vertical changes in both T & S
  - If both T & S increase, what happens to density & stability?
  - If both T & S decrease, what happens to density & stability?
- Must determine density from T & S to answer this question

The Real Ocean

- Curious example—the Red Sea
  - Surface = 30˚C, 42.5 g/kg
    - Heating & evaporation
  - Bottom = 36˚C & 257 g/kg
    - Rift valley & hydrothermal vents
- Vertically stable or unstable?
  - Stable - S overcomes T
- Puget Sound in winter
  - Surface = 4˚C, 20 g/kg
  - Deep = 8˚C, 31 g/kg
  - Stable because low surface S overcomes low T