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<https://github.com/julianmak/academic-notes>

The repository principally contains the compiled products rather than the source for size reasons.

- ▶ Associated Python code (as Jupyter notebooks mostly) will be held on the same repository. The source data however might be big, so I am going to be naughty and possibly just refer you to where you might get the data if that is the case (e.g. JRA-55 data). I know I should make properly reproducible binders etc., but I didn't...
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# OCES 2003 : Descriptive Physical Oceanography

(a.k.a. physical oceanography by drawing pictures)

## Lecture 5: Sea water properties (temperature and salinity)

# Outline

- ▶ **thermodynamic** vs. **mechanical** forcing of ocean
  - two lectures on former, four lectures on latter
- ▶ ultimately care about **density**  $\rho$  (sort of, see  $\rho_\theta$  and  $\gamma$  later...)
  - **temperature**  $T$  and **salinity**  $S$  contributions
  - horizontal and vertical structures
  - **sea surface temperature/salinity** (SST, SSS)
  - links to forcing

**Key terms:** density, buoyancy, temperature, salinity, SST, SSS, thermo/halocline, watermass property



## Recap: equations of motion

Denoting  $\mathbf{u} = (u, v)$  and  $\mathbf{u}_3 = (u, v, w)$ , to numerous approximations (!!!) (see OCES 3203) ocean dynamics is governed by

$$\rho_0 \left( \frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} + 2\boldsymbol{\Omega} \times \mathbf{u} \right) = -\nabla p + \mathbf{F}_u + \mathbf{D}_u \quad (1)$$

$$\frac{\partial p}{\partial z} = -\rho g \quad (2)$$

$$\nabla \cdot \mathbf{u}_3 = 0 \quad (3)$$

$$\left( \frac{\partial T}{\partial t} + \mathbf{u}_3 \cdot \nabla T \right) = F_T + D_T \quad (4)$$

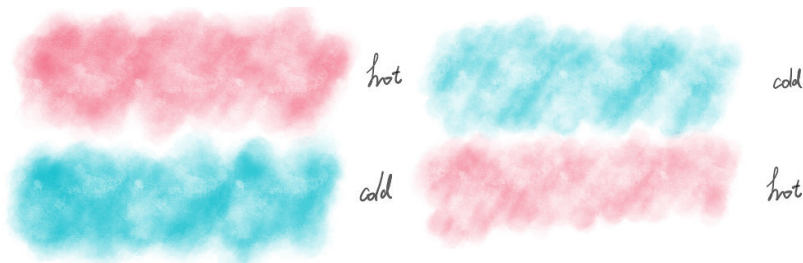
$$\left( \frac{\partial S}{\partial t} + \mathbf{u}_3 \cdot \nabla S \right) = F_S + D_S \quad (5)$$

$$\rho = \rho(T, S, p) \quad (6)$$

Respectively, (1) momentum equation, (2) hydrostatic balance, (3) incompressibility, (4) temperature equation, (5) salinity equation, and (6) equation of state (EOS)

# Buoyancy: motivating example

Q. which one is **unstable**?



**Figure:** (Un)stable temperature configurations.

# Buoyancy: motivating example

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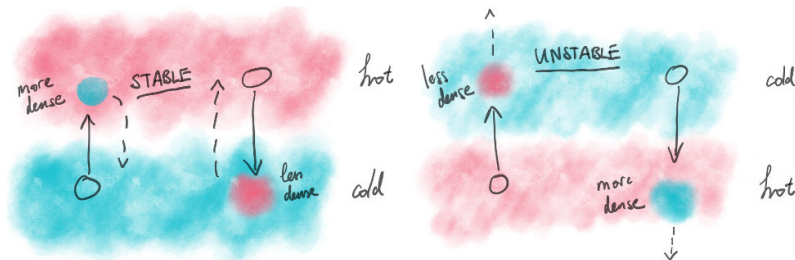
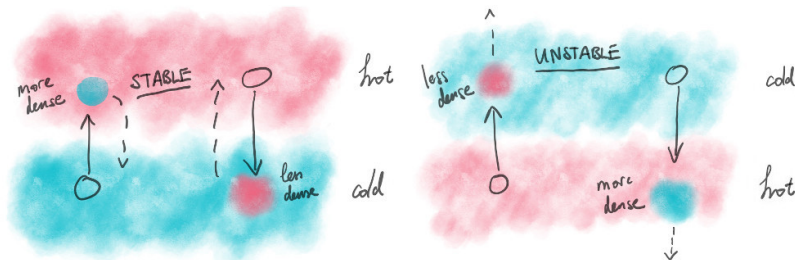


Figure: (Un)stable temperature configurations.

- **density** (!)  $\rho$  (units:  $\text{kg m}^{-3}$ )
- **buoyancy**  $b = -(\delta\rho/\rho_0)g$  (so units of...?)  
→ how “floaty” something is (e.g. warm water, lighter density, **more** buoyant)

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ultimately it's **density/buoyancy** we care about



# Sea water properties

Q: What are the distinguishing features of sea water?

Main focus for here: what controls **density** of seawater?

Another hint: how is it **different** to **air**?

# Sea water properties: temperature

Denote **temperature** (!) by  $T$

(other temperatures / density next lecture)

- ▶ units of  $^{\circ}\text{C}$  or  $\text{K}$  ( $0^{\circ}\text{C} = 273.15 \text{ K}$ )
- ▶ **isotherm** = lines / surfaces of constant temperature
- ▶ above around  $4^{\circ}\text{C}$  (!!!) warmer  $\sim$  less dense, i.e.

$$\rho \nearrow \text{ as } T \searrow$$

→ water actually **most dense** around  $4^{\circ}\text{C}$  (EOS next lec.)

→ (otherwise consequence for ice?)

- ▶ measured by **thermometer**, **sound speed** etc.

# Sea water properties: salinity

Denote **salinity** (!) by  $S$

- ▶ given in  $\text{g kg}^{-1}$  or sometimes PSU (practical salinity unit)  
→ **dimensionless** really, use of PSU **strongly discouraged**
- ▶ **isohaline** = lines/surfaces of constant salinity
- ▶ higher salinity = more things dissolved in water, so

$$\rho \nearrow \text{ as } S \nearrow$$

- ▶ chemical measure through **chlorinity** (e.g. titration)

$$S_A \approx 1.80655 \times \text{Chlorinity}$$

→ **absolute** salinity  $S_A$

- ▶ usually now done through **electrical conductivity** (see lec. 19)  
→ **practical** salinity  $S_P$

# Sea water properties: opacity

Sea water is **dense** and has things **dissolved** in it

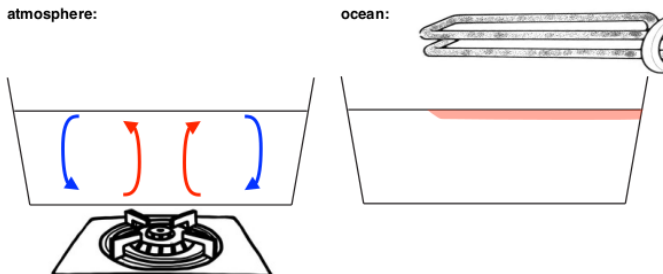
- ▶ stops light going through (either diffusing or absorbing), **opaque**  
→ light doesn't penetrate very deep, consequence for **primary production**



**Figure:** Picture of the sea. CC0 Public Domain, taken from [phys.org](https://www.phys.org)

# Sea water properties: opacity

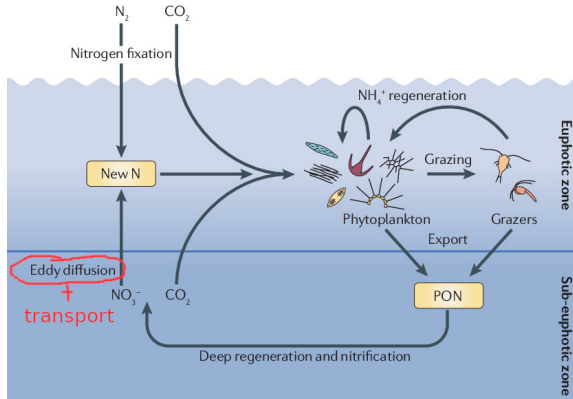
One very important and interesting difference between atmosphere and ocean:



**Figure:** Schematic of principal sources of thermal forcing between atmosphere and ocean. Courtesy of David Marshall (Oxford).

- ▶ actually quite hard to drive up/down motion + deep circulation! (cf. **Sandström's theorem**)  
→ but there is one, so **why?** (see Lec 11 - 18)

# Sea water properties (sort of): other things



- ▶ things like nutrients, carbon, oxygen are dissolved in seawater
- ▶ negligible (?) impact for the physics, but important for biogeochemistry or tracking watermasses (see Lec. 14)

# Warning!

There are different types of temperature...

- ▶ in-situ  $T$  vs . potential  $\theta$  vs. conservative  $\Theta$
- ▶ subtle but !!!VERY IMPORTANT!!! differences  
→ for dynamics usually we don't care about  $T$

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...and different types of salinity!

- ▶ **practical**  $S_P$  vs. **absolute**  $S_A$   
→ absolute salinity (sometimes  $S_A$ ) part of **TEOS-10**



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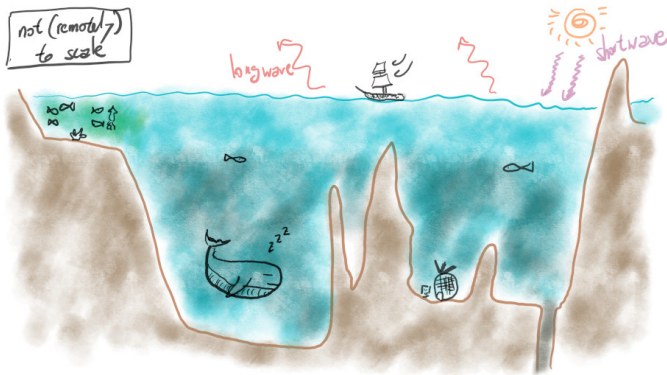
- ▶ **practical**  $S_P$  vs. **absolute**  $S_A$   
→ absolute salinity (sometimes  $S_A$ ) part of **TEOS-10**

...and we have different **densities**  $\rho/\rho_\theta/\gamma$  too!

- ▶ just be aware that subtleties do exist and do matter...

# Observed *TS* profiles: horizontal (Lon, Lat) or ( $x, y$ )

## ► sun + radiation



**Figure:** Schematic of temperature forcing at the ocean surface. Only showing **shortwave** and **longwave** radiation (**latent heat** + **sensible heat** can be gain or loss; not shown here).

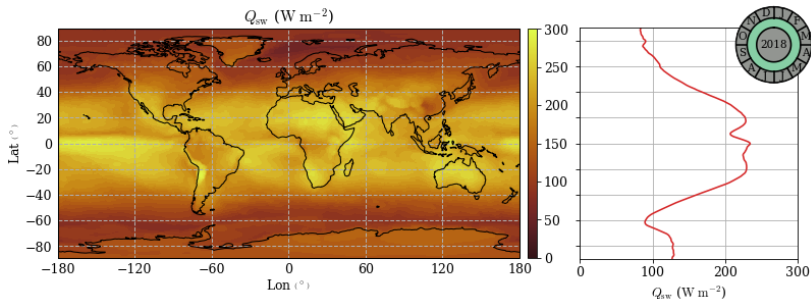
# Observed $T$ profiles: horizontal (Lon, Lat) or $(x, y)$

Sea Surface Temperature (SST) **mostly(!)** by the **sun**

► **shortwave radiation**  $Q_{sw}$  here (units:  $\text{W m}^{-2}$ )

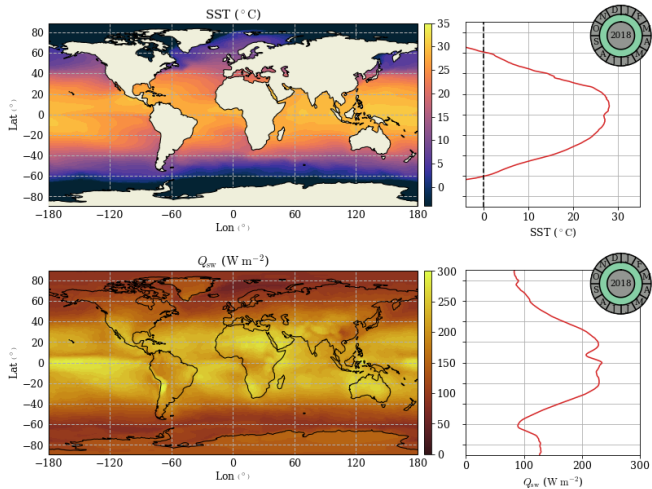
→ not shown are **longwave radiation** (seen as a **heat loss**),  
**latent + sensible heat** (can be gain or loss) (look up any physical

oceanography book under “heat budgets”)



**Figure:** Year-averaged (left) and year and **zonal** averaged (right) shortwave radiation, from the JRA55 dataset (Kobayashi *et al.* 2015, *J. Meteor. Soc. Japan*). See `plot_jra55_sample.ipynb`

# Observed $T$ profiles: horizontal (Lon, Lat) or $(x, y)$



**Figure:** As previous figure but for SST (top) and shortwave radiation (bot).

- notice correlation between SST and  $Q_{sw}$

## Observed $T$ profiles: horizontal (Lon, Lat) or $(x, y)$

- ▶ time-varying data with seasonal cycle (movie here)

# Observed $S$ profiles: horizontal (Lon, Lat) or $(x, y)$

- river runoff, evaporation, precipitation (see Lec. 5)

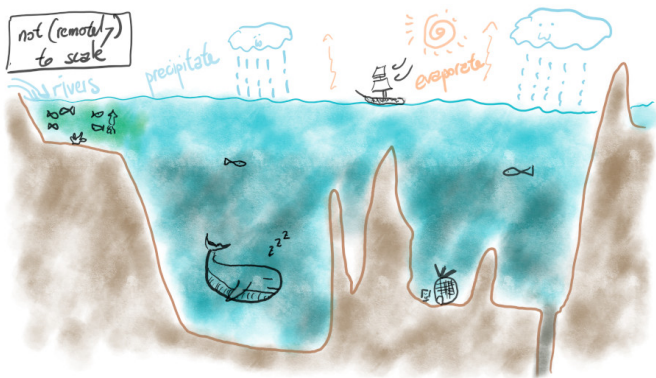
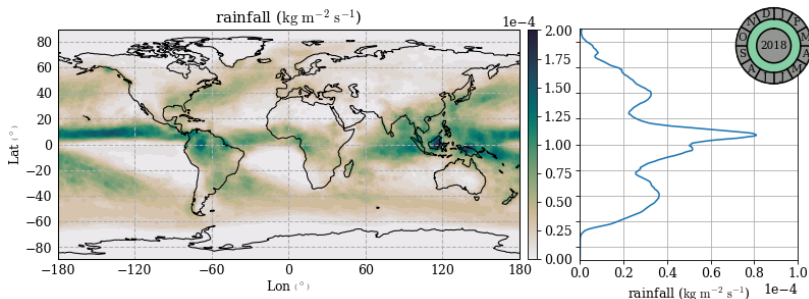


Figure: Schematic of ocean forcing.

# Observed $S$ profiles: horizontal (Lon, Lat) or $(x, y)$

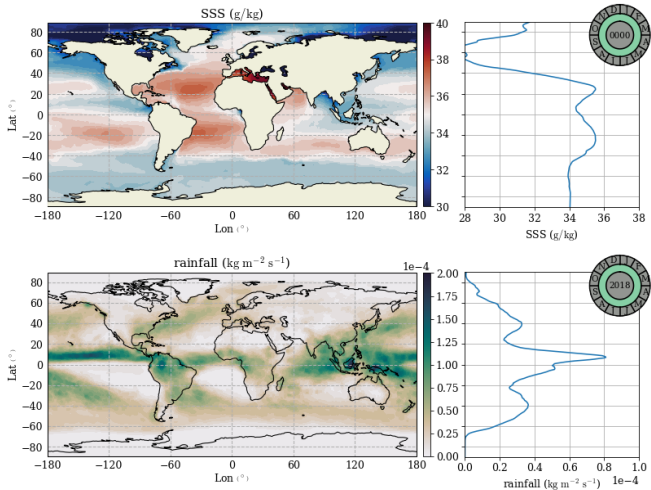
Sea Surface Salinity (SSS) by

- ▶ **decrease** in salinity by **precipitation** (units: depends...)
  - ▶ **increase** in salinity by **evaporation** (units: depends...)
  - ▶ **decrease** in salinity by **runoff** (units: depends...)
- river, ice melt



**Figure:** Year-averaged (left) and year and **zonal** averaged (right) rainfall (so **decrease** in salinity), from the JRA55 dataset (Kobayashi *et al.* 2015, *J. Meteor. Soc. Japan*). See `plot_jra55_sample.ipynb`

# Observed $S$ profiles: horizontal (Lon, Lat) or $(x, y)$



**Figure:** As previous figure but for SSS (top) and rainfall (bot). Notice how the Atlantic is **more salty** than the Pacific.

**Q.** why is SSS high when rainfall is also high?

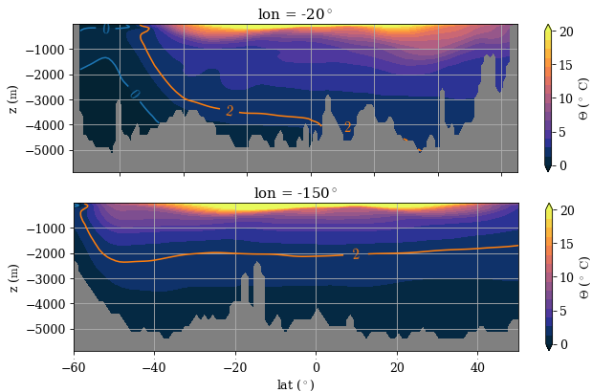


# Observed $S$ profiles: horizontal (Lon, Lat) or $(x, y)$

- ▶ time-varying data with seasonal cycle (cheating here with SSS!)

## Observed $T$ profiles: sections e.g. $(x, z)$ or $(y, z)$

### ► meridional section (i.e. $(y, z)$ ) of $T$

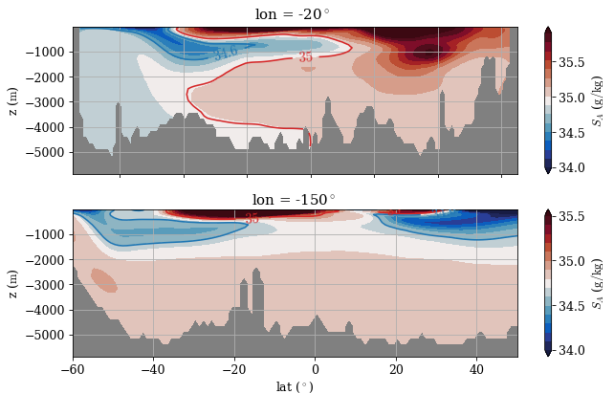


**Figure:** Meridional section of yearly-averaged conservative temperature in the Atlantic (top) and Pacific (bot), based on World Ocean Atlas 2013 data. Meridional range chosen to roughly correspond to Talley *et al.* (2011) Fig. 4.11 and 4.12. See `plot_WOA13_sample.ipynb`

- intrusion of bottom cold waters in Atlantic
- marked temperature contour is “higher” in Pacific

# Observed $S$ profiles: sections e.g. $(x, z)$ or $(y, z)$

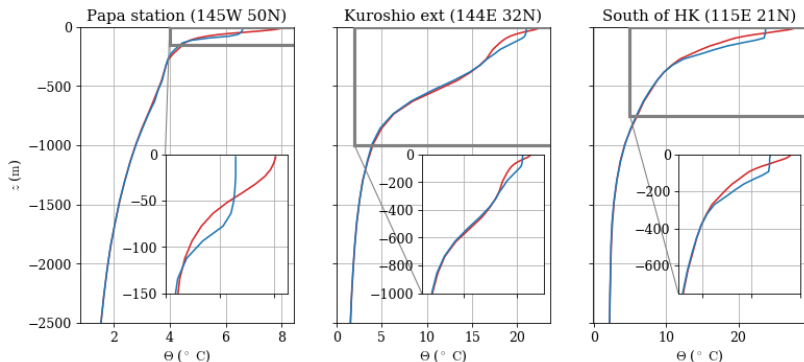
## ► meridional section (i.e. $(y, z)$ ) of $S$



**Figure:** Meridional section of yearly-averaged absolute salinity in the Atlantic (top) and Pacific (bot), based on World Ocean Atlas 2013 data. Meridional range chosen to roughly correspond to Talley *et al.* (2011) Fig. 4.11 and 4.12. See `plot.WOA13.sample.ipynb`

- distinct salinity signature in salinity in Atlantic
- notice a fresh intermediate layer in Pacific

## Observed $T$ profiles: vertical usually (depth) or ( $z$ )



**Figure:** Vertical variation of  $\Theta$  at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

- notice a rapidly changing top part (“sharp”, think **large gradient**) and slower varying (“smooth”) bottom part

# Observed $T$ profiles: vertical usually (depth) or ( $z$ )

**mixed layer** (usually (!)  $O(100\text{ m})$ )

- ▶ very top bit where **stratification** is weak (see previous panel (c) in winter)  
→ strong **vertical mixing** (see Lec. 17)

## Observed $T$ profiles: vertical usually (depth) or ( $z$ )

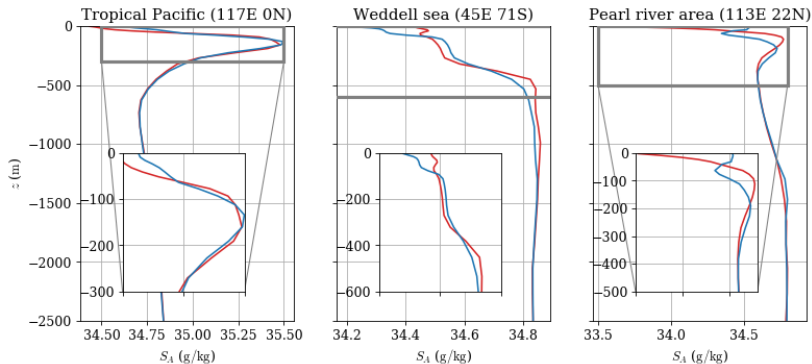
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**thermocline** (usually  $O(200 - 1000 \text{ m})$ )

- ▶ the transition region between the “sharp” and “smooth” part in **temperature**  
→ hence the **thermo** part  
→ it's **gradients** we care about, and thermocline is where temperature **gradient** is largest **below** the mixed layer  
→  $\rho \sim T$  (or  $\Theta$  which is used here), so it indicates changes in **density**

## Observed $S$ profiles: vertical usually (depth) or ( $z$ )



**Figure:** Vertical variation of  $S_A$  at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

- similarly for salt, **halocline**
  - large **evaporation**, **ice melt** and **river runoff** here

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→ because **mixing** relatively weak on large-scale (see lec. 10 + 17)
- !!! complication: different types of  $T$  and  $\rho$  relating to concept of **work done** related to pressure... (next lec)