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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...
- ▶ I do not claim the compiled products and/or code are completely mistake free (e.g. I know I don't write Pythonic code). Use the material however you like, but use it at your own risk.
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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** ρ (sort of, see ρ_θ and γ 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: forces

- ▶ sea water moves around since there are **forces** acting on it
 - e.g. wind \Rightarrow “pushing” water
 - e.g. uneven heating \Rightarrow movement to redistribute heat

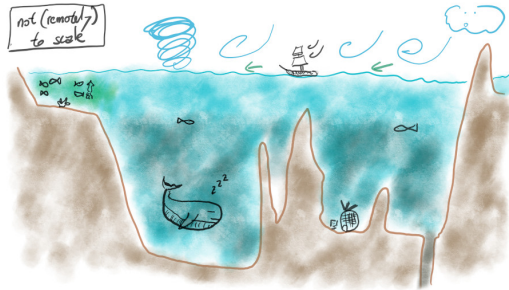


Figure: Schematic of ocean forcing.

to understand/predict circulation \sim how forces act

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**?

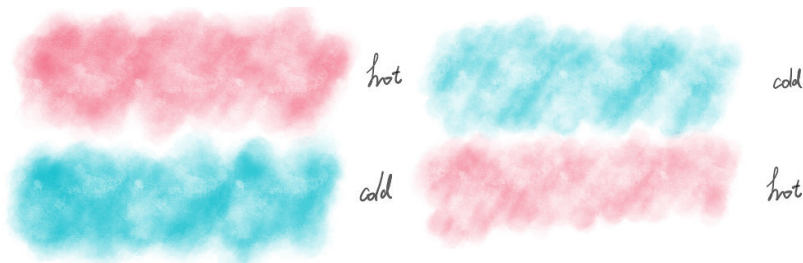


Figure: (Un)stable temperature configurations.

Buoyancy: motivating example

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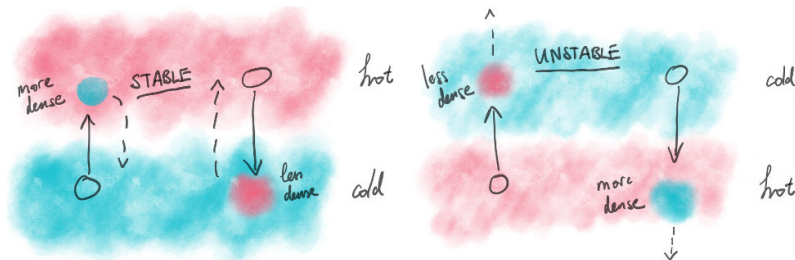


Figure: (Un)stable temperature configurations.

- **density** (!) ρ (units: 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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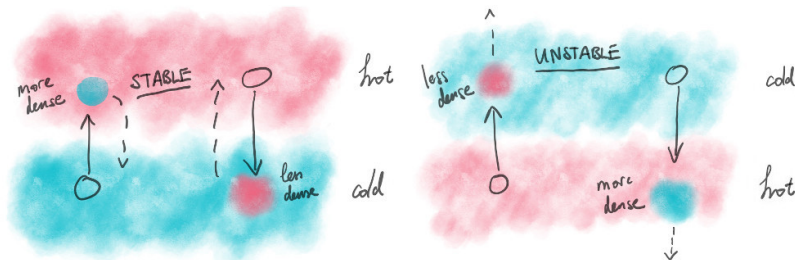


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ultimately it's **density/buoyancy** we care about

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

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

→ water actually **most dense** around 4°C (EOS next lec.)

→ (otherwise consequence for ice?)

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

Sea water properties: salinity

Denote **salinity** (!) by S

- ▶ given in 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)

Broad overview: EM spectrum (see also Lec. 15, 20)

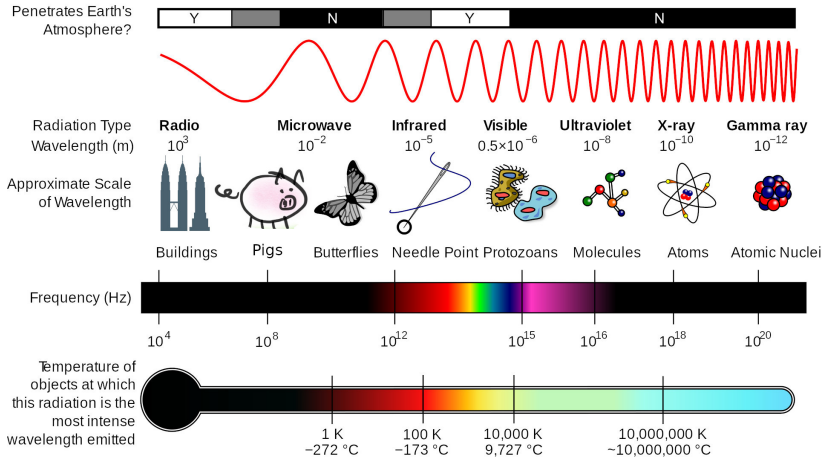


Figure: The electromagnetic spectrum by wavelength and frequency. Image from Wikipedia, adapted from an image from NASA.

Sea water properties: opacity

One very important and interesting difference between atmosphere and ocean:

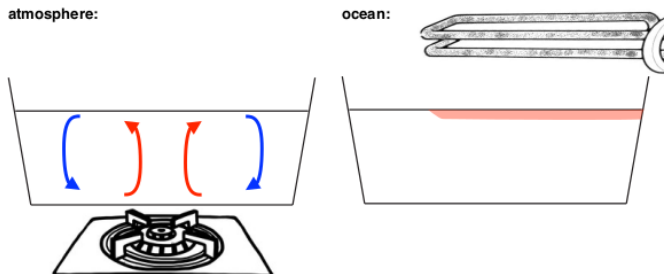
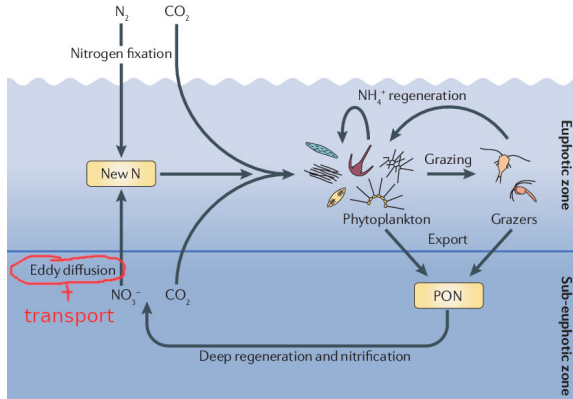


Figure: Schematic of principal sources of thermal forcing between atmosphere and ocean. Courtesy of David Marshall (Oxford).

- ▶ 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 θ vs. conservative Θ
- ▶ 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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...and different types of salinity!

- ▶ practical S_P vs. absolute S_A
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...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

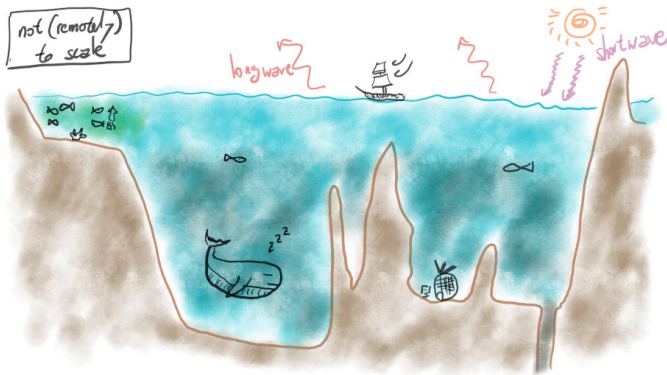


Figure: Schematic of temperature forcing at the ocean surface. Only showing **shortwave** and **longwave** radiation (**latent heat** + **sensible heat** can be gain or loss; not shown here).

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

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

► **shortwave radiation** Q_{sw} here (units: 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”)

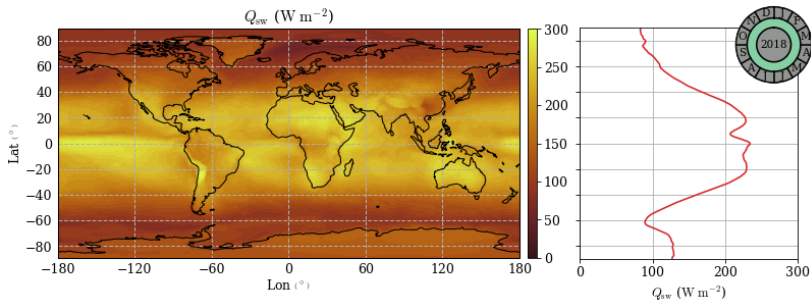


Figure: Year-averaged (left) and year and **zonal** averaged (right) shortwave radiation, from the JRA55 dataset (Kobayashi *et al.* 2015, *J. Meteor. Soc. Japan*). See `plot_jra55_sample.ipynb`

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

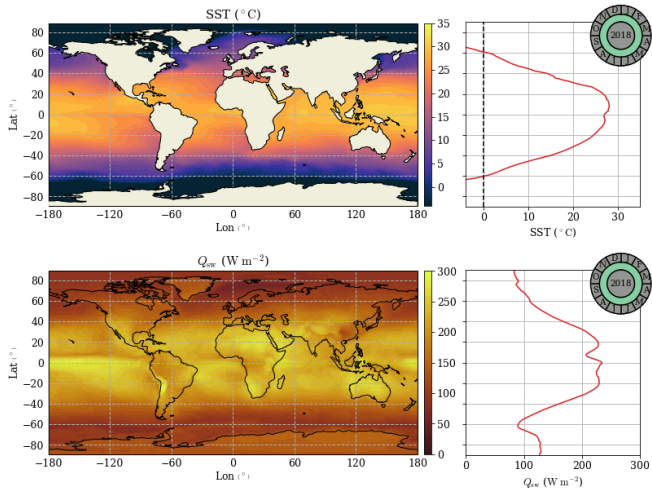


Figure: As previous figure but for SST (top) and shortwave radiation (bot).

- 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)

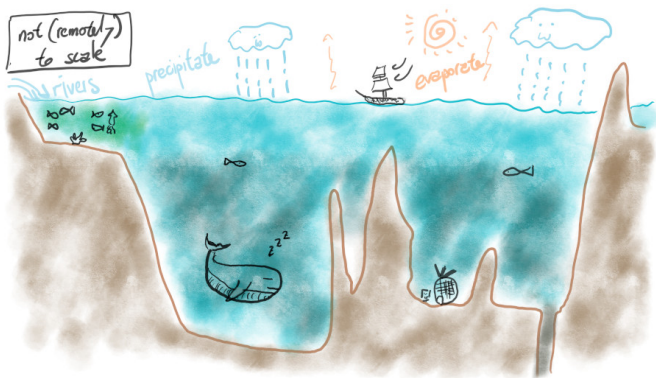


Figure: Schematic of ocean forcing.

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

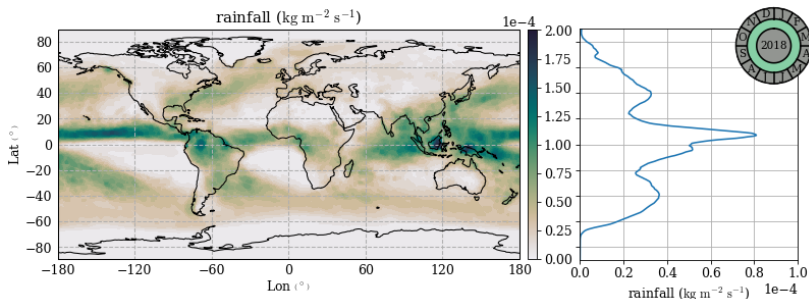


Figure: Year-averaged (left) and year and **zonal** averaged (right) rainfall (so **decrease** in salinity), from the JRA55 dataset (Kobayashi *et al.* 2015, *J. Meteor. Soc. Japan*). See `plot_jra55_sample.ipynb`

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

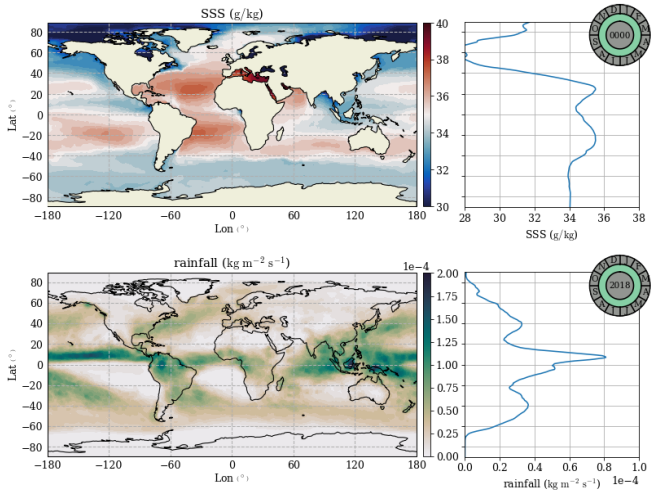


Figure: As previous figure but for SSS (top) and rainfall (bot). Notice how the Atlantic is **more salty** than the Pacific.

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

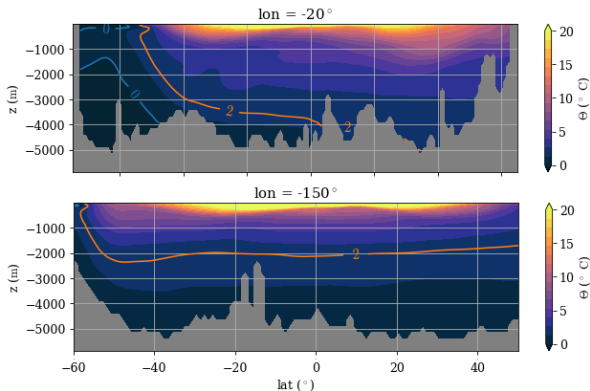


Figure: Meridional section of yearly-averaged conservative temperature in the Atlantic (top) and Pacific (bot), based on World Ocean Atlas 2013 data. Meridional range chosen to roughly correspond to Talley *et al.* (2011) Fig. 4.11 and 4.12. See `plot_WOA13_sample.ipynb`

- 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)

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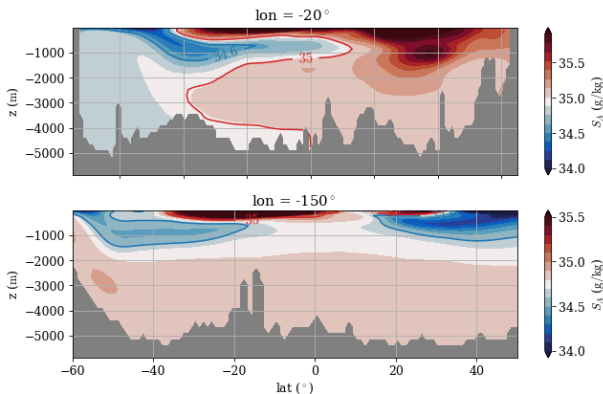


Figure: Meridional section of yearly-averaged absolute salinity in the Atlantic (top) and Pacific (bot), based on World Ocean Atlas 2013 data. Meridional range chosen to roughly correspond to Talley *et al.* (2011) Fig. 4.11 and 4.12. See `plot.WOA13.sample.ipynb`

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

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

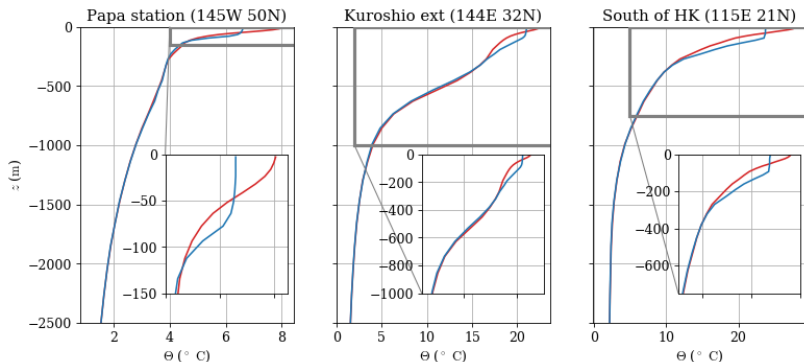


Figure: Vertical variation of Θ at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

- 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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- ▶ very top bit where **stratification** is weak (see previous panel (c) in winter)
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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 Θ which is used here), so it indicates changes in **density**

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

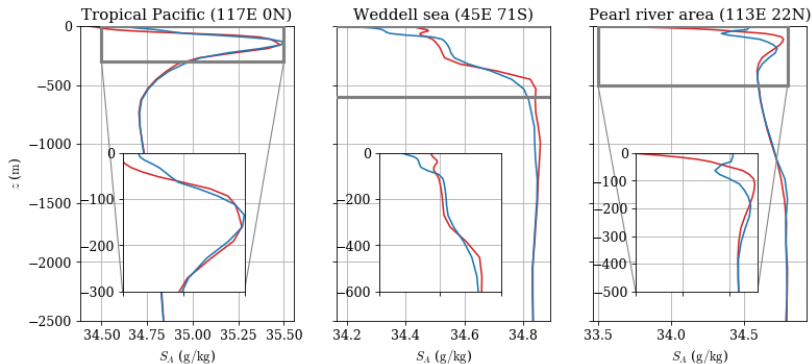


Figure: Vertical variation of S_A at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

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

Summary

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