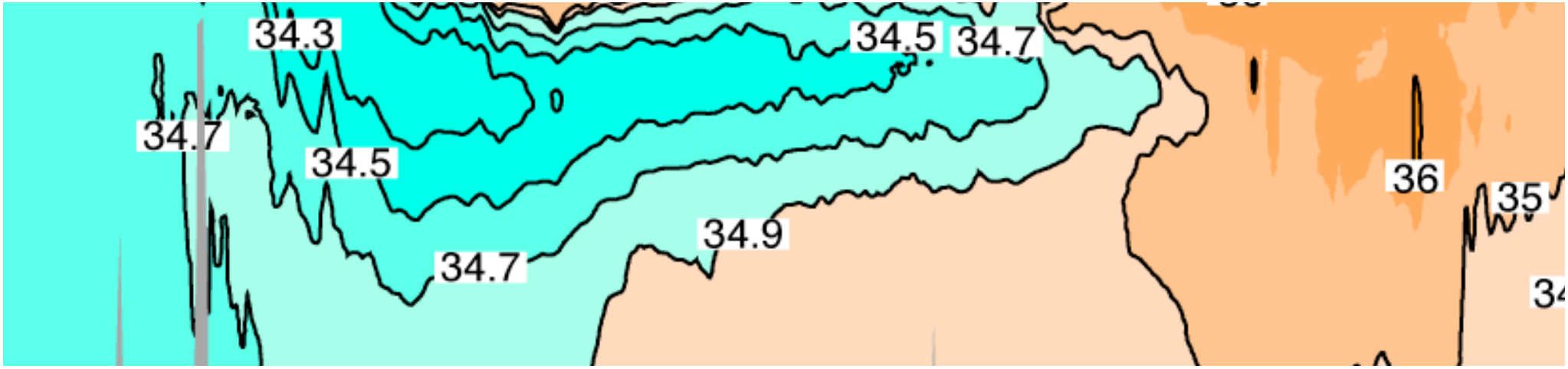


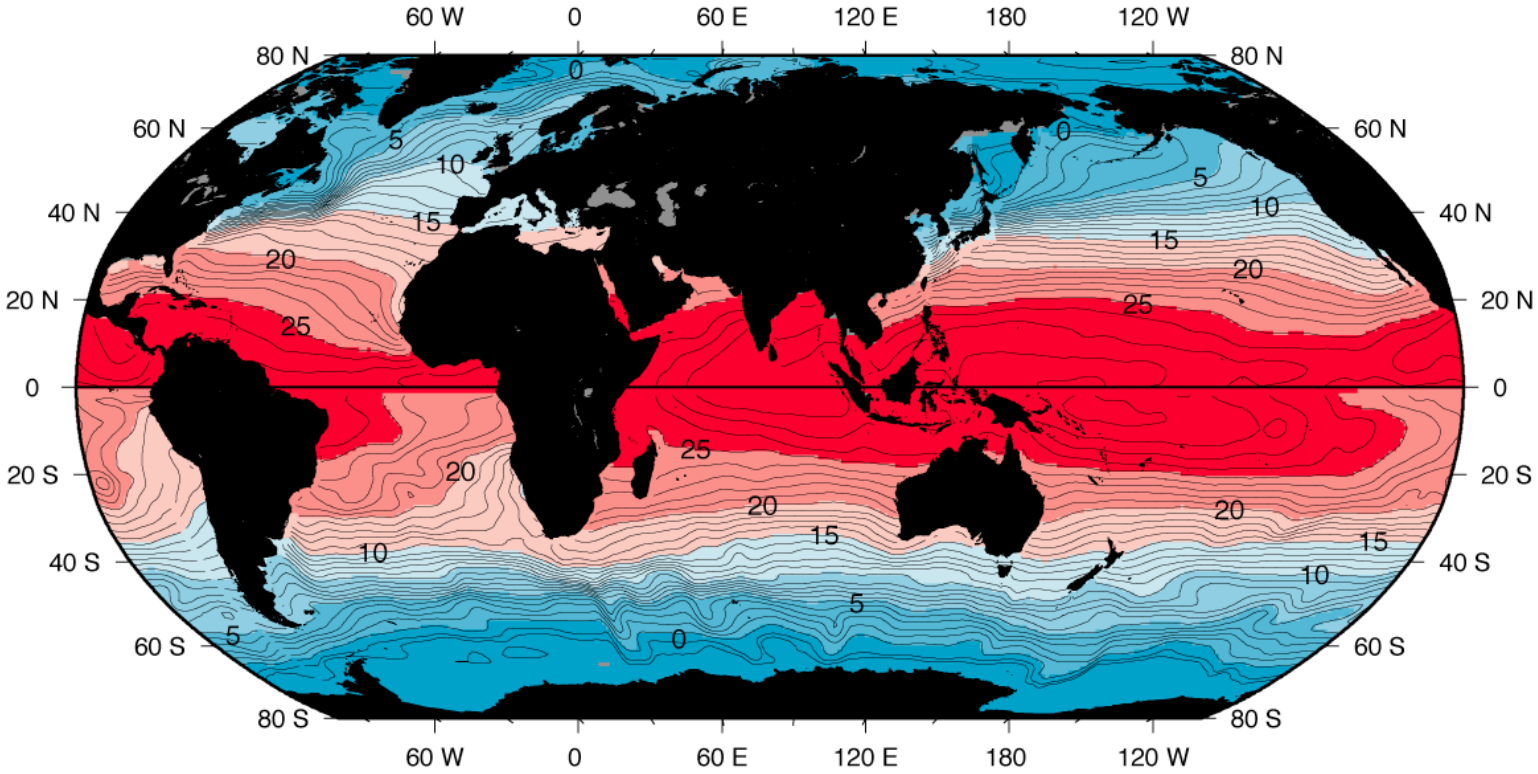
SIO 210: Typical distributions

Reading: DPO Chapter 4

1. Review surface
2. 4-layer structure
3. Water masses
4. Definitions - structures
5. Mechanisms

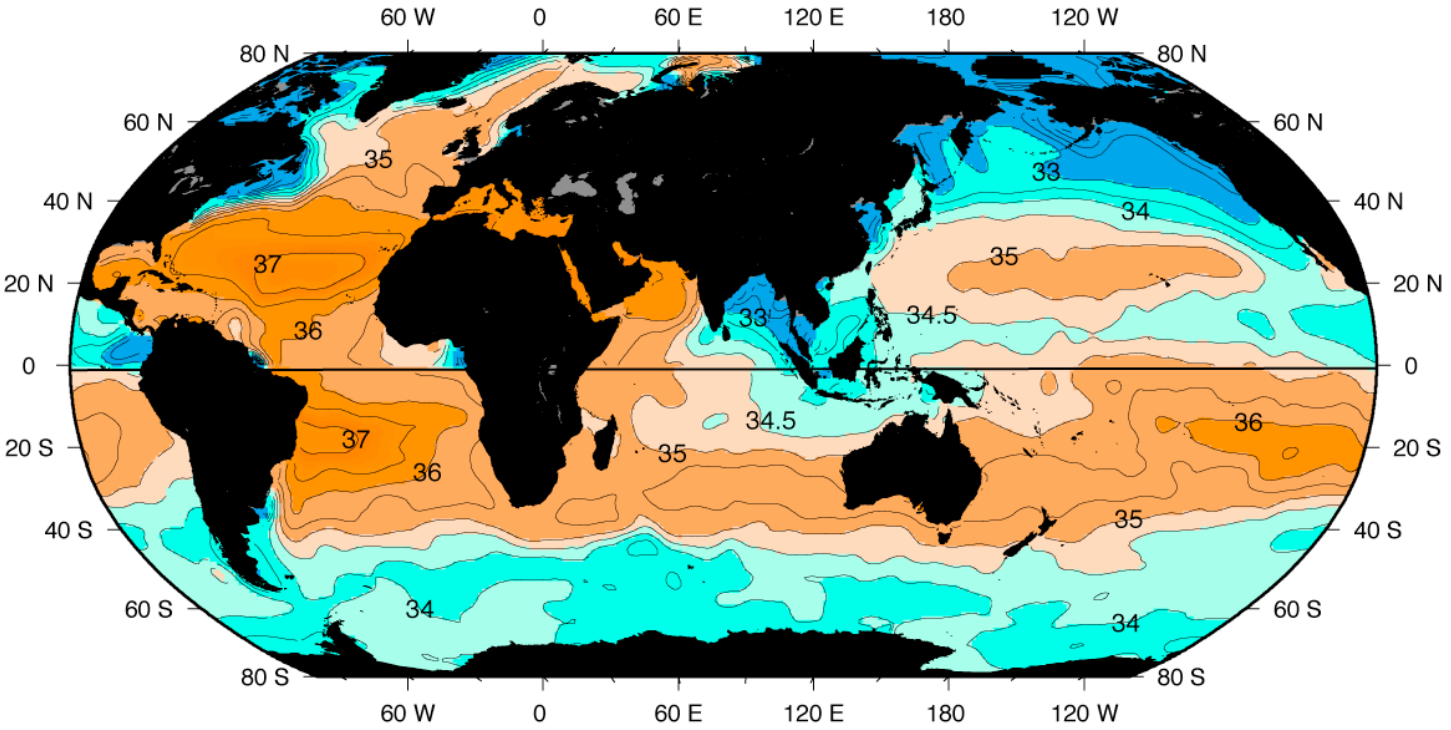
5. Upper layer
6. Intermediate layer
7. Deep and bottom layers

1. Review: Surface temperature: note where the 4°C isotherm occurs (most ocean volume is colder than this)



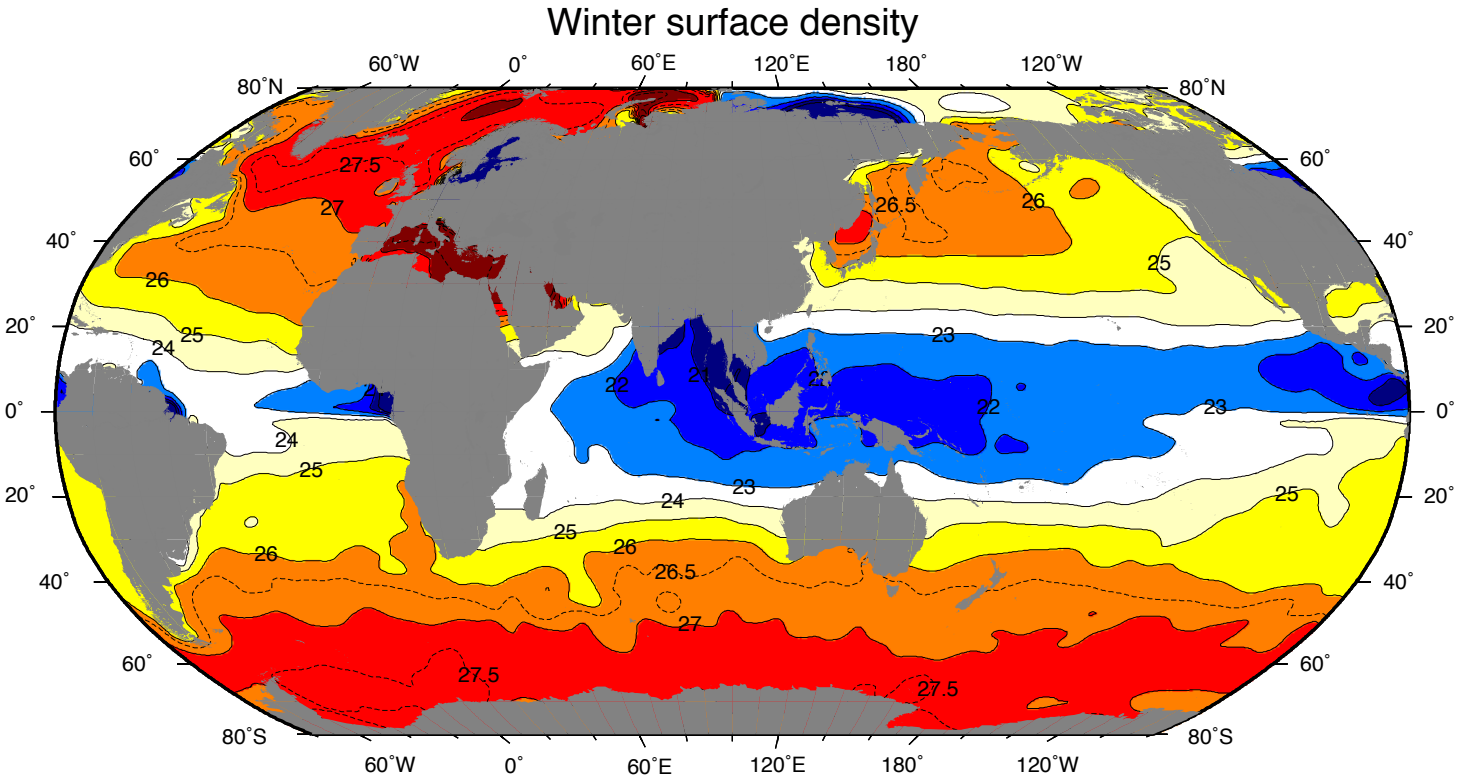
DPO Figure 4.1: Winter data from Levitus and Boyer (1994)

1. Review: Surface salinity



Surface salinity (psu) in winter (January, February, and March north of the equator; July, August, and September south of the equator) based on averaged (climatological) data from Levitus et al. (1994b).

1. Review: Surface density (winter)



Surface density σ_θ (kg m^{-3}) in winter (January, February, and March north of the equator; July, August, and September south of the equator) based on averaged (climatological) data from Levitus and Boyer (1994) and Levitus et al. (1994b).

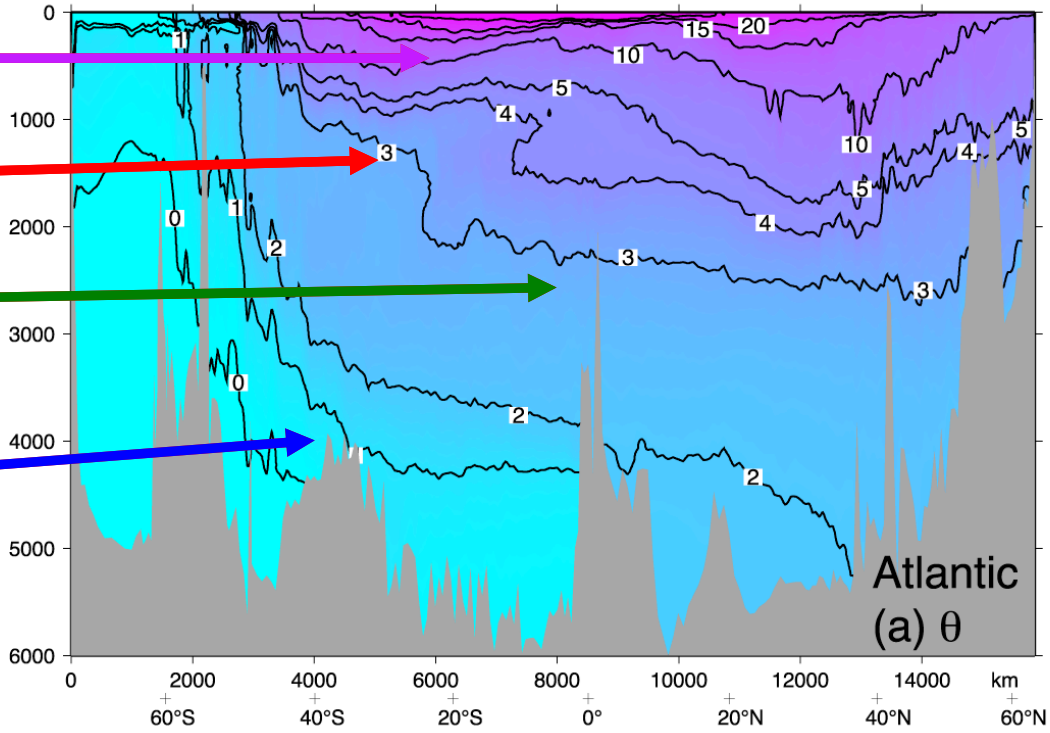
2. The (approximately) 4-layered structure of the ocean

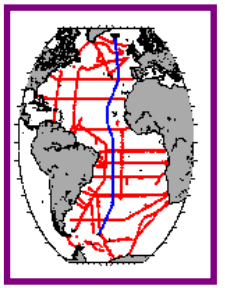
We can use four layers to describe the world's oceans.

1. Upper ocean (down through the permanent pycnocline)
2. Intermediate layer
3. Deep layer
4. Bottom layer

2. Atlantic vertical section: overall vertical structure of 4 layers

1. Upper
2. Intermediate
3. Deep
4. Abyssal

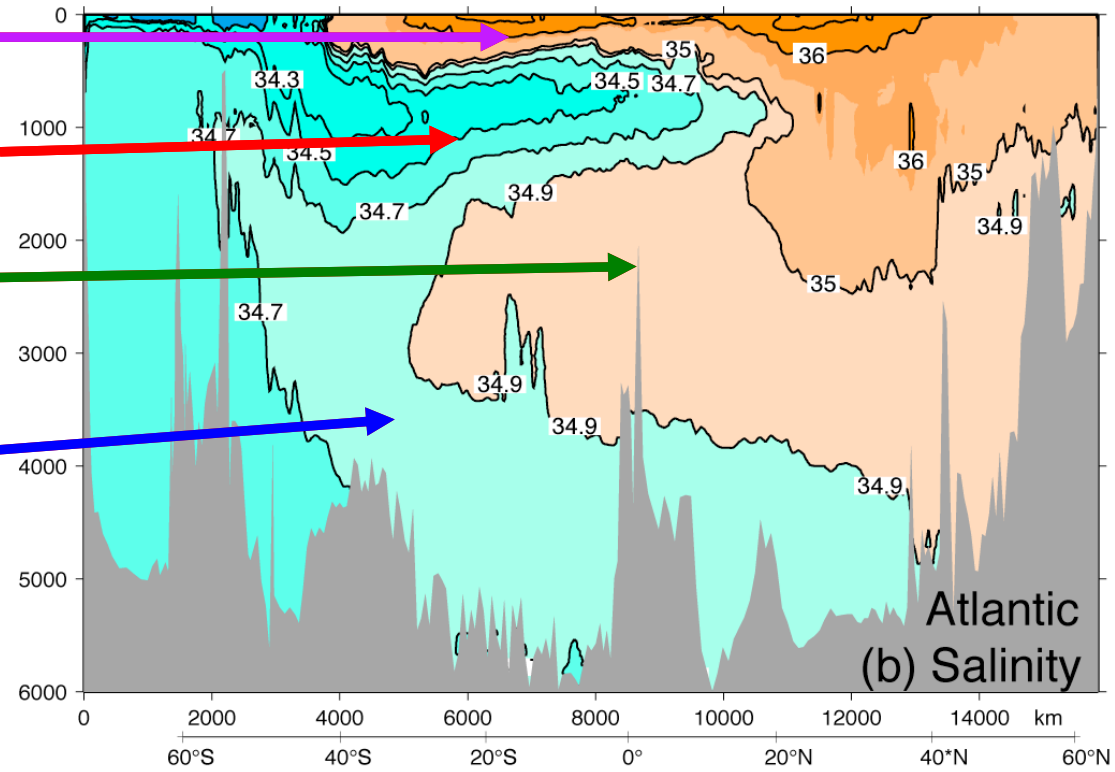


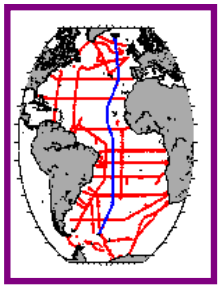


DPO Fig. 4.11

2. Atlantic vertical section: overall vertical structure of 4 layers

1. Upper
2. Intermediate
3. Deep
4. Abyssal



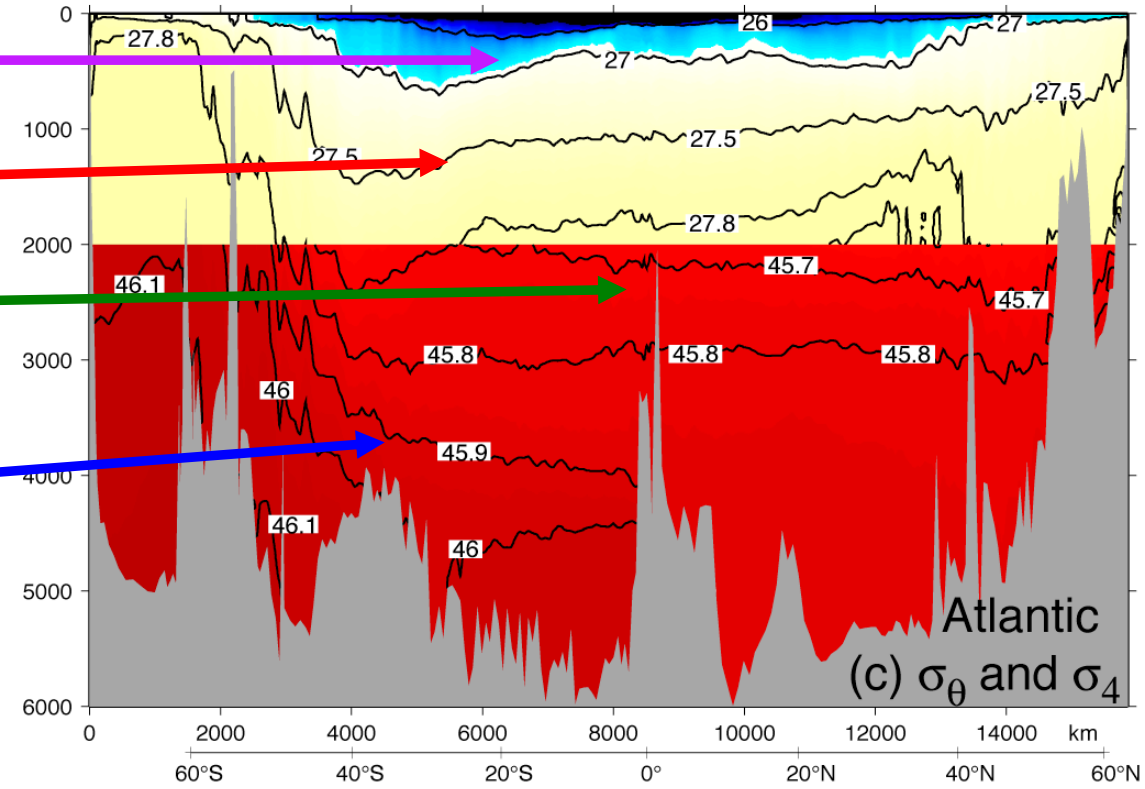


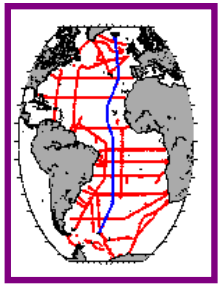
Talley SIO210 (2019)

DPO Fig. 4.11

2. Atlantic vertical section: overall vertical structure, 4 layers

1. Upper
2. Intermediate
3. Deep
4. Abyssal



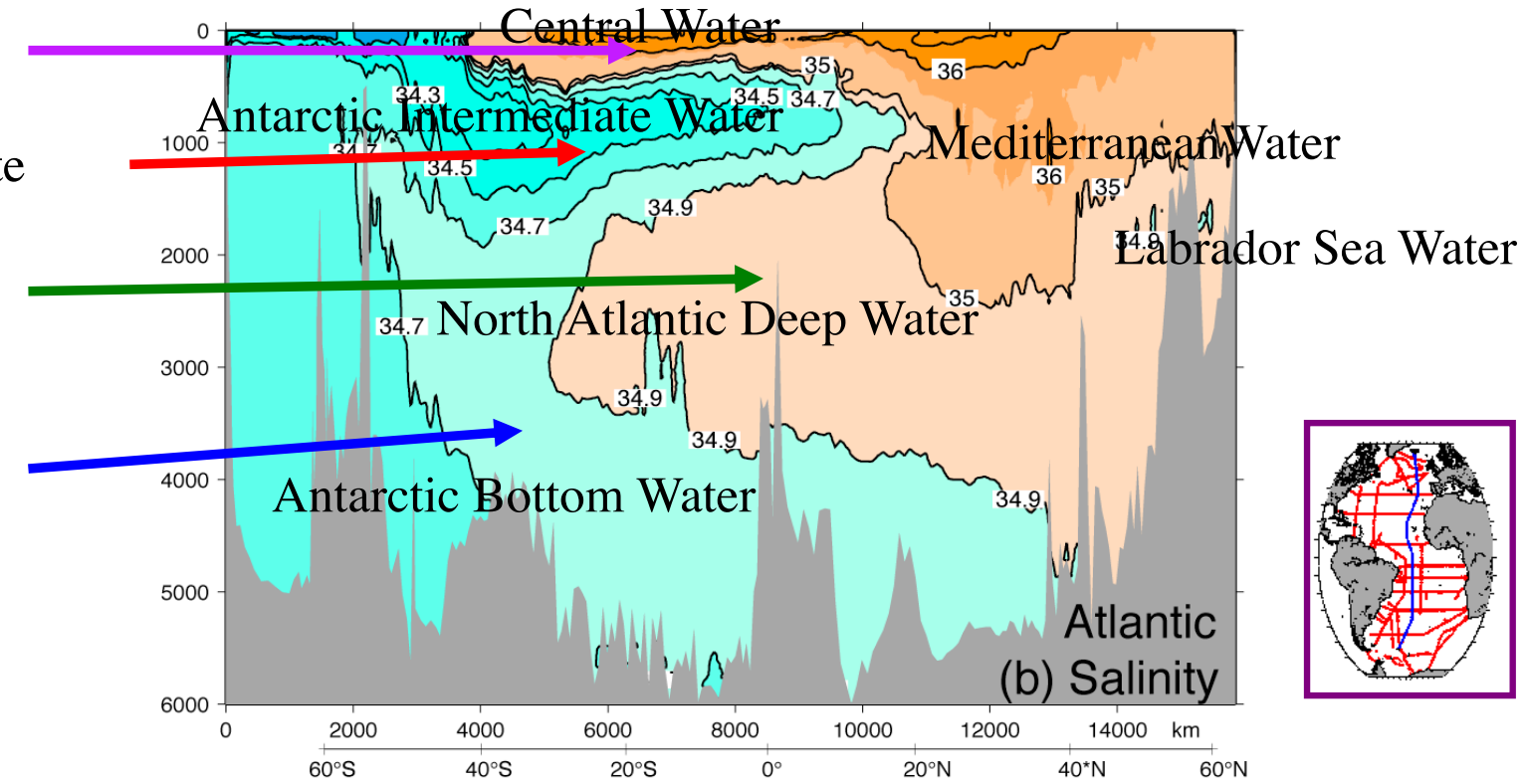


Talley SIO210 (2019)

DPO Fig. 4.11

3. Atlantic vertical section: name the layers
Principal water masses

1. Upper
2. Intermediate
3. Deep
4. Abyssal



Talley SIO210 (2019)

DPO Fig. 4.11

3. Water masses

Water mass: "body of water with a common formation history". Names are capitalized.

A water mass has

an identifiable property (usually an extremum of some sort)

an identifiable formation process

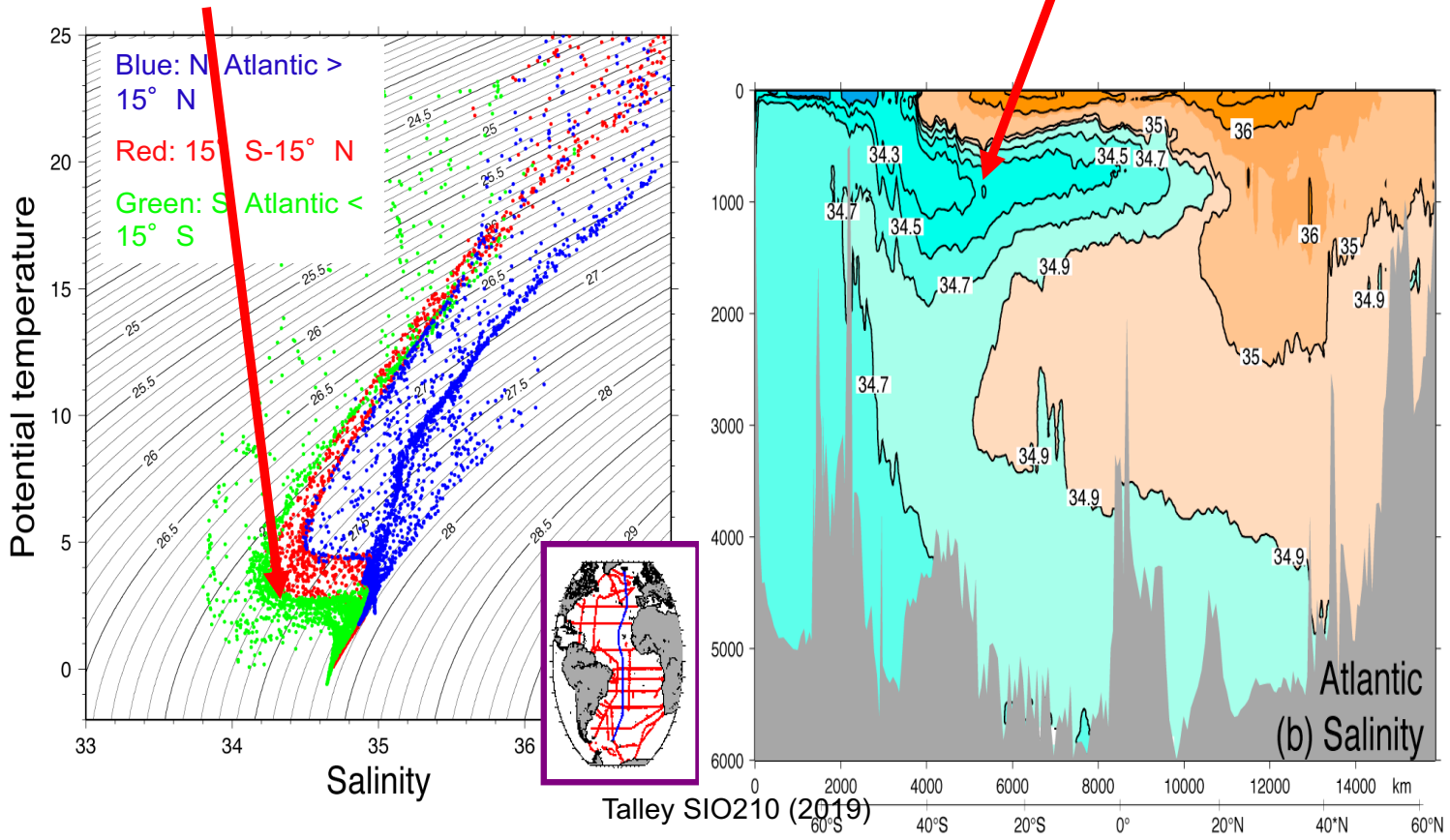
Water type: point on a temperature-salinity diagram (or more carefully, point in property-property-property-nthproperthy space)

Source water type: water type at the source of water mass

In practice, we just name the first, but are always aware that there are specific properties at the sources.

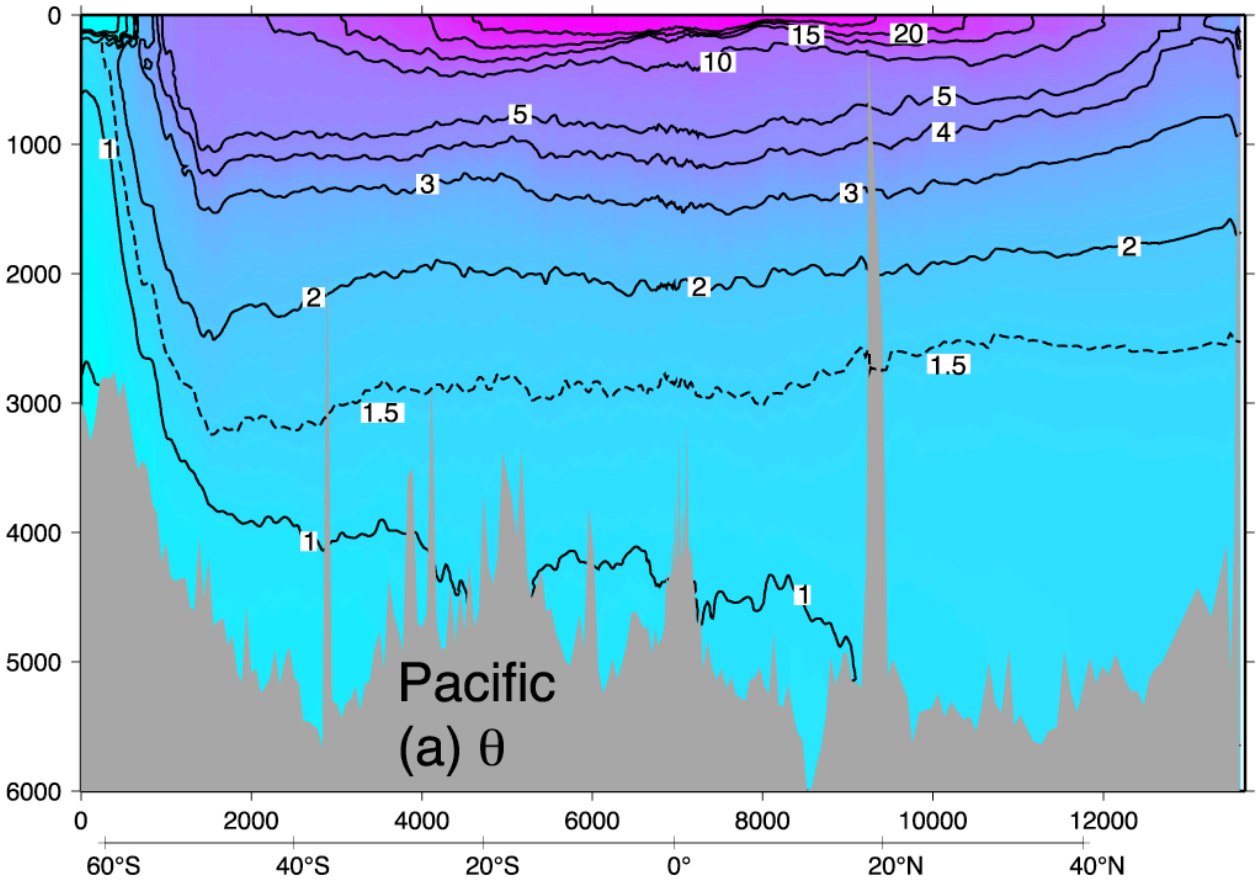
3. Water mass

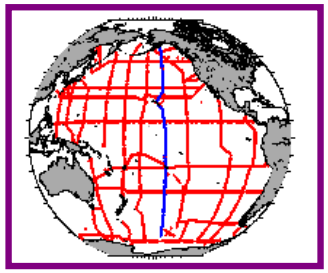
Example: Antarctic Intermediate Water - (a) low salinity layer, (b) originating in surface mixed layers near Antarctic Circumpolar Current



Talley SIO210 (2019)

4. Definitions: structures
Example: Pacific potential temperature section

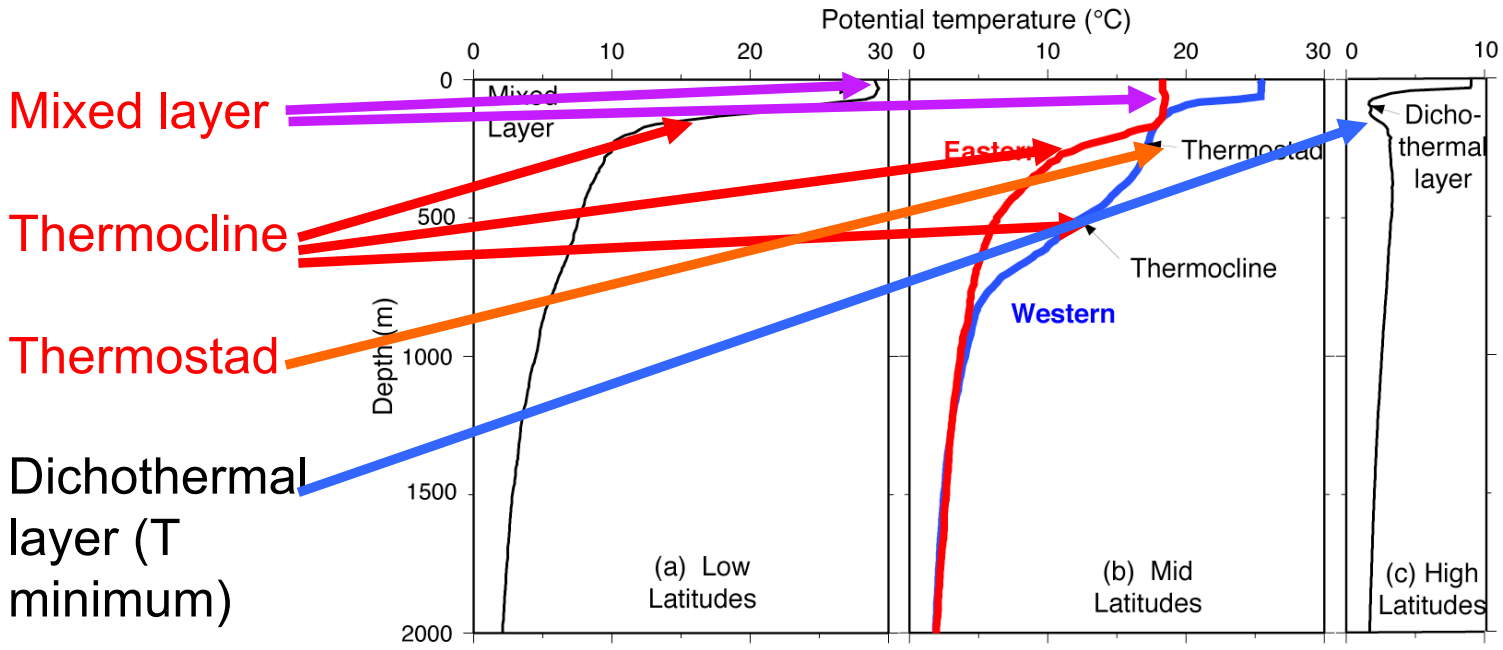




Talley SIO210 (2019)

DPO Fig. 4.12a

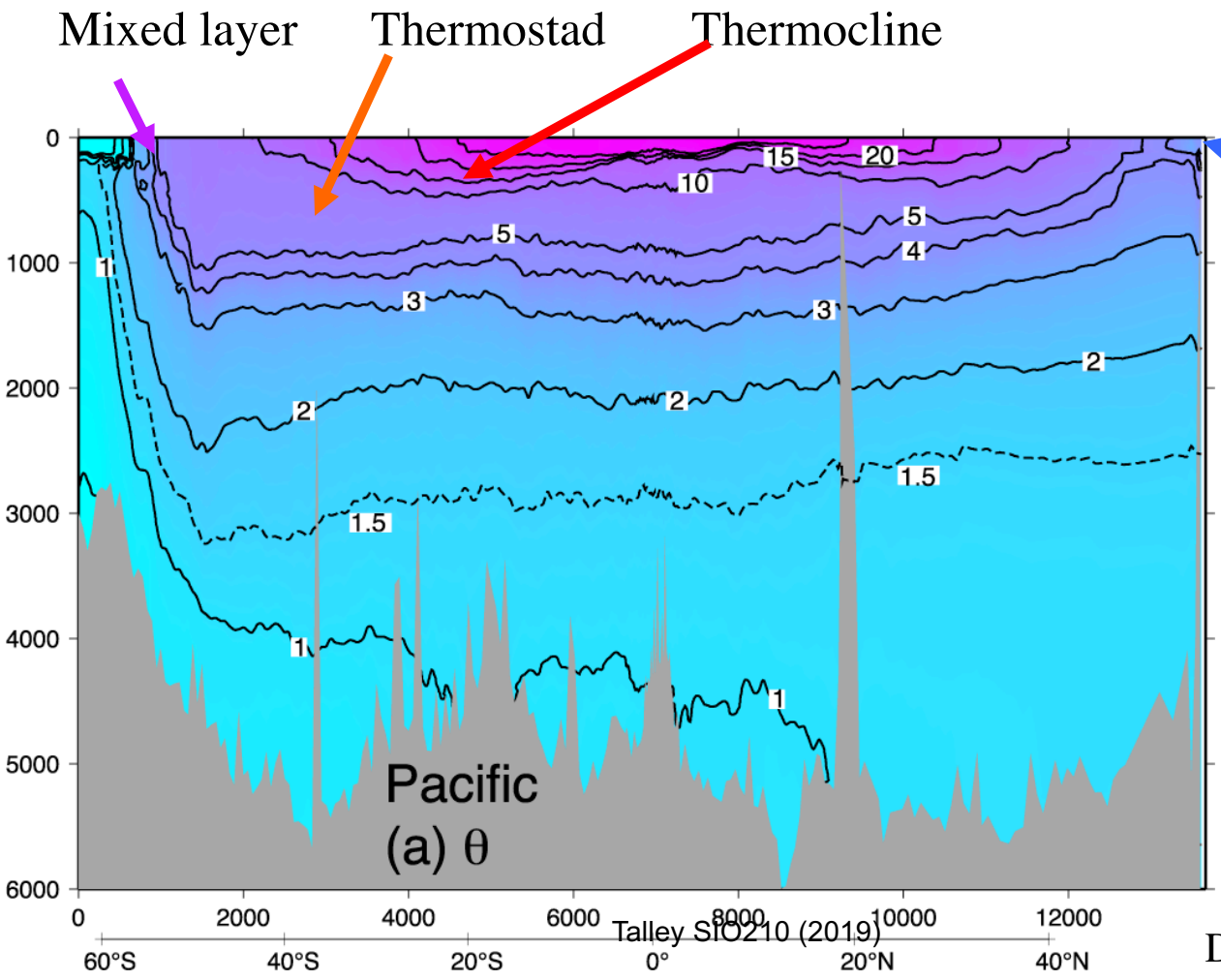
4. Definitions: vertical structures (temperature)

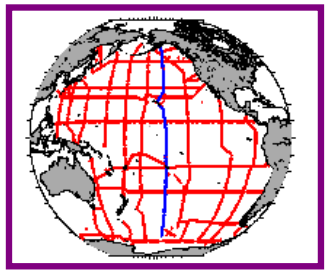


Typical North Pacific profiles

DPO Figure 4.2

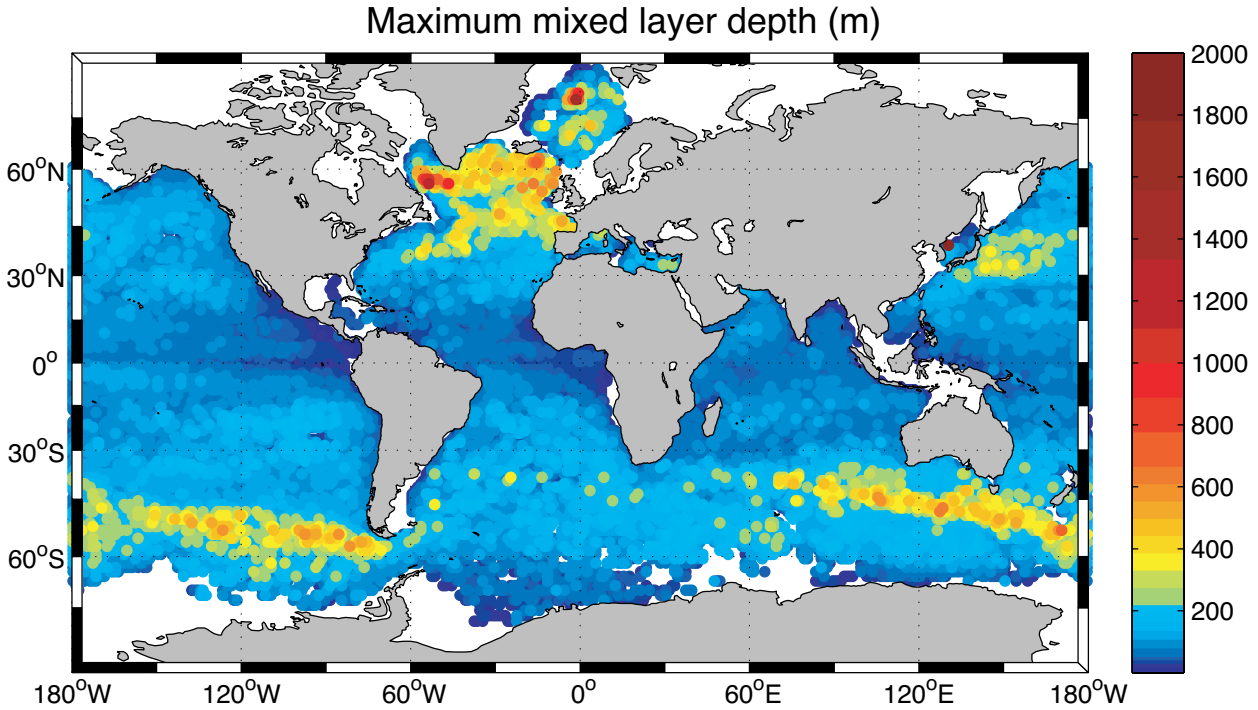
4. Pacific potential temperature section





DPO Fig. 4.12a

4. Definitions: Mixed layer

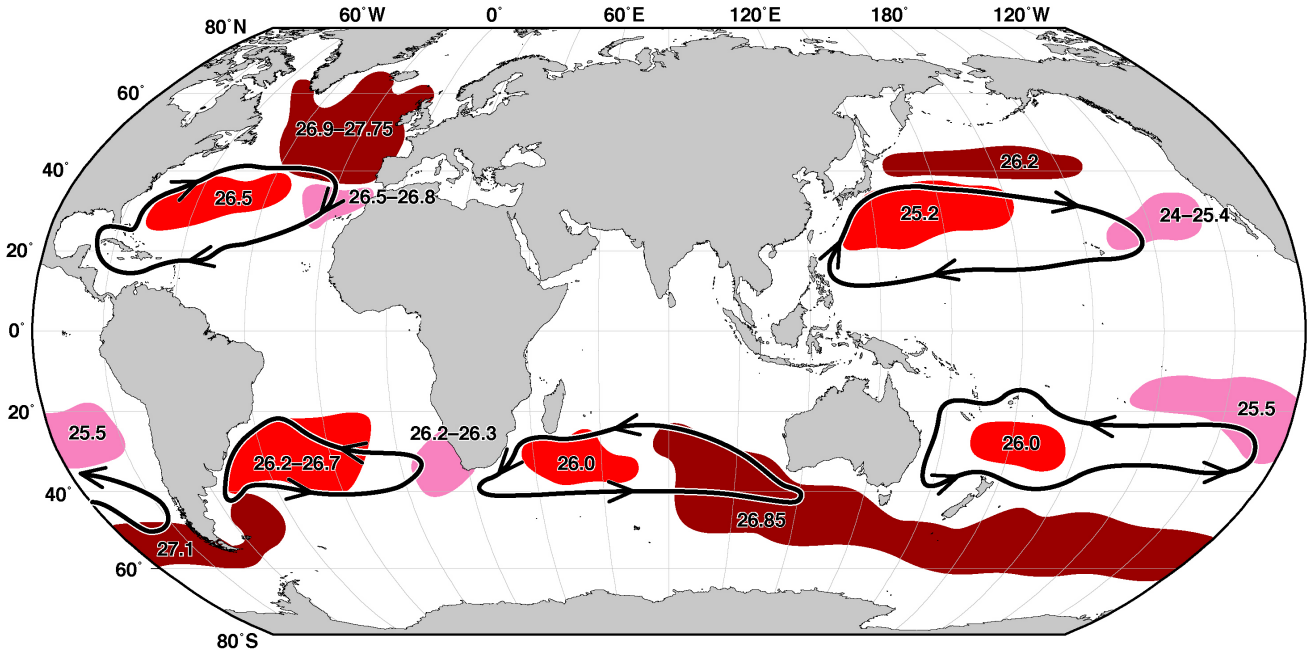


Typically 20 to 200 m (late winter)
Thicker (> 500) in some special locations, notably in
(1) band in the Southern Ocean and (2) northern North Atlantic

DPO Fig. 4.4c from Holte et al.

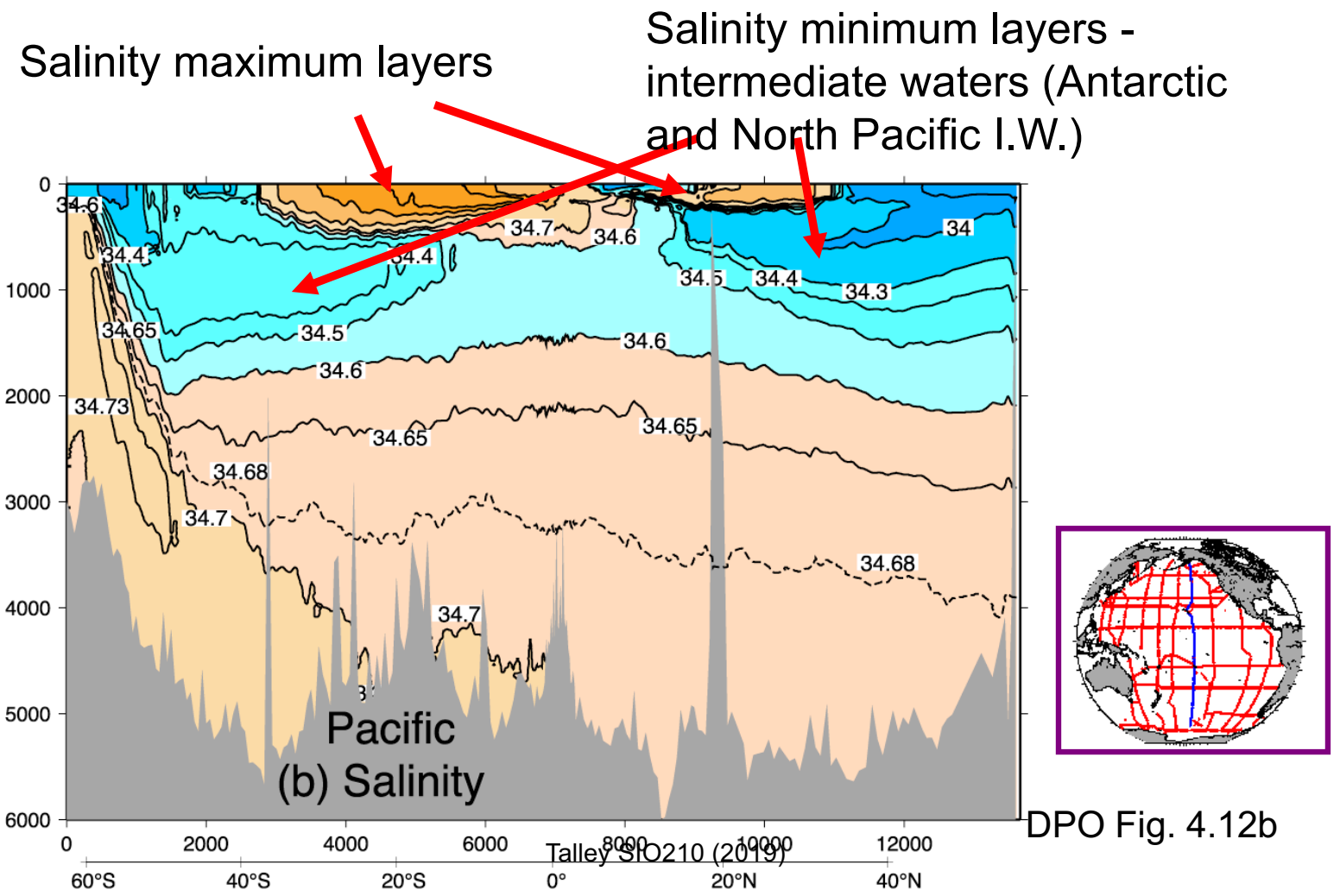
4. Definitions: Thermostads (pycnostads)

Location of thermostads - coordinated structures, derived from thick winter mixed layers that are capped at the top by spring-summer warming, then spread into the interior along isopycnals



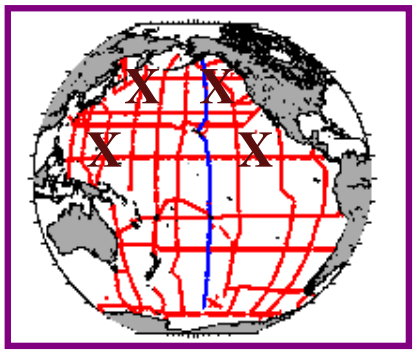
Hanawa and Talley (2001); DPO 14.12

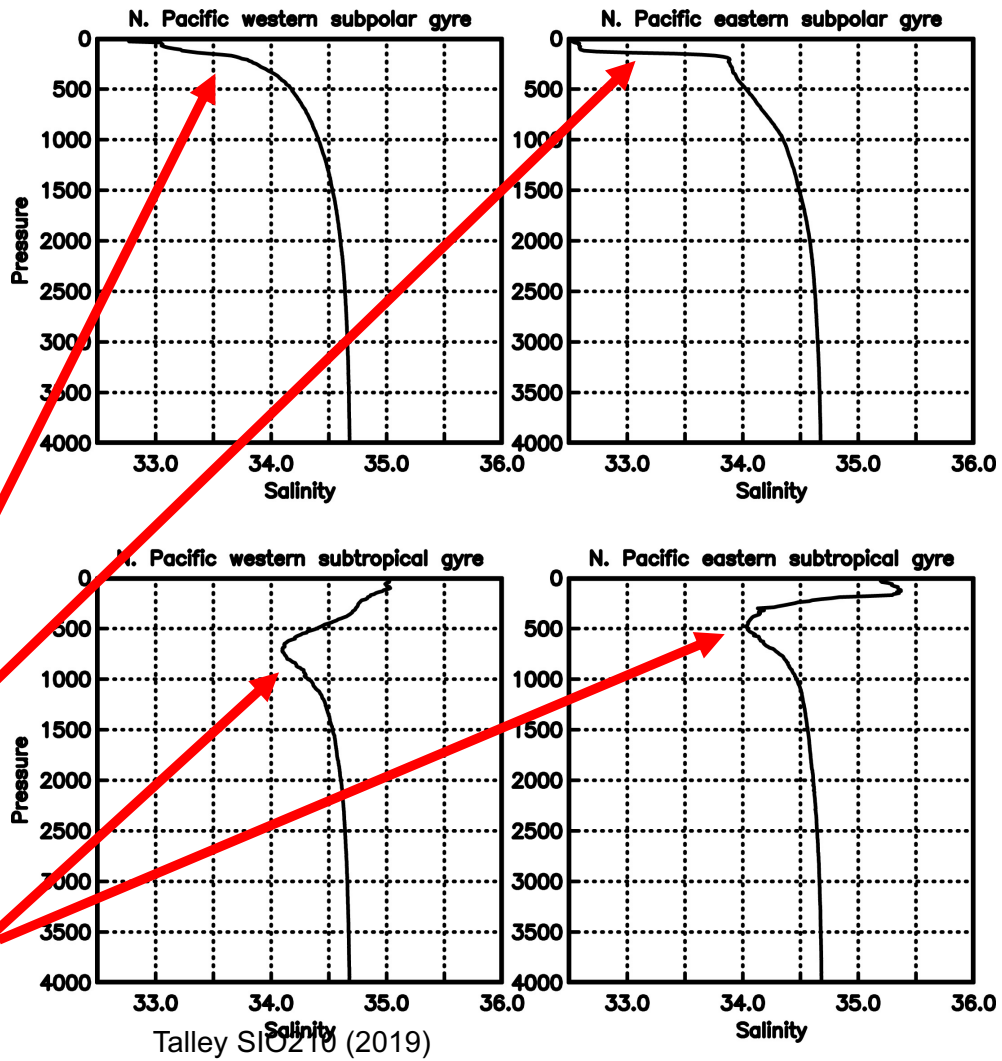
4. Definitions: Pacific salinity vertical section



DPO Fig. 4.12b

4. Definitions: Salinity structures



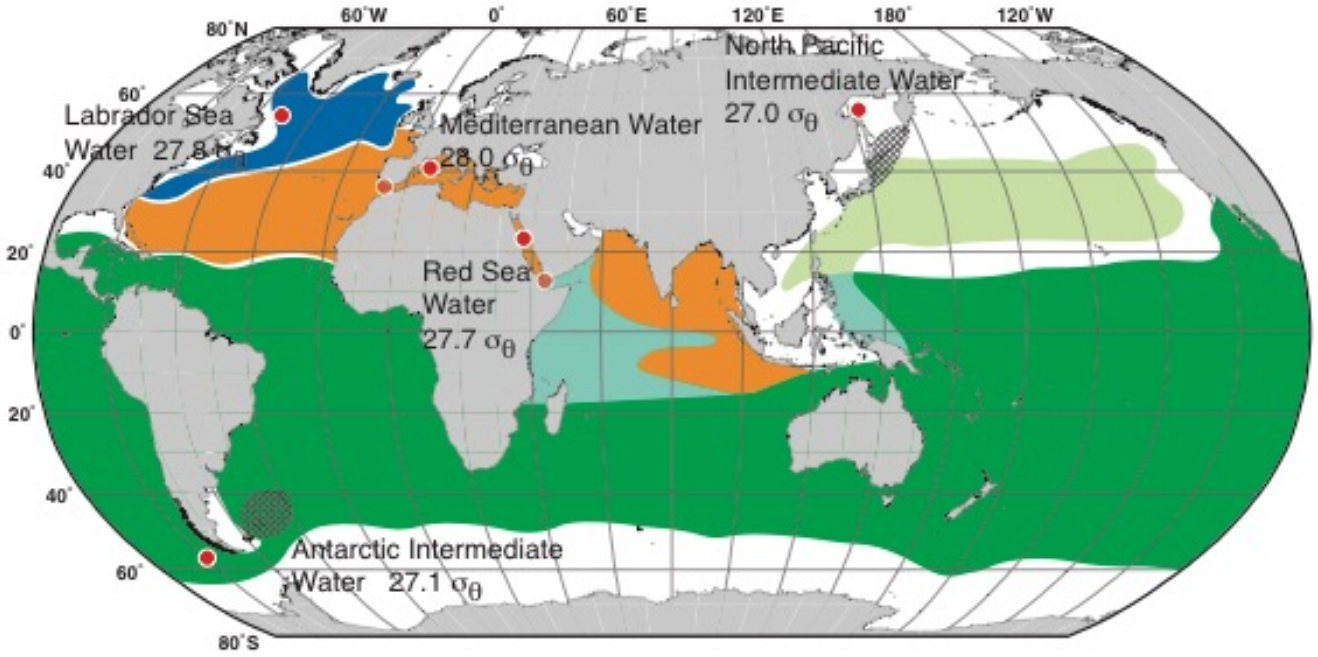


Halocline

Salinity minimum

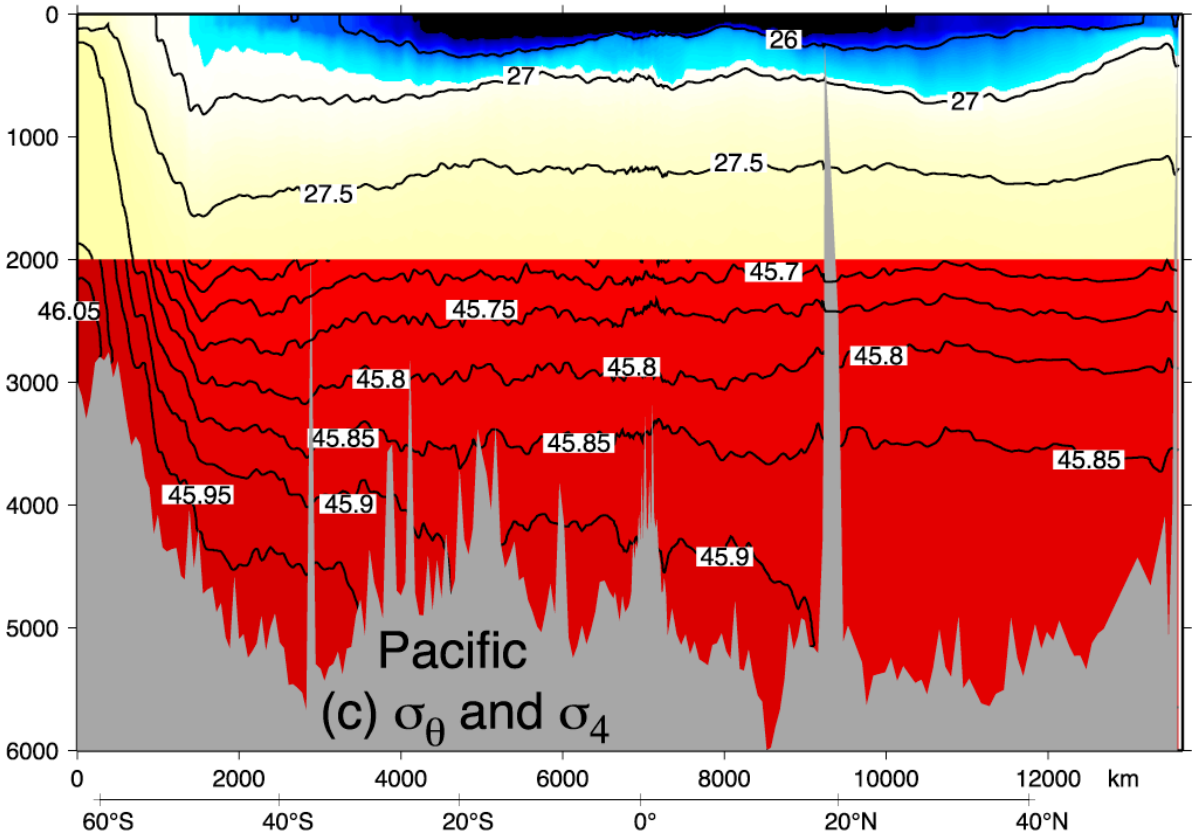
3. Definitions: Intermediate water masses (salinity extrema)

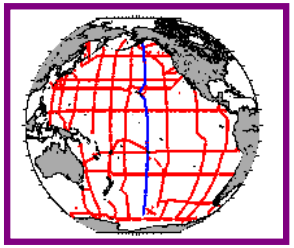
- Low salinity intermediate layers (salinity minimum layers)
- High salinity intermediate layers (salinity maximum layers)
- (Return to this in section 5 of these lectures)



DPO Fig. 14.13

4. Definitions: structures
Pacific section of potential densit(ies)





Talley SIO210 (2019)

DPO Fig. 4.12

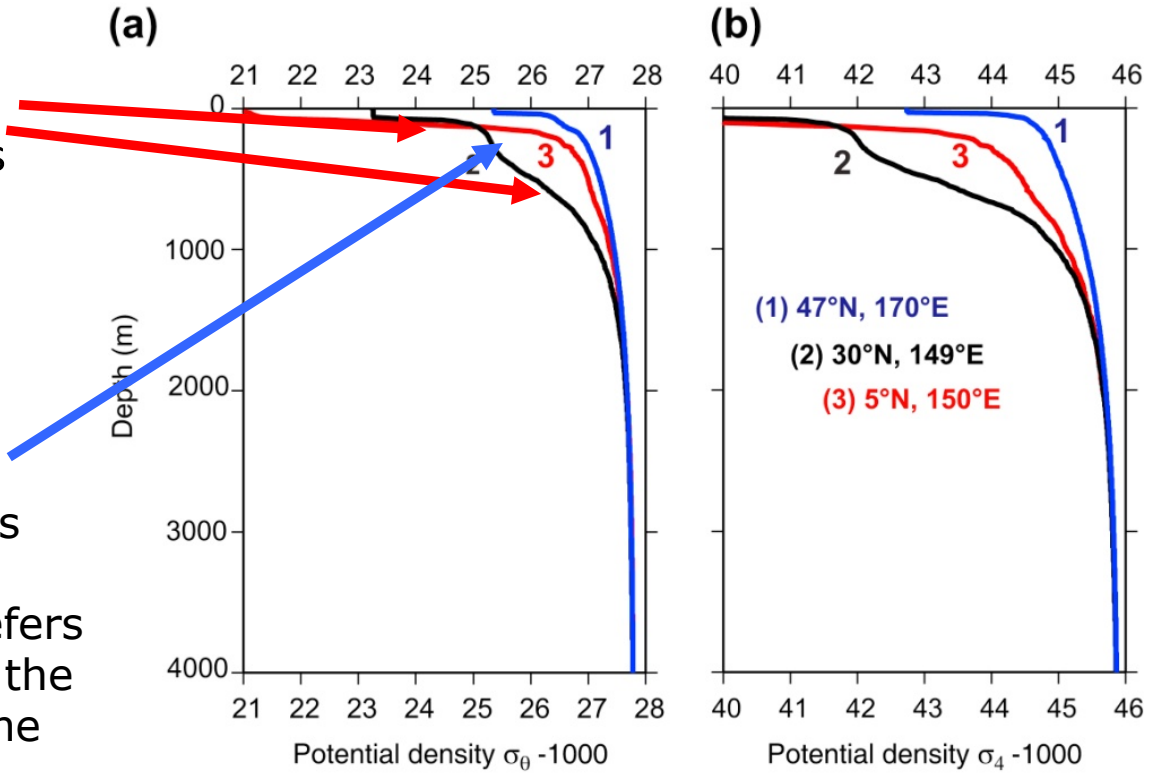
4. Definitions: Typical potential density structure

Pycnocline:

Where density changes rapidly (large vertical gradient)

Pycnostad:

Where density changes slowly (small vertical gradient), generally refers to being embedded in the pycnocline, hence in the upper ocean.



DPO Figure 4.20

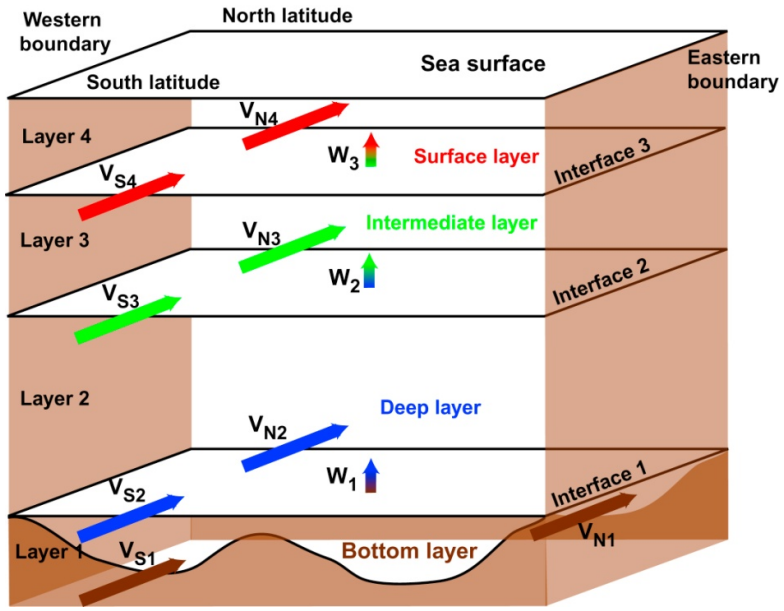
4. Definitions: Summary of terminology for vertical structure

Mixed layer

Thermocline, halocline, pycnocline:
Vertical locations of high vertical gradient
(large $\Delta T/\Delta z$, for thermocline, etc.)

Thermostad, halostad, pycnostad:
Vertical locations of low gradient, usually embedded in the …cline
(small $\Delta T/\Delta z$, for thermostad, etc.)

5. Concepts and mechanisms for ocean property distributions



Flow is 3-dimensional:

- east, north, vertical
- x, y, z in local Cartesian coordinates
- longitude, latitude, vertical (λ, ϕ, z) in geographic coordinates.

Also very useful to think of flow relative to isopycnal surfaces, which are not flat:

- "x","y" along isopycnals, "z" diapycnal

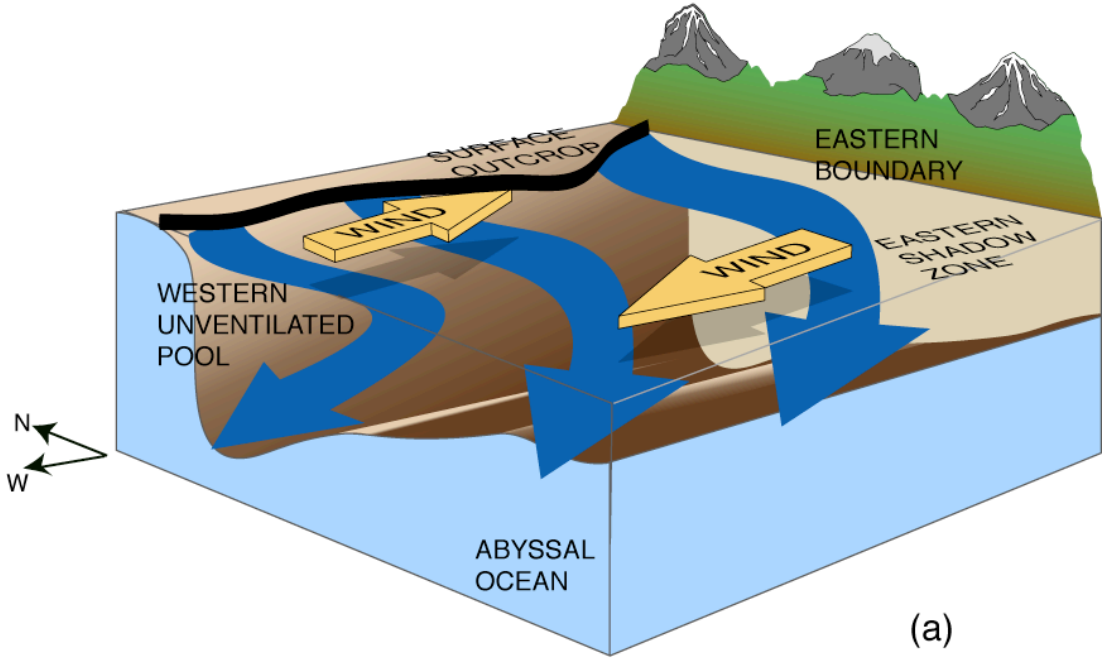
5. Concepts and mechanisms for ocean property distributions

a) Ventilation:
   a) Exchange at the sea surface ('breathing')
   b) Physical and many biogeochemical water properties are set mostly at the sea surface (heat, freshwater, gas exchange) and modified internally (mixing, biological processes, radioactive decay)
   c) Subduction: flow of waters from surface layer into the interior along isopycnals/isoneutrals

b) Isentropic (isopycnic, isoneutral) flow (velocity) and mixing:
   a) Flow and mixing along isopycnals
   b) no input of heat or freshwater (no buoyancy) ('adiabatic' process)
   c) water parcels tend to follow isopycnals as they enter and flow through the ocean interior.
   d) Mixing along isopycnals is easy – no change of energy
      - Principally due to mesoscale eddies that stir the fluid laterally

c) Diapycnal (dianeutral) velocity and mixing:
   a) across isopycnals
   b) requires external input or diapycnal mixing of heat or freshwater ('diabatic' process)
   c) Diapycnal mixing requires change of energy
      - Mixing principally due to breaking internal waves

5. Concepts: (a) Ventilation (upper ocean) through subduction

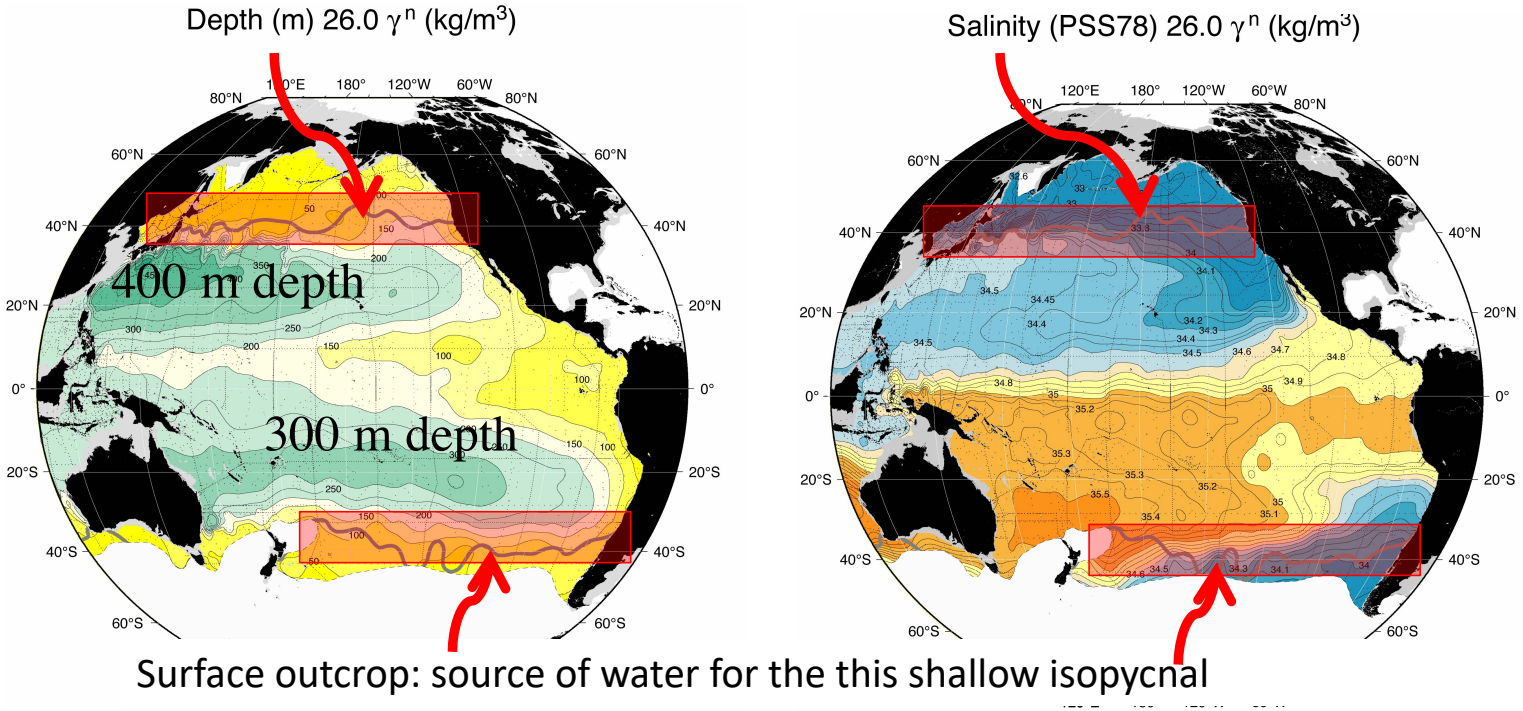


Subduction: flow from surface mixed layer into interior along isopycnals.

This process forms the main thermocline: Central Water and Mode Waters

DPO Figure 7.15

5. Concepts: (a) Ventilation of the upper ocean

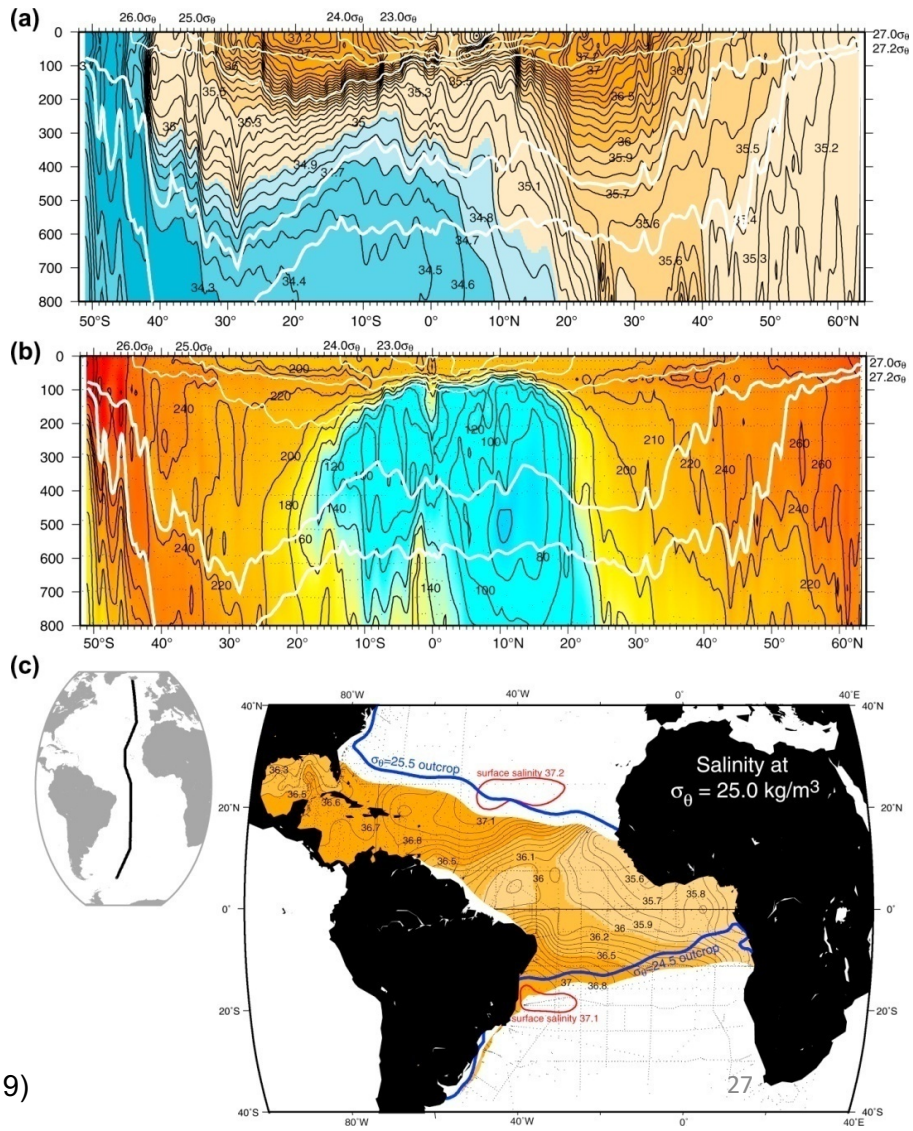


Water in ocean interior originates at surface outcrops. (There is no interior source of high density.)

The water mostly flows into the ocean interior along isopycnals (presuming only weak diapycnal mixing).

5. Concepts: (a) Ventilation (upper ocean) through subduction

(water mass name: "Subtropical Underwater" or "Salinity Maximum Water")



Vertical sections of (a) salinity and (b) oxygen (μmol/kg) with selected potential density contours, along approximately 25° W in the Atlantic Ocean. (c) Salinity at σ_θ = 25.0 kg/m^3.

DPO FIGURE S9.28

5. Concepts: (a) Ventilation (upper ocean) through subduction

3D North Atlantic STUW

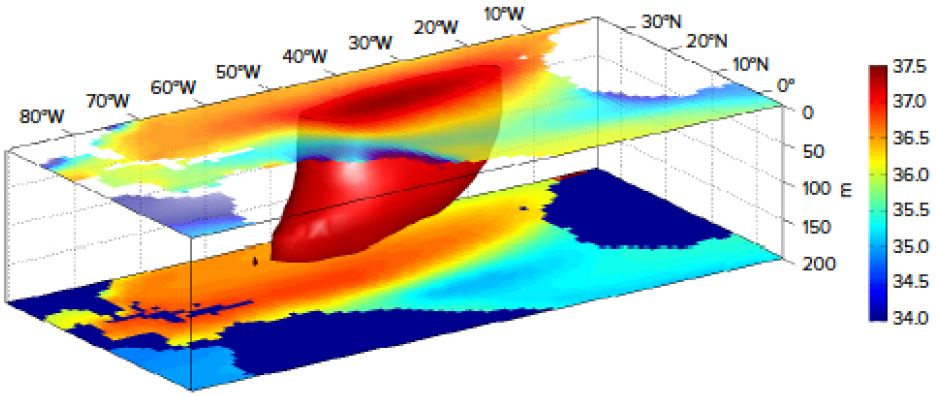
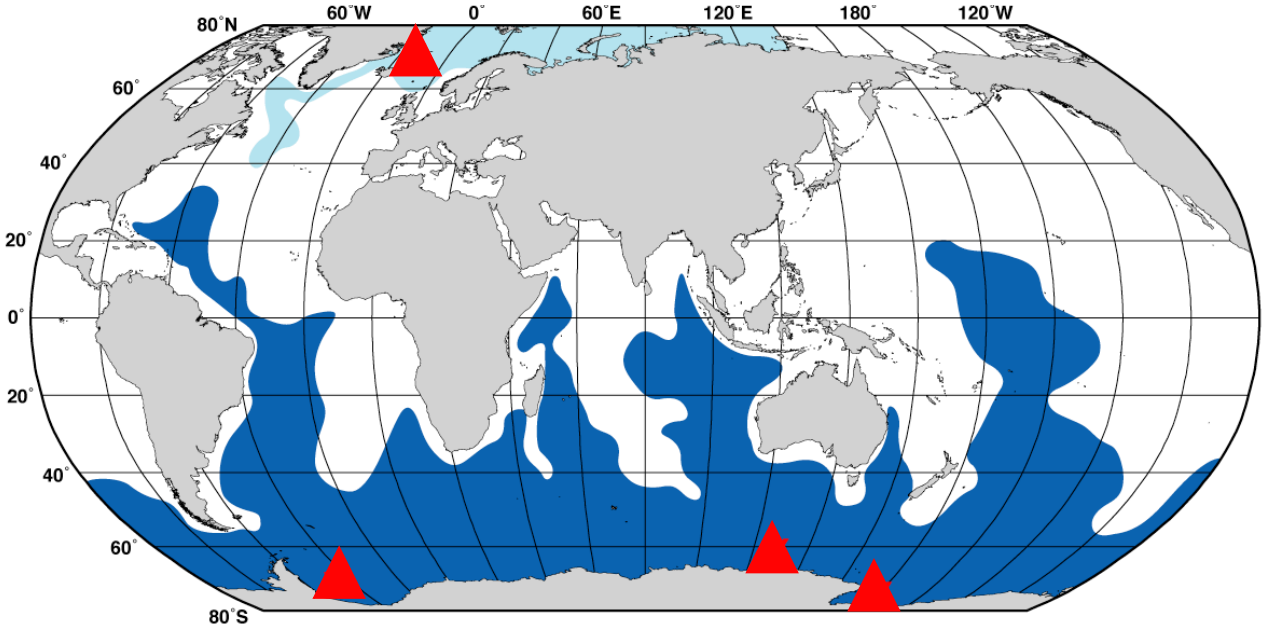


FIGURE 4. The three-dimensional shape of the 37.0 isohaline from a perspective over South America. The color scale indicates salinity at the surface and at 200 m depth. The continental and island land masses are transparent at the surface and blue at 200 m depth. The vertical exaggeration is about 20,000:1. The one-degree data of the 2009 World Ocean Atlas climatology were used.

Example: STUW is ventilated through subduction. Highest surface salinity water can be seen moving down .

Schmitt and Blair (Oceanography, 2015)

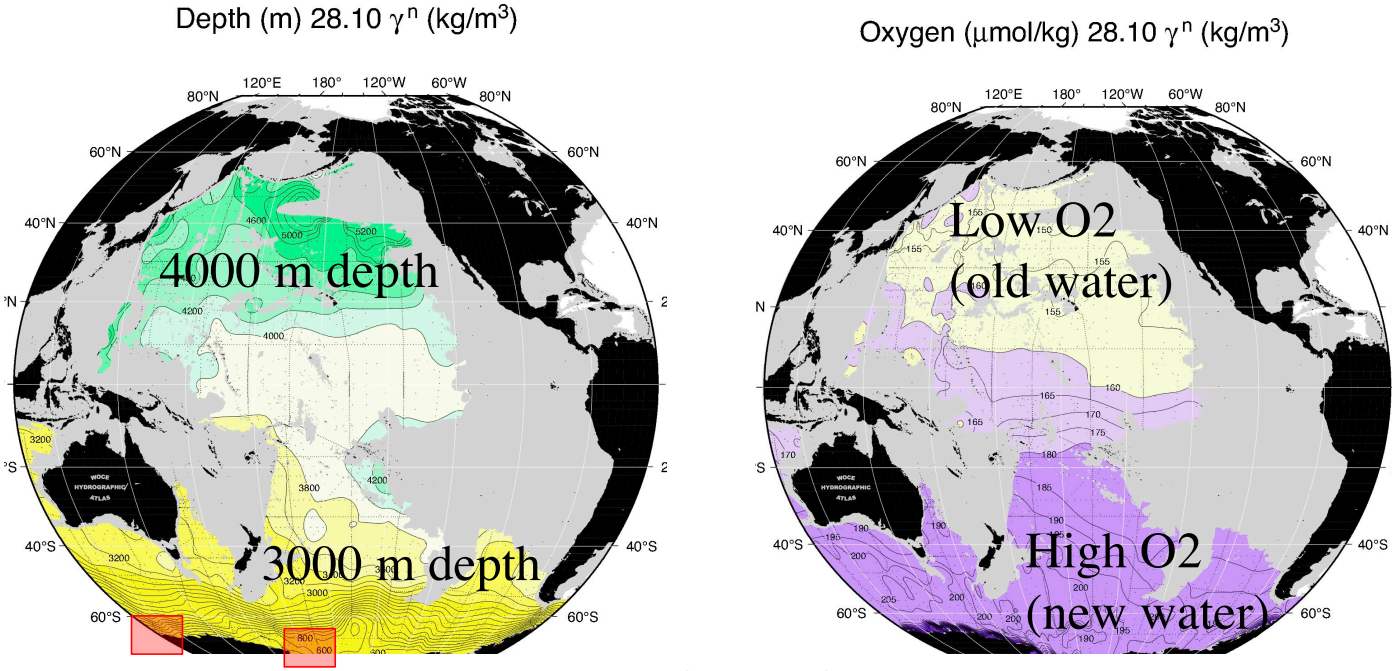
5. Concepts: (a) Ventilation of the deep ocean



- Localized deep convection or brine rejection, with subsequent local turbulent mixing and then flow mostly along isopycnals
- Process forms North Atlantic Deep Water, Antarctic Bottom Water (and also Mediterranean Water, Red Sea Water)

DPO Fig. 14.14a

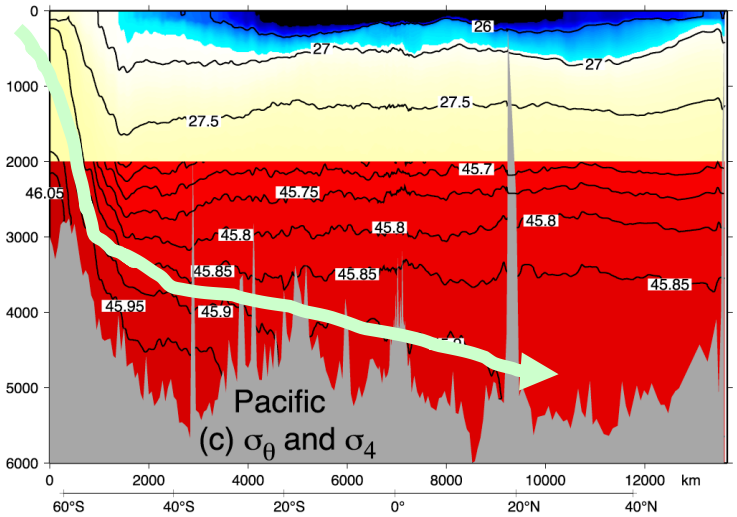
5. Concepts: (a) Ventilation of the deep ocean

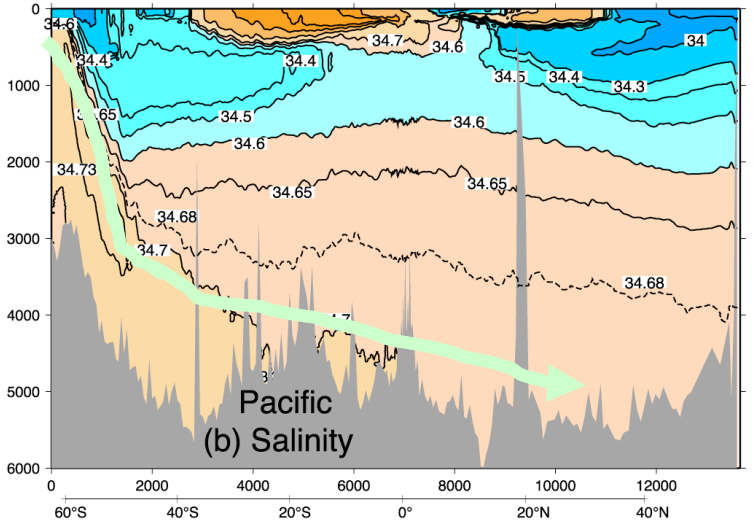


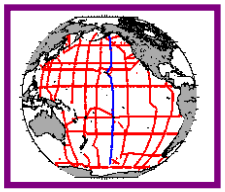
Very local high latitude sources of water for this deep isopycnal

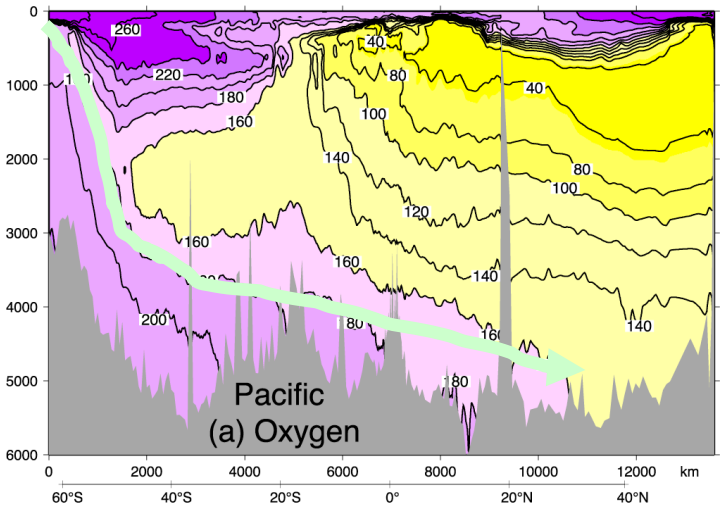
(Sources for this deep isopycnal include various sea ice formation regions along Antarctica, and dense water formation in the Nordic Seas, north of the N. Atlantic)

5. Concepts: (b) isentropic processes



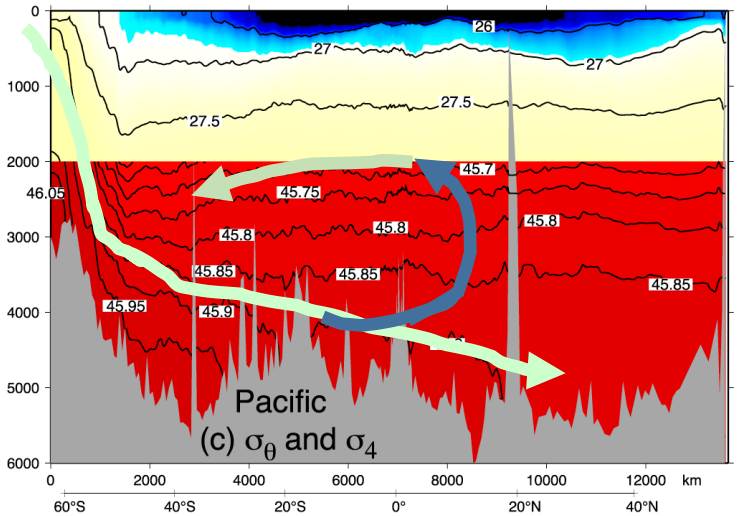


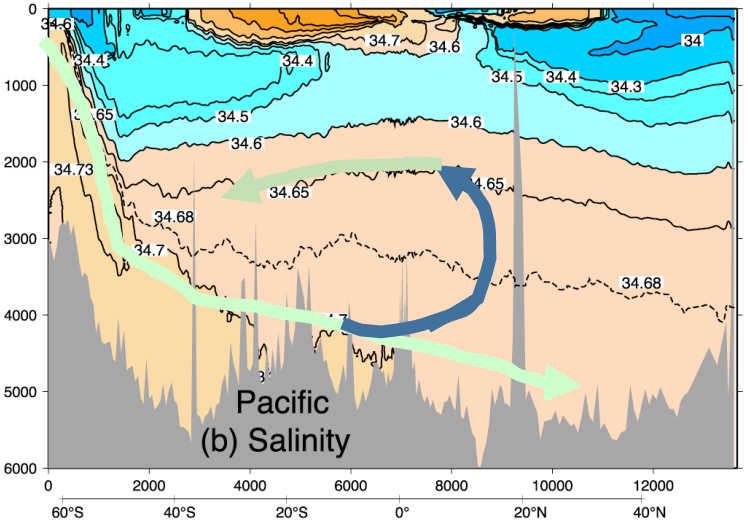


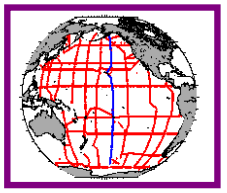


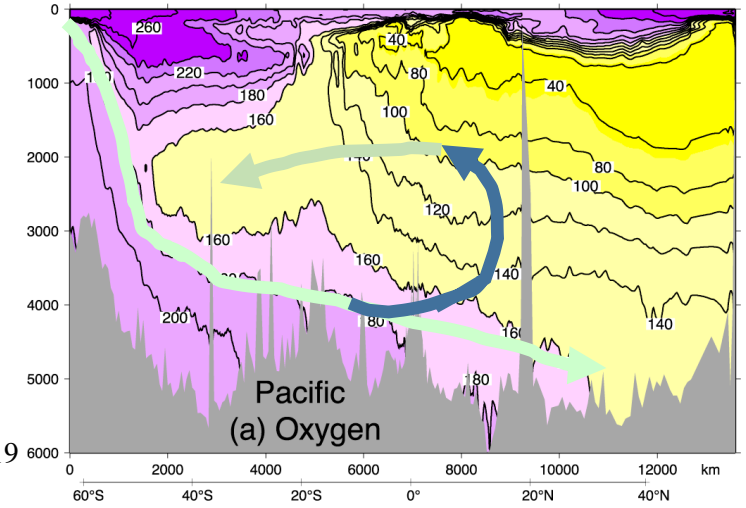
Flow and mixing is mostly along isopycnals (isentropes, isoneutral surfaces).

5. Concepts: (c) diapycnal processes









Flow and mixing is mostly along isopycnals (isentropes, isoneutral surfaces).

Diapycnal flow requires diapycnal mixing, which is very weak (but crucially important at largest scales, even though flow and mixing are dominantly along-isopycnal). This is the 'overturning' circulation.

This process forms Pacific Deep Water and Indian Deep Water, and contributes to NADW.

Summary for Distributions I

- Water mass, water type
- Structures
  - Mixed layer
  - Thermocline, halocline, pycnocline
  - Thermostad, halostad, pycnostad
  - Temperature minimum layer (dichothermal layer)
- Mechanisms/processes
  - Ventilation, subduction
  - Deep convection
  - Brine rejection
  - Isentropic/isoneutral flow and mixing
  - Diapycnal flow and mixing

Water masses introduced in this lecture

Central Water
Mode Water
Subtropical Underwater (or Salinity Maximum Water)

Antarctic Intermediate Water
Mediterranean Water
Red Sea Water
Labrador Sea Water
North Pacific Intermediate Water

North Atlantic Deep Water
Pacific Deep Water
Indian Deep Water

Antarctic Bottom Water