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- ▶ 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 3: *not* oceans (seas, shelves, lakes etc.)

Outline

- ▶ the not oceans + terminology
 - seas, shelves, and the rest of it
- ▶ some interesting facts and cases
 - Mediterranean + Labrador + Weddell Sea (**overturning circulation**)
 - Black sea (**anoxia**)
 - South China Sea (**ecology**)
 - **Eastern Boundary Current Systems (EBUS)**
 - dynamics more complicated (waves, tides, 3d turbulence...)

Key terms: seas, shelves, estuary, anoxia, ecology

Recap: oceans vs. not oceans

Seas, shelves, estuaries etc.

- ▶ smaller L , slightly smaller H (usually < 1200 m),
 H/L small-ish except near coasts (consequences for dynamics)

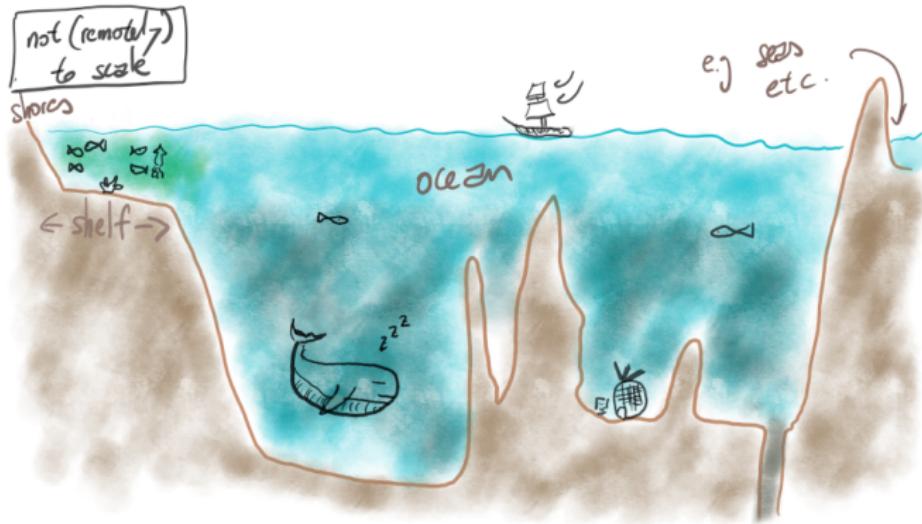
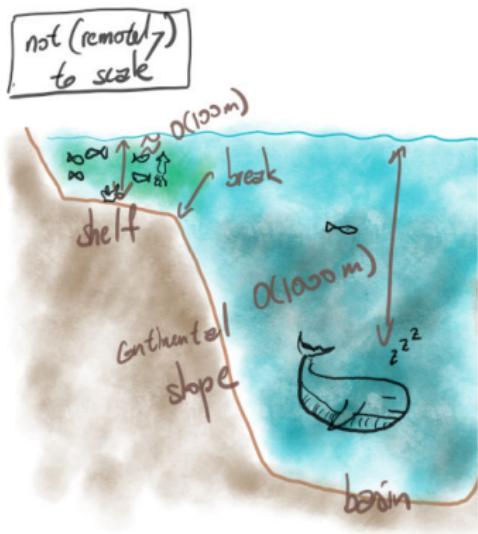


Figure: Figure based on Figure 2.2 of Pickard & Emery (1990), 5th edn.

Seas



Smaller bodies of **salty** water connected to another sea or ocean

- ▶ no hard-and-fast definition, sometimes used interchangeably with ocean in US English
 - hence why I refer to oceans and **not**-oceans
- ▶ generally shallower than oceans
 - e.g. South China Sea can get quite deep (see later)

Figure: Figure based on Figure 2.2 of Pickard & Emery (1990), 5th edn.

Seas

The following are not technically (?) not seas but **lakes**:

- ▶ **Sea of Galilee** (of the biblical fame)
→ freshwater, sometimes called **Lake Tiberias**
- ▶ **Dead Sea** (of the cosmetics fame?)
→ a *salt* lake
- ▶ **Caspian Sea** (of the caviar fame)
→ a salty lake, fed by the Volga river



Figure: (Top) Sea of Galilee in 2020 at higher water levels; image from Times of Israel. (bottom left) Lowest point on land near the Dead Sea; taken by either myself or Kevin Adebawale Data of USAID. (bottom right) Beluga sturgeon of the Caspian Sea; image from the Royal caviar club.

Shelf seas

- ▶ the sea region over the continental shelf
 - not very deep, $O(100\text{ m})$
- ▶ on the side of continental plate, separated by a shelf break
 - large slope gradients (steep)
- ▶ most of world's fisheries on shelves

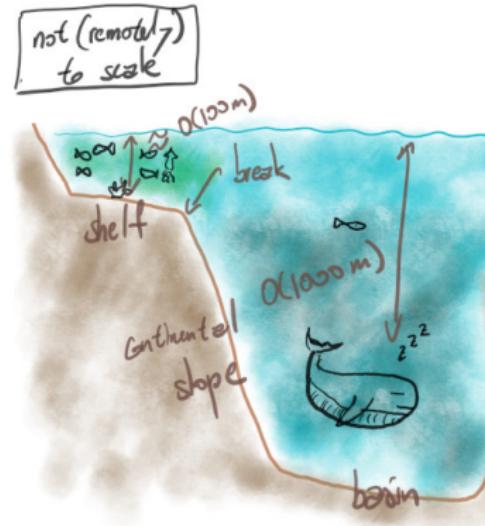


Figure: Figure based on Figure 2.2 of Pickard & Emery (1990), 5th edn.

Shelf seas

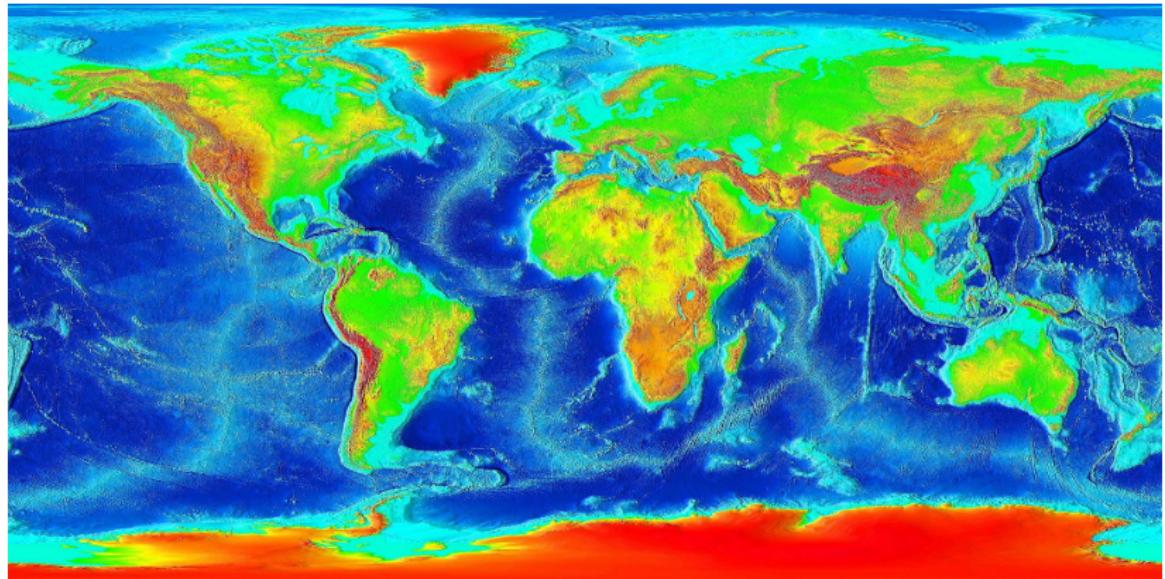


Figure: Locations of shelf seas denoted by the cyan colour. Taken from Wikipedia (https://en.wikipedia.org/wiki/Continental_shelf) made from NOAA data.

Shelf seas

shelf seas are relatively shallow, so

- ▶ drastic change in H/L , different dynamics (see assignments?)
 - tides, waves, Ekman upwelling, rivers etc.
 - nutrients

Shelf seas

shelf seas are relatively shallow, so

- ▶ drastic change in H/L , different dynamics (see assignments?)
 - tides, waves, Ekman upwelling, rivers etc.
 - nutrients
- ▶ sunlight can reach a reasonable portion of water column
 - light + nutrients = primary productivity
 - physics + biogeochemistry and ecology
 - $\approx 8\%$ of global area, 15 – 20% of primary productivity
- ▶ role in carbon cycle + economy? (see assignments?; see OCES 4001)

Marginal/semi-enclosed seas

Sea region that is somewhat shielded from the oceans by land features

- ▶ loose definition, degree of “shielding” variable
 - e.g. **North sea** is fairly connected
 - e.g. **Black sea** is not really connected to the ocean (it is to the **Med sea**)
(see later)
 - e.g. Arctic sometimes seen as a sea for the Atlantic

- ▶ some examples later

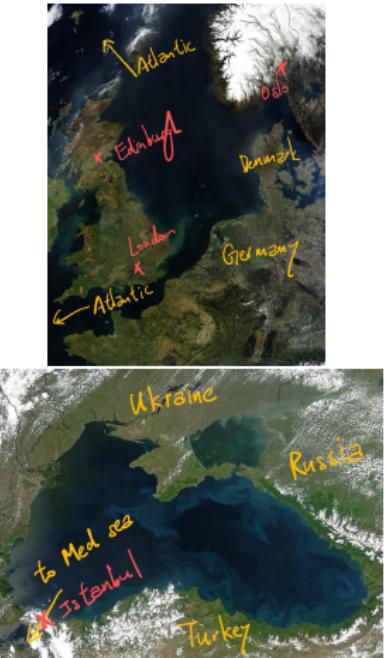


Figure: (top) the North Sea, connected to the Atlantic. (bot) The Black Sea, connected to some seas (including the Mediterranean sea) which is then to the Atlantic. Pictures from NASA.

Marginal/semi-enclosed seas

- ▶ seas and oceans sometimes connected through **straits** (or **channels**)
- ▶ straits normally have a **sill**
 - **sill depth** restricts water movements/exchanges (see later and Lec. 13 + 14)
 - flow over sills lead to **internal waves** (see Lec. 15, 16, 18)
- ▶ **Strait of Gibraltar** here, details/importance differ for others
 - e.g. **Strait of Malacca** + shipping, mean depth ≈ 25 m

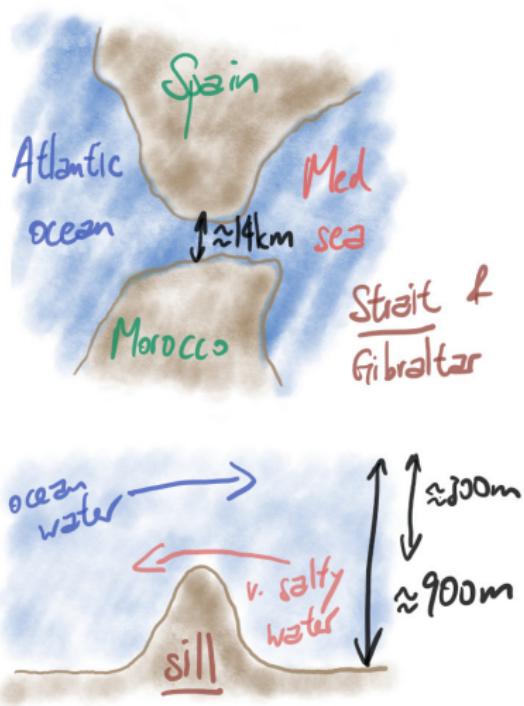


Figure: Strait and sill, using the Strait of Gibraltar as an example.

Estuaries

- ▶ estuaries are coastal regions of water
 - normally fed by rivers (freshwater) and affected by tidal flow from the sea (salty water)
- ▶ shallow and smaller
 - 3d dynamics, fresh/salty water mixing, waves, tides, and Coriolis effect not entirely negligible...
- ▶ classification + characteristics much later (see assignments?)



Figure: (left) Estuary in the Amazon; from Science Photo Library. (right) Pearl River Delta showing Humen bridge; from Wikipedia, user Tung Wu.

Other bodies of water

- ▶ **fjords** are inlets with steep sides carved by **glaciers**
 - from the Norse word *ferd* for “lake-like”
 - normally has salty water (some in the Great Lakes in N. America don't)
 - only really in higher latitudes (why?)
- ▶ some ambiguity with use of the word (like seas), regional variations

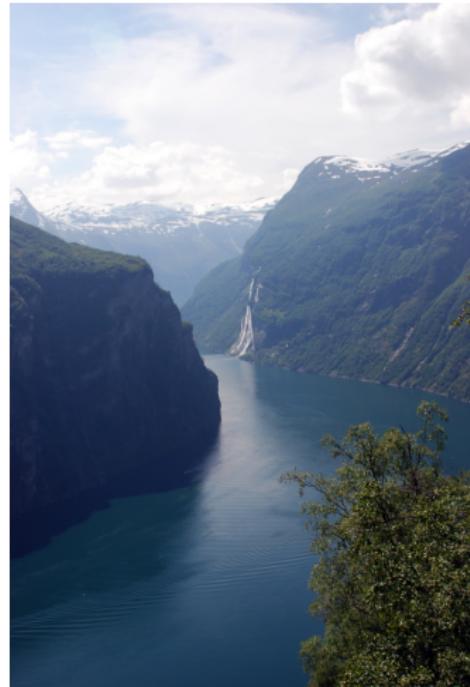


Figure: Geiranger fjord in Norway; notice the steep sides. Taken from Wikipedia.

Other bodies of water

- **lakes** lie on **land**
 - most (!) lakes are freshwater (notable exceptions in the Great Salt Lake, Dead Sea)



Figure: What lake am I? Pictures originally from Royal Caribbean website and TopPNG.

- e.g. lagoon, sounds, gulf, cove, ... (see more at Wikipedia)

Features of interest: Med Sea

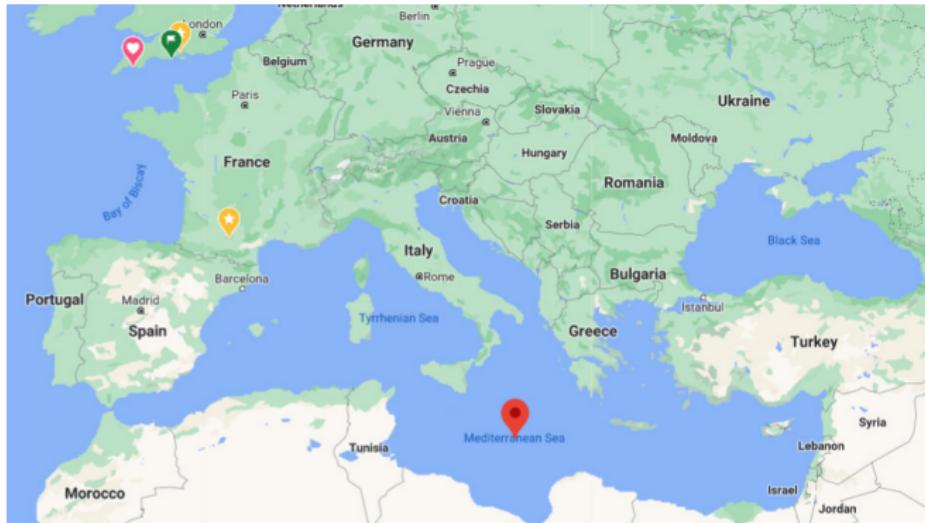


Figure: Geographical map of Mediterranean Sea and Black Sea. From Google maps.

- ▶ connected to Atlantic through the **Strait of Gibraltar** (see four slides ago)
- ▶ important for climate, food and trade for the surrounding countries (see e.g. OCES 4001)

Features of interest: Med Sea

(more in Lec. 5, 13 + 14)

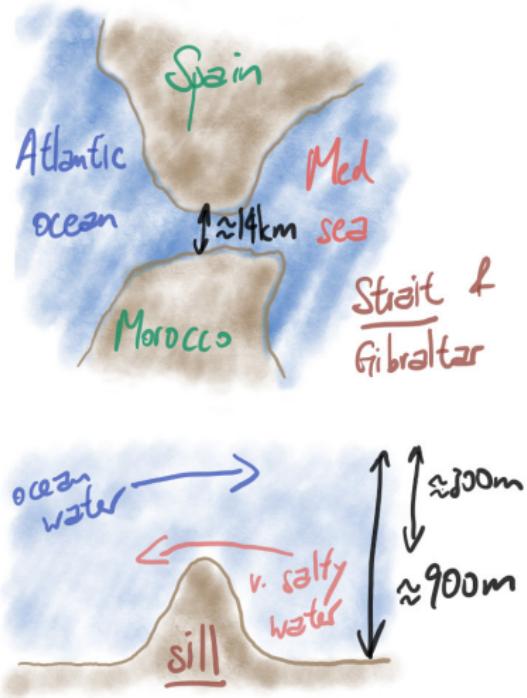


Figure: Strait and sill, using the Strait of Gibraltar as an example.

- ▶ cool surface water comes in from ocean and rivers, but region is warm so large evaporation
→ salty denser water
- ▶ occasional cold bursts from atmosphere from land
→ cold + saline = very dense! water sinks, fills bottom, flows out eventually
- ▶ sill holding some water back, more time for watermass transformation

Features of interest: Lab Sea (more in Lec. 5, 13 + 14)



Figure: Geographical map of the Labrador Sea. From Google maps.

- ▶ connected to North Atlantic
 - recall Atlantic surface currents seem to converge mass northwards, so where does it go? (see last Lec, and Lec 13 + 14)

Features of interest: Lab Sea

(more in Lec. 5, 13 + 14)

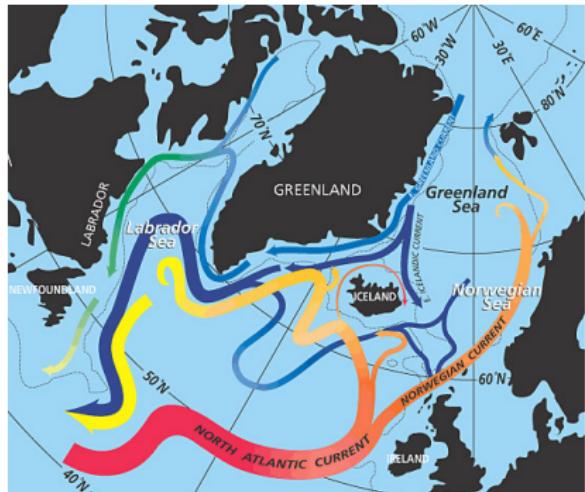


Figure: Schematic of North Atlantic Circulation. Taken from Wikipedia, image from Jack Cook at WHOI.

- ▶ return water gets very cold, dense, and sinks in the region
 - deep convection, cabelling etc. (see Lec. 5, 6, 17)
- ▶ mass returns southwards at depth, identifiable as the **NADW** (North Atlantic Deep Water)
 - more on watermass properties later (see Lec. 5 + 6)

- ▶ important part of the (A)MOC (see Lec. 13 + 14)

Features of interest: Weddell Sea

(more in Lec. 5, 13 + 14)

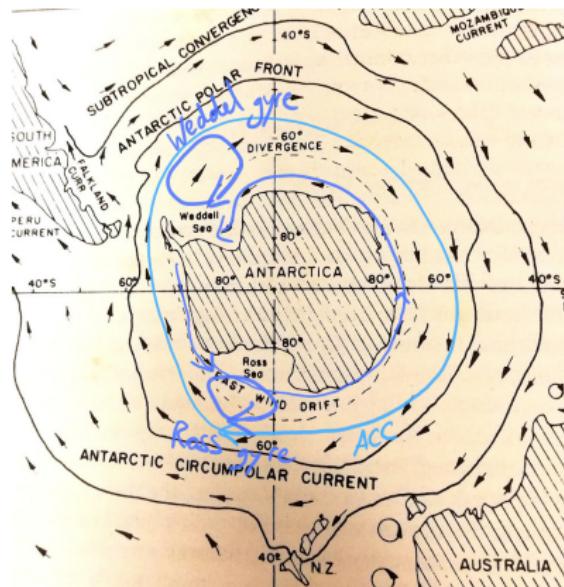


Figure: Features in the Southern Ocean. Modified Figure 7.45 from Pickard & Emery (1990), 5th edn. According to historian Thomas R. Henry, “*The Weddell Sea is, according to the testimony of all who have sailed through its berg-filled waters, the most treacherous and dismal region on earth. The Ross Sea is relatively peaceful, predictable, and safe.*” (from Wikipedia)

- ▶ East of Drake passage
(the bit between Antarctic and S. America)
 - just downstream of the **ACC**, fairly turbulent region (see quote in the figure caption)
- ▶ it's very cold here!
 - sills etc. allow very cold but fresh water to form
 - spills over as **overflows** forming **AABW** (Antarctic Bottom Water)

Features of interest: MOC (more in Lec. 5, 13 + 14)

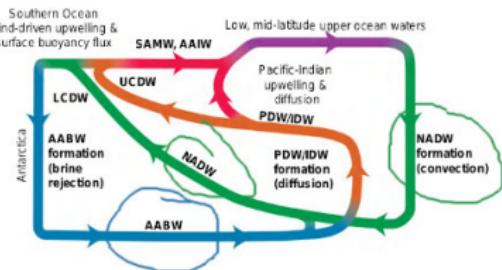
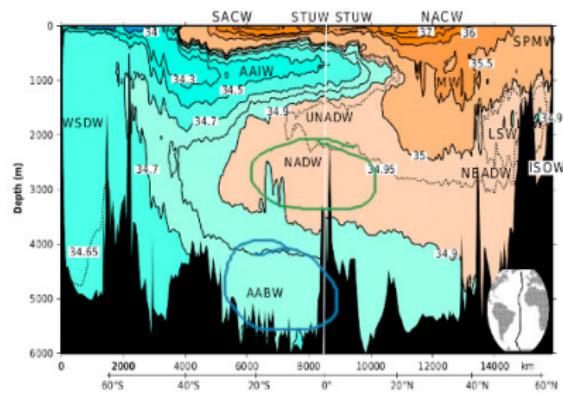


Figure: (left) Meridional sections using salinity as data, over WOCE section A16 and A23. (right) Schematic of branches of MOC. Figure 9.17a and 14.11c of Talley *et al.* (2011), 6th edn.

- more on watermass properties, MOC and related dynamics later in the course (Lec. 5, 6, 13, 14, 17 particularly)

Features of interest: Black Sea

- ▶ classic example for **anoxia** (no oxygen in water)
- ▶ fed by rivers (fresh) + exchange with Med sea water (salty)
 - **strongly stratified**
 - limited **mixing** (see Lec. 10, 15 - 18) + exchange of water

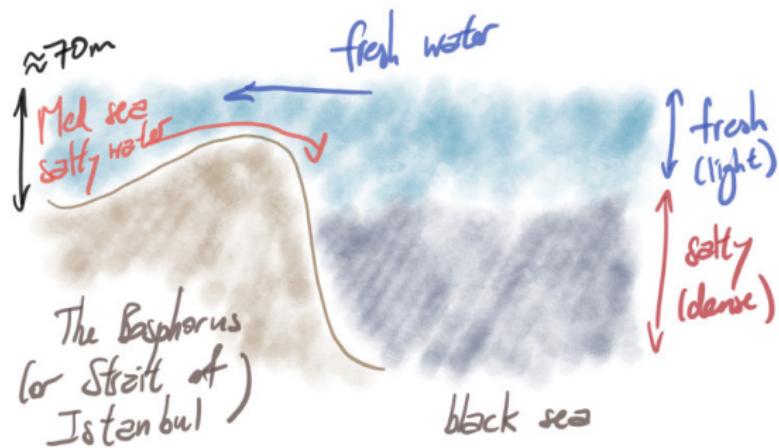


Figure: Black sea schematics water property schematic.

Features of interest: Black Sea

- ▶ life only in shallow region, oxygen doesn't reach the deep
→ sulfides producing organisms in deep (cf. rotten eggs)
- ▶ little decomposing of stuff (because no oxygen)
→ reason for black sea being "black"?

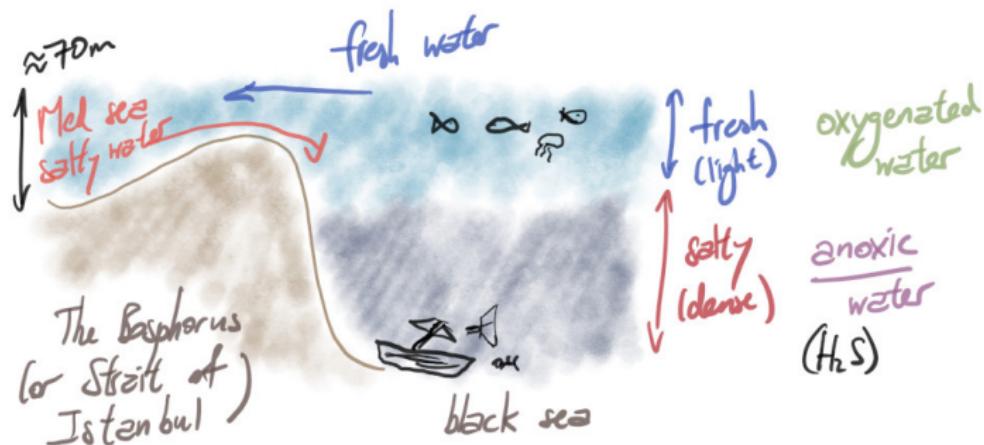


Figure: Black sea schematics water property schematic.

Features of interest: South China Sea

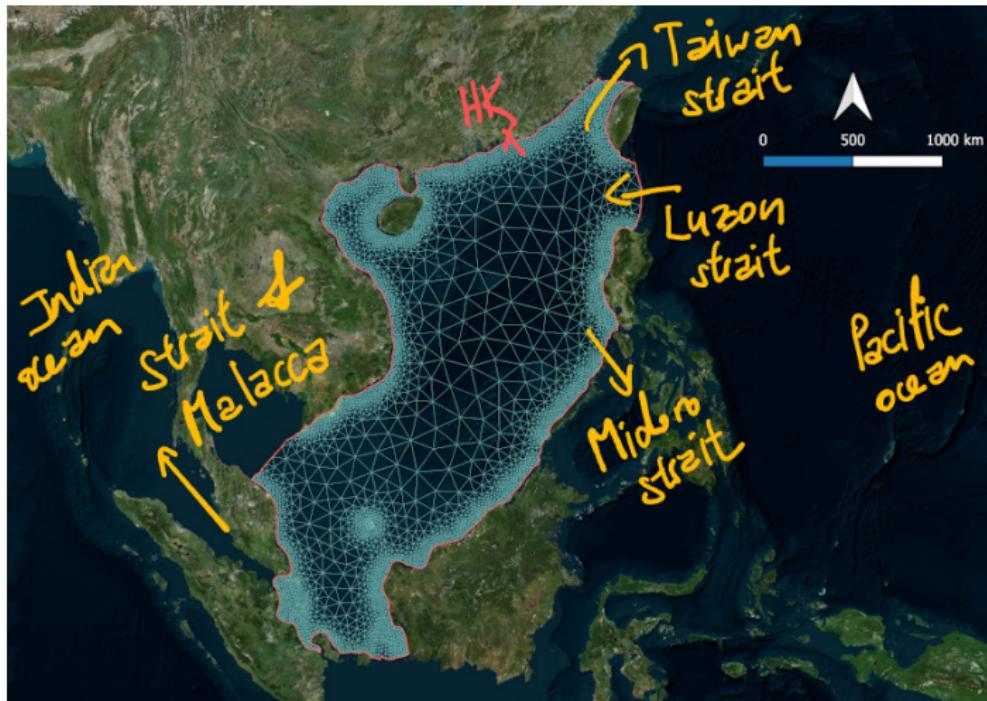


Figure: South China Sea and related straits. Finite element mesh for a recent HKRGC GRF submission, courtesy of Chinmayee Mallick.

Features of interest: South China Sea

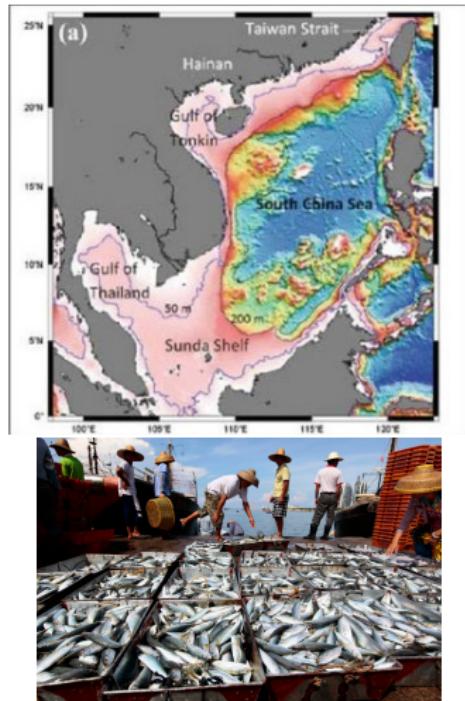


Figure: (top) SCS bathymetry, with shallow regions (< 200 m) in pink. From Liu and Dittert (2010). (bot) Fisherman taking stock of their haul in the South China Sea. Image from Reuters.

- ▶ SCS has shelf and deep regions
 - deep regions can go down to 4000 m like oceans
- ▶ important for shipping and fisheries
 - fisheries tend to be on shelf, coincide with nutrient rich water
 - monsoon + Ekman upwelling (see Lec. 9)
 - river forcing (see Lec. 5, assignments?)

Features of interest: South China Sea

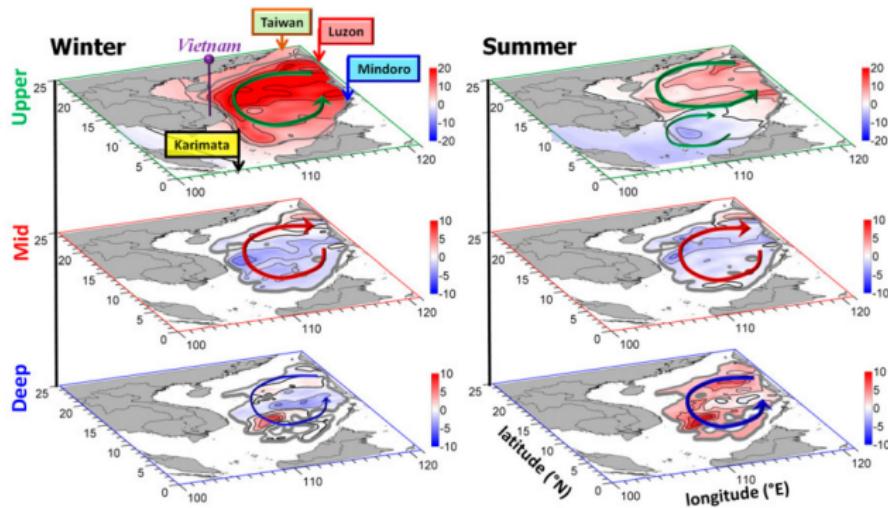


Figure: Schematic of cyclonic-anticyclonic-cyclonic circulation in the SCS, with numerical simulation data. From Gan *et al.* (2016), *J. Phys. Oceanogr.*.

► what drives the **sandwich circulation?**

→ wind (see Lec. 9), eddies (baroclinic instability? see Lec. 17), upwelling (see Lec. 13, 16, 17), in/outflow in Luzon, others.? (ongoing research question)

Summary

- ▶ touched on features occurring in seas that we want to explain
 - straits + sills, and their influence
 - touched on watermass properties (T , S , oxygen)
 - influence and role in MOC (Med, Lab, Weddell sea)
 - shelf seas and the role in human activity (SCS)
- ▶ more on related dynamics in *not* ocean regions later because it is “harder” (or, really, “less clean”) (see assignments?)
 - H/L not that small and L smaller makes a lot of difference...

Outlooks

- ▶ have now highlighted some seemingly disparate features of interest, subsequent lectures to link them through **dynamics**

- 1. forces: thermodynamic (Lec. 5 + 6) and mechanical (Lec. 7 - 10)
- 2. large things: gyres + WBCs (Lec. 11 + 12), MOC (Lec. 13 + 14)
 - “easy”(!?)/cleaner because **geostrophic** constraint
 - focus on large scales \rightleftharpoons small scales
- 3. smaller things: waves, instabilities, tides (Lec. 15 - 18)
- 4. observations of large and small (Lec. 19 - 20)
- ✗ dynamics in *not* oceans
 - hard/messy because **geostrophic** constraint weaker

Mostly by drawing pictures!