Lecture 1

> why study the ocean ?
>
> - covers 75% pf earth's surface, which contains 97% water.
> - Many important roles for the climate and life on earth.
> - Ocean absorbs heat inversely proportional to the latitude.
> - Produces 70% of oxygen from the atmosphere.
> - Important part of the water cycle.
>
> 1. Important for agriculture and climate of course

Important source of food, important shipping route, so also a large impact on the economy.

The ocean absorbs the surplus carbon (25%) for human activities. And (90%) of heat.

The ocean is severely impacted by human activities

1. Consequence for ecosystems (*very sever*)
2. Consequences for food supply and economy
3. $\longrightarrow$ sea level rise due to the additional heat in the ocean which increases its volume.

[Definition] (Oceanography) :

Study of the physical . chemical and biological aspects of the ocean. Numerous disciplines involved.

There are multiple ways to study the ocean:

- In situ (*on site*)
- Theory
- Remote (*Satellites and whatnot*)
- Modeling (Numerical analysis)

Course Outline

1. Part 1 : The physical setting
    - Why does the ocean absorbs heat,
    - typography
    - Seawater properties
2. Part 2 : Ocean Circulation
    - Atmospheric circulation
    - Wind-drive circulation (**)
    - Thermohaline circulation (*slower circulation (worldwide)*)
    - Waves and tides
    - Coasts (*how the ocean interacts with the coast*)
3. Part 3 Life in The Ocean
    - Biogeochemistry (*life to happen in the ocean* $\longrightarrow$ very important for climate)
    - Photosynthesis ?
4. Part 4 Human's impacts on the ocean
    - Pollution

- Natural resources and exploitation
- Climate changes

Reviewing the Syllabus

- Office hours posted on the syllabus for TAs and *in person* with the lecturer.

Learning Outcomes :

$\longrightarrow$ Waken curiosity about the ocean and oceanography. Read and understand scientific paper. Expand climate change critical thinking.

> No textbook required ! But there is one available at the library.
>
> - No online access to it. Only handbook
> - There are online resources that will be posted on MyCourses though.

> Questions and problem sets are done online (*1 week to complete them*).

Grading

- Questions and problems sets : 4x 20%
- Paper summary: 1x 10%
- Data analysis: 10%
- Midterm : 20%
- Final (*on all material*) 40%

Lecture 2

Part I (Physical setting)

- Ocean topography
- Seawater properties
- Sea Ice
- Ocean basins and properties

Today we do ocean topography (~ 4 classes)

Outline of the lecture

1. Dimensions of the ocean
2. Earth structure and plate tectonics
3. The main features of ocean floor
4. **Bonus** Sediments can tell us about the past ocean circulatiosn (*Not in the exam*).

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1. Dimension of the ocean

- Earth and coordinates system
- Typical dimensions of the ocean basis (* why the ocean looks the way it looks ? *)

> Maps influence or way or representation denepnding on the projection of the map (*both are widley usede projections*)
>
> - Maps is made in **2D** such that we can see the whole ocean at once.

> - exists many maps projections
>
> 1. **Mercator Projections** (**SQUARE**) $\rightarrow$ widely used for navigation but size are distorted
> 2. **Molleweide Projection** $\rightarrow$ angles are not rpeserved but area is preserved.
> - **Lambert Azimuthal Equal Area Projection** $\rightarrow$ not used as often

A. Earth and Coordinates system

> The earth rotates around the sun
>
> - THe earth's rotation axis is tilted towards the sun *(summer*) outwards *(winter)*.
> - You don't get the samea amout of heat depending on
>
> 1. place on earth
> 2. time during year
> - Earth's radius is 6378 km.
>
> 1. earth's ocean depth is $\sim 3-4$ km , which is a small relative percentage !

Since the earth is roughly a sphere we use spherical coordinates.

- **Latitude** :
- **Parallels** : Imaginary lines around the earth that are parallel to the equator

Low latitudes : -30 to ---- mid latitudes : 30 to 60 ---- high latitudes : 60 to 90 (**symmetrical with southern hemisphere**)

- **Longitude** : the anagle betweent he standard merdian and any other merdian
- **Merdians**: intersection at earths surface o f a place perpendicular to the equatorial plane and passing through earth's axis

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Oceans dimensions range from around 1500 km to 13000 km. (*Maximum width is in the Atlantic*) and (*Maximum width is on pacitif*).

> horizontals dimensions are 1000 times greater than vertical dimensions? (scale of paper with width of paper lol)

B. Earths structure and plate tectonics

Structure

Earth's interior is layered (** Inner core $\rightarrow$ Outer core $\rightarrow$ Mantle $\rightarrow$ crust **)

$$\rho = \frac{m}{V}$$

Things get sorted out according to the density , the sites have different densities , which is why layering exists.

- Lower mantle is hot
- Upper mantle :
  1. astenosphere (deformable, cpable of flow)
  2. Lithosphere (rigid cold)
- Oceaninc crust and another crust (2 compoennts for crust)

Continential Drift

The shapes of the continents revealed continental drift. Not only shapes but also similarity in species and rocks(mountains) , etc.

- 16th century first theory
- 20th cemented theory

Seafloor spreading (beyond the continential drift theory)

- oceaninc crust is much younger than continential crust (*radioactive decay experimemt)*
- earthquakes and volcanoes are concentrated in zones that extend in lines.
- sediments are thickest at the edge of the atlantic than int he middle (sediments are dead animals forming sediments at the bottom of the ocean)
- There are ridges in the middle of the ocean which are in shapes of the costlines !

> all these observations lead scientists to developping the *Seafloor spreading theory*
>
> - the new seafloor develops at mid ocean ridges
> - the material spreads outwards in the form of magma (things accumulate then spread outwards ?)
> - $\vdots$
>
> Basically in the sea there are accumulate of sort of pyramids and since its earth under magma from the core appears and spreads all around a?

The concept of plate tectonics

Earths outer layer consistes of dozen of major lithospheric plates

> tectonic plates move ath rate of ~ 0.6 cm per year. (*like grow of nails lol*)

> mountains are formed by tectonic plates colliding (**with ocean shrinking in between them**)

plate tectonics movement types

- Divergent plate boundaries (mid-atlantic- idge) -> moves appart
- Convergent plate boundaries (*move towards eachother *)
- Traansverse slide next to each other

problem : Over the course of 2 million years, a sea mount on a tectonic palte in the pacific ocean has moved 100 km away from a spreding zone (mid ovean ridge)

1. what is the average speed in units of cm/yt of the plate movement ?

$$\text{Given } T = 2\times10^6 \text{ yr} \qquad \text{and} \quad D = 10^2 \text{ km}$$
$$\implies V = \frac{D}{T} = \frac{10^2}{2\times10^6} = \frac{10^7}{10^6} = 5 \text{ cm/yr}$$

   In assignment always give the full solution for partial points

2. from the above information and considering that the pacific ocean is around 12000 km wide, what is the upper bound on the age of the odlest sea floor in this basin in million year ?

$$L = 12000 \text{ km} = 12\times10^4 \text{ km} = 12\times10^9 \text{ cm}$$
$$H = \frac{AB}{B} = \frac{L/2}{V} = \frac{12\times10^9}{2\times5} = 12\times10^8 \text{ yr}$$
$$= (\text{conversion})120 \text{ million years}$$

C. The main features of ocean floor

Divergence zone

Lecture 3

> Note there are reading chapters provided on the slides.

Programs in the department

-> Research opportunities

- Atmosphere
- Ocean
- ice (*Sea ice specifically*)
- Together they form **Weather & Climate**

> MATLAB and Python are mostly used for coding in this department

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Summary of what we did

- Different map projections
- Earth and coordinate system (*latitude and longitude systme*)
- Dimensions of the ocean (*musch wider than tall*)
- Structure of the earth's interior to explain ocean basis form and what now
- Reviewed the theory of continential drift
- **Seaflor spreading** theory. (*forms in the middle of the ocean under sea floor ridges*)
- The concept of tectonics; dozen of plates that interact under 3 processes (collide, slide , outward).
- We ended on the consequence of the interaction between the plates
    1. for divergence zone : the formation of an ocean basis drifts away because of the middle nwe material and eventually a new ocean basing is formed and the ocean keeps expanding.

C. Convergence zones

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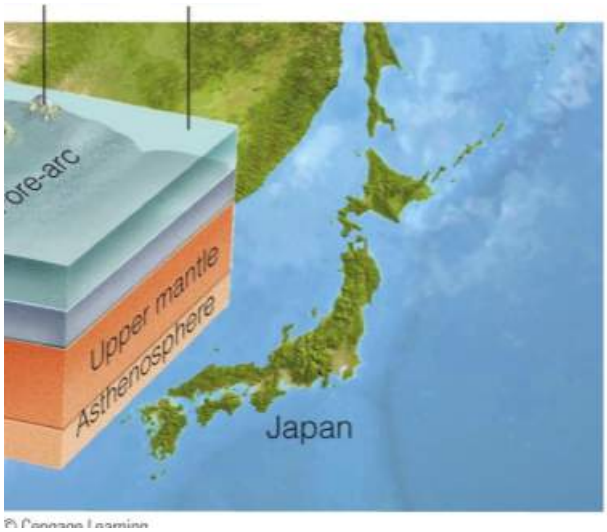
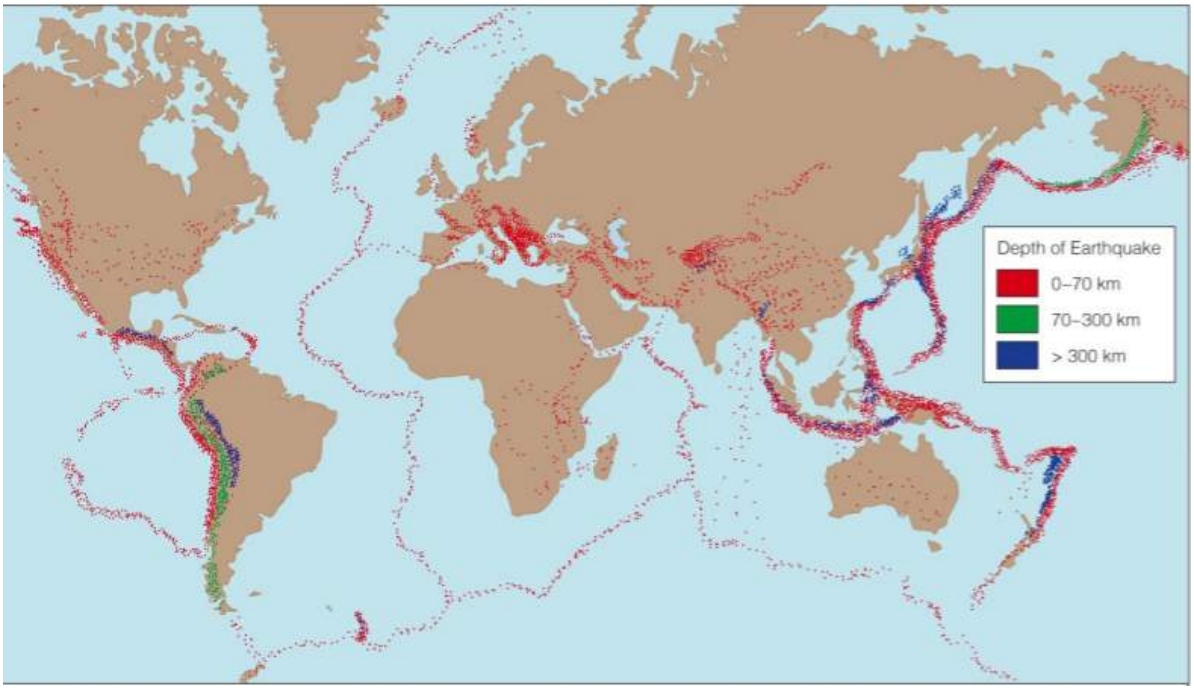
ocean-ocean convergence form deep trenches and islands arcs in subduction zones (* crust goes between another crust *)



Note the crust line at the right of the map

> [Note] Earthquakes are mostly around the zones of the
>
> - ridges
> - Pacific rim ?
> - Around convergences ? (europe big spot)
> - Subduction at the right of Japan
> - sliding plates to the left of american continent upwards



On the depths of the earthquakes (from the map) →

Overview of the ocean floor

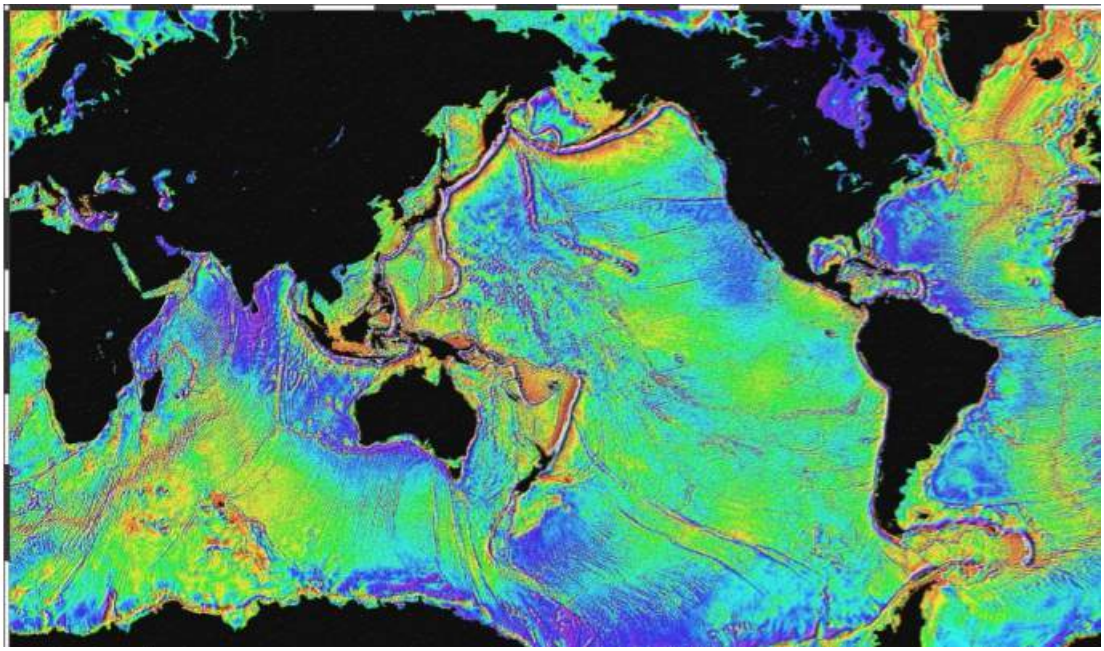
We didivde in 2 main provinces

- continental margin : submerged outer edge of a continent

  Consists of *continental shelf, slope and rise*
- Ocean basis deep sea floor beyond the confinental margin

  Consists of *abyssal plains, ridges, trenches, isnald arcs, etc*

  > note isnlands arcs are littel volcanic isles rising from volcanic activity underneath



We can see the ocean circulation in this map, reconstructed through satellite measurements

> [Notes] ridges are the spot in the ocean over the volcanic zone

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2. Seawater Properties

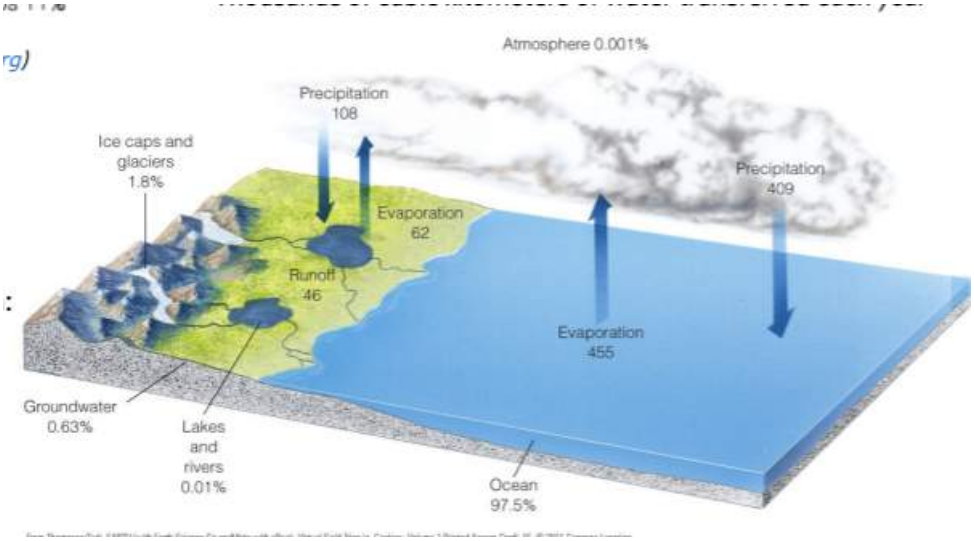
- A. the water molecule
  - structure
  - properties of the molecule
- The physical and chemical properties of seawater
  - Heat temeprature, heat , themal inertia
  - Solubility salinity and gases
  - density
- Differnt phyiscal states of water
  - 3 physical states
  - ice formation
  - vapor formation
- The propagatiom of light adn sound in water
  - propagation of light
  - propagation of sounds

Water on Earth

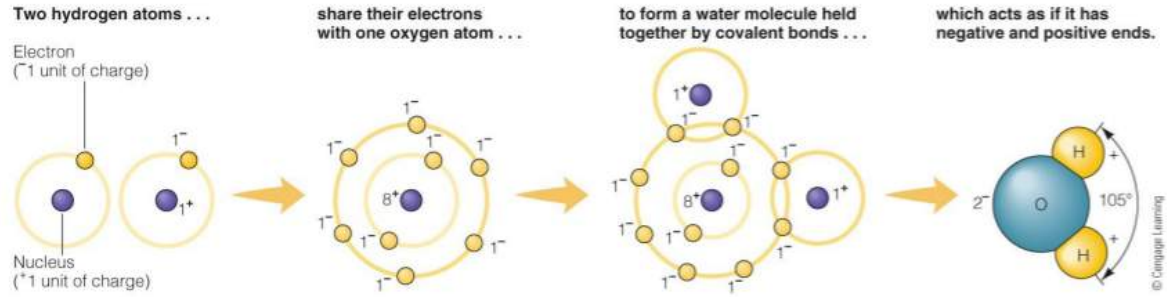
> - 97% of free water is in the ocean
> - 2% in the ice caps (drinkable water) [greenland and antartica]
> - $< 1\%$ rovers, lakes ,wetlands ,groundwater

Hydrological cycle :

- water cycles continuously (review online)



A. Water Molecule (*structure*)



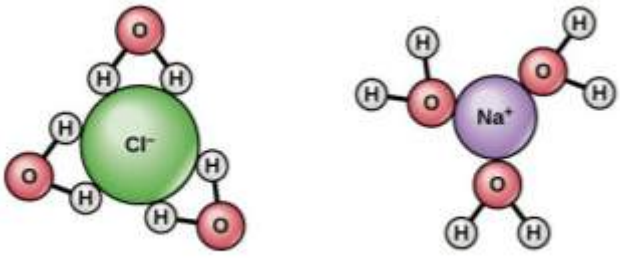
> water has a polarity due to it's configuration. Negative siede (oxygen) and positive side (hydrogen atoms)

Main properties of the water molecule

1. Cohesion (Attachement by hydrogen bonds)

   Gives water high surface tension. They <u>stick to one another</u> → insects walking on the water !

2. Dissolution (⋆) : can separate components from a compound (salt, acts like a magnet)



3. Adhesion: attachement of water molecules to other substances by hydrogen bonds

   Tendency of water to stick (*drops of water on skin*)

4. Capillary action (tendency to spred through textile ?)

B . The physical and chemical properties of water

Heat and temperature are related but different

- **Heat :** Energy produced by atoms vibration (measured in joules)
- **Temperature** : the response of an object due to input or removal of heat energy (measured in degree celsisu)

> note input of heat $\not\Longleftrightarrow$ necessarely a change in temperature

Heat capacity (C_v)

- measure of heat requiired to raise the temperature of 1 g of a substance by 1° C
- Different substances have different heat capacities C_v

> water has a very large heat capacity 1 calorie/gram/$^\circ$C

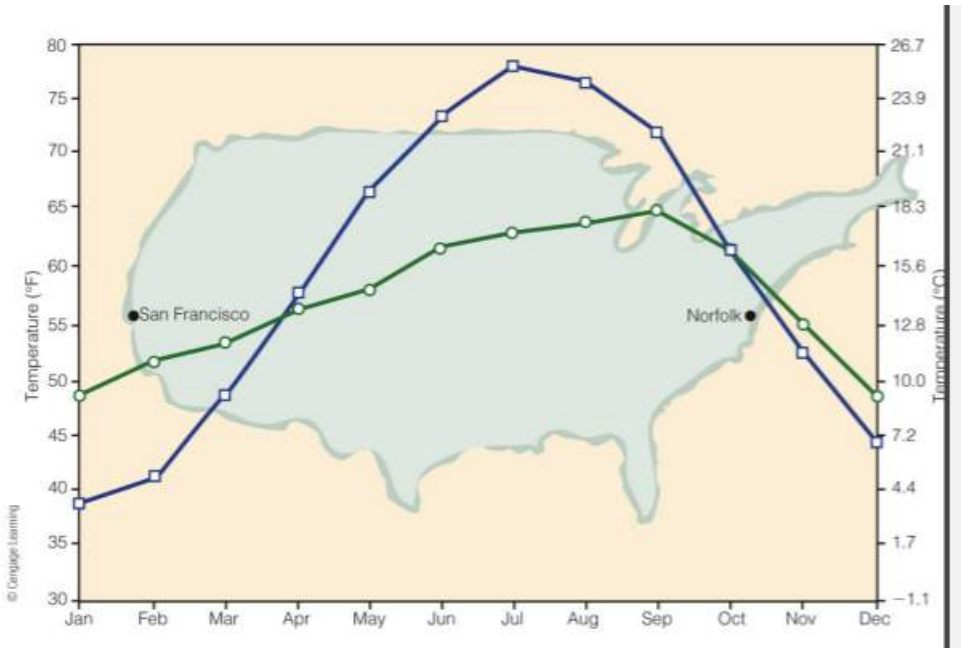
Thus, water can absorb/releas large amounts of heat while changing little in temperature

Thermal Inertia

[Definition] tendency of a substancce to resist change in temperature with the gain or loss of heat energy

- the ocean cools slower than land because thermal inertia is larger

  Takes lots of heat but temp doesn't change much because of C_v and thermal inertia



Guess which curve corresponds to Norfolk and which to San Francisco. Why? (West $\rightarrow$ East). Since san ffranc is next to the pacific ocean and wind blows to interior of continet then we have swings of temperature Review

Solubility, salinity, gases and pH

Water is a poweful solvent

- Solvent a substance capable of dissolving other polar molecules and ionic compounds

[Definition] (Salinity) : A measure of the dissolved solids in seawater expressed usually in g/kg or parts per thousand in percentage by weight.

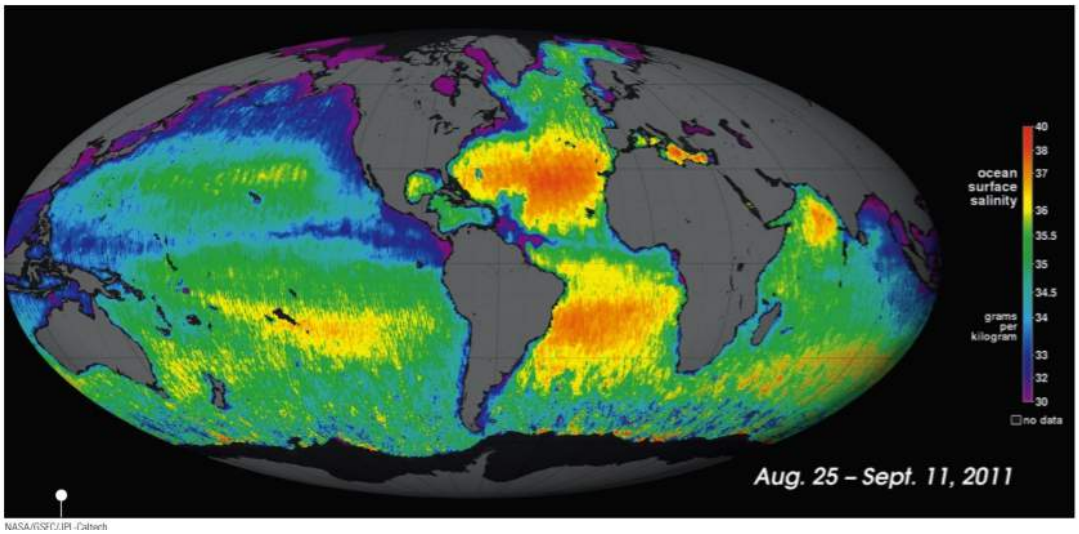
For instance, seawater of salinity of 35%. (percent with two 0 s lol) means that

- 3.5% of that seawater consists of dissolved substances
- boiling away 100 kg of that seawater would produce a residu weighting 3.5 kg.

salinity varies across the ocean

- the oceans salinity caries from about $33\%_0$ to $37\%_0$
- evaporation , precipitation , and freshwater runoff from the continents influence salinity

Why is the Mediterranean Sea so salty?
Why is the Arctic so fresh?
How about the North East corner of South America?



Pay attention ot the scale, pretty narrow range in absolute value.

> Salinity is impacted by evaporation, fresh water in water = dissolution so decrease in salinity. Meltig of glaciers also decrease salinity through dissolution
>
> - why is the mediteranian sea so concentracted ? A lot of evaporation , because narowness for instance.
> - why is the artic so fresh ? Artic is fresh on the average because rivers are their input, melting glaciers (*NOT THE MAJOR CONTRIBUTION THOUGH !*)
> - North east coast of south america ? closer to amazon river

Lecture 4

> for the assignment
>
> - Maintain objectivity (climate change is good or bad NO)
> - No quoting citations

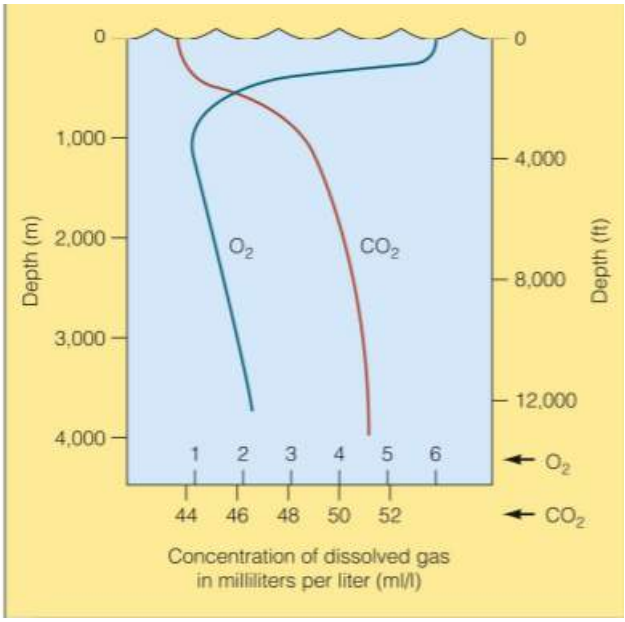
Recap

- One important thing about the water molecule it's its polarity. (also dissolution, salinity).
- Difference between heat and temperature.
- Ocean has a very large heat capacity and thermal inertia.
- Water is a very powerful solvant, dissolution of table salt in the water for instance
- Presented definition of salinity. Boiling seawater, residue is salt.
- The ocean salinity varies from 33 ppercent to 37 ppercent due to evaporation ,precipitation ,etc ?

B. The Physical and chemical properties of seawater

THe main gases that we find in the ocean are

- Nitrogen (important for organisms)
- Oxygen (very important for organisms as well $\rightarrow$ photosynthesis)
- Carbon (dissolved in the ocean and use by plants for syntehsis)



Carbon dioxide is low at the surface and oxigen is almost *mirrored*

pH is an important property of seawater and has impact on marine life

> pH scale goes from $0 \rightarrow 14$

- **Acid** : substance that releases hydrongen ions (H^+)
- **Base** : substance that combines with a hydrogen ion in solution

> ocen acidification (*more on that later*).
>
> > seawater is slightly alkaline; it's average is pH is about 7.8.

What has been measured since it's a change of 0.1 in the pH scale of the ocean

> changing pH scale by little it corresponds to large scale in the concentatration of hydrogen and ions --> big consequence for the ecosystem

---

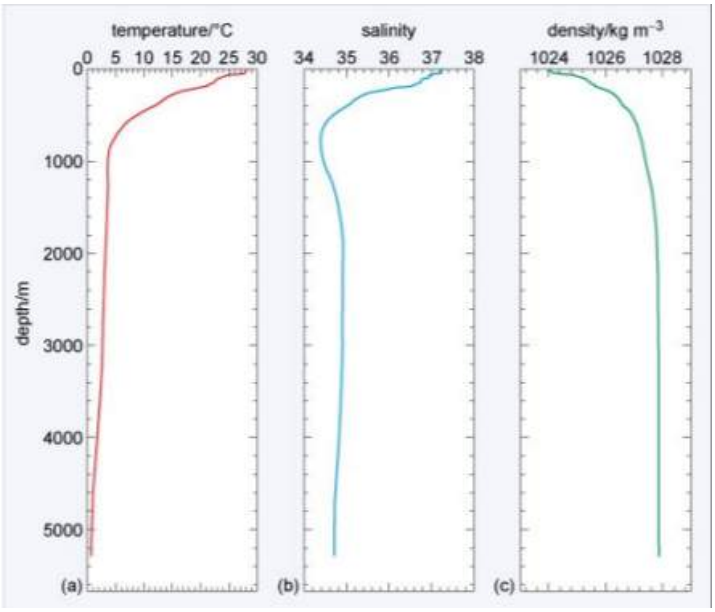
Density and associated drivers

> knowint the deinsity of seawater is key to understand ocean circulation
>
> - Density is mass per unit volume of a substance $\mathrm{kg/m^3}$.
> - Seawater has a greater density than pure water because of the solids dissolved in it (salts)
> - Density depends on salinity, tempertaure and pressure

$$\rho = \frac{m}{V} = F(T,S,P)$$

$$\text{light} \xrightarrow{\rho} \text{dense}$$
$$\text{warm} \xleftarrow{T} \text{cold}$$
$$\text{fresh} \xrightarrow{S} \text{saline}$$
$$\text{shallow surface} \xrightarrow{P} \text{dep}$$

1 meter cube box fyll of books, and 1 meter box full of air (*intuitive difference*)

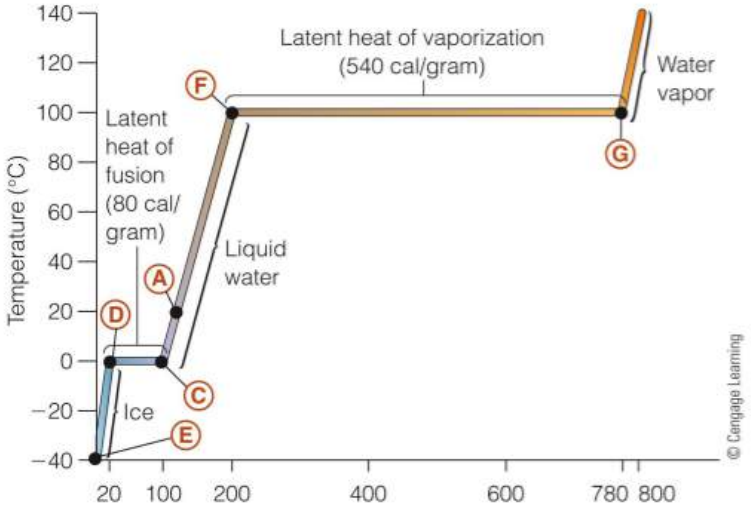


> ↑ understand these graphs quantitaitvely ?

C. The different physical states of water

The 3 physical states of water on Earth

Ice formation



- <u>Sensible heat:</u> heat exchanged accompanied by a change in temperature
→ detectable by a thermometer
- <u>Latent heat:</u> heat exchanged without a change in temperature
→ change in state
- <u>Latent heat of fusion:</u> Heat removed from a liquid during freezing (or added to a solid during thawing) that produces a change in state but not a change in temperature

> Going to the right of the wate rwe add heat to the system and to the left we remove heat .
>
> - Starting at A , we remove heat and go to point C (removal of heat $implies$ removal of T *this is called Sensible heat*)
> - If we keep removing ehat from the system $C \to D$, the curve is flat so no change in T. We reach 0°C so , since it's pure water ice starts forming . Crystals of ice form, The molecules of water rearrange to form crystals

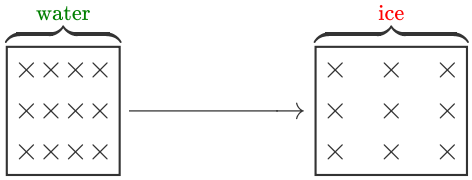
> the removal of heat is used to change state not temperature *this is called Latent Heat*

- If we keep removing , we go from $D \rightarrow E$, ice gets colder and colde.

- From $A \rightarrow F$ we increase the energy (*Sensible heat*).
- At F, we're at 100% $^{\circ}$C so water starts boiling
- If we keep adding energy we go from $F \rightarrow G$, curve is flat because we stay at same energy, energy is used to change the water from liquid $\rightarrow$ gaseous. (*laten heat*).
- Indeed at G it's all being converted to water vapor

> note that we need to put more energy to change liquid into gas than liquid into ice, because we need to break the hydrogen bonds

[Fact] Ice is less dense that water.



> Q: what fraction of the ocean is covered by sea ice at all time ?
>
> > A: 15%

- Ice absorbs incoming energy form Sun during summer/day

> Lots of heat exchanges, without much change of temperature $\rightarrow$ change of phases

---

Vapor formation

> Q: How much water evaporate each year from the surface ocean ?
>
> > A: 1 m
> >
> > Some of it goes back in, other goes on the land for us, etc

- about 50% of the solar energy entering ocean results in evaporation

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Propagation of light and sound in the water

[Definiton] (*Light*) form of electronmagnetic radiation that travels as waves through space, air, and water.

- **Reflection** the change in direction of light at interface between two differentint media so light returns in the medium it originated from
- **Scattering** - The dispersion of light
- **Absorbption** - Conversion of light energy to heat

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\
 \                              \ | /
----------  Reflection     -> --   --  <-- Scattering inside
   \/                           / | \

  \
   \
----------  absorbtion
     \
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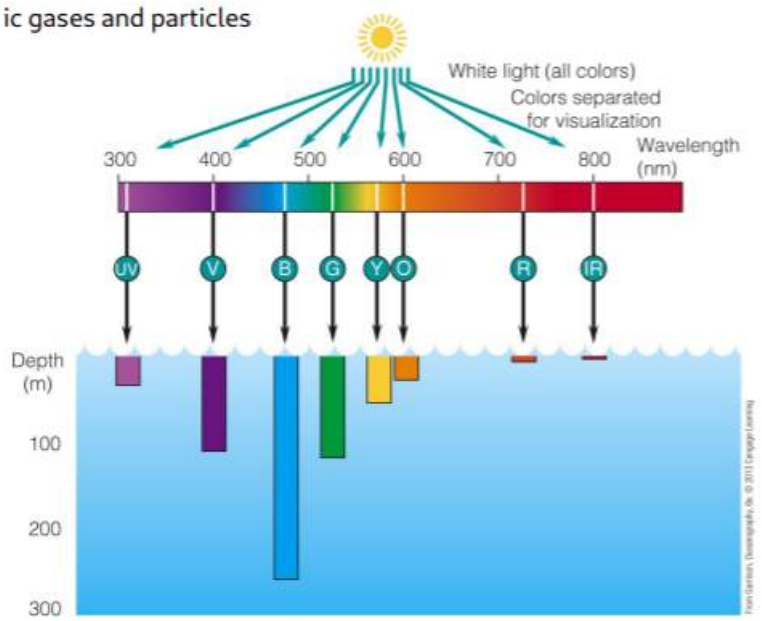
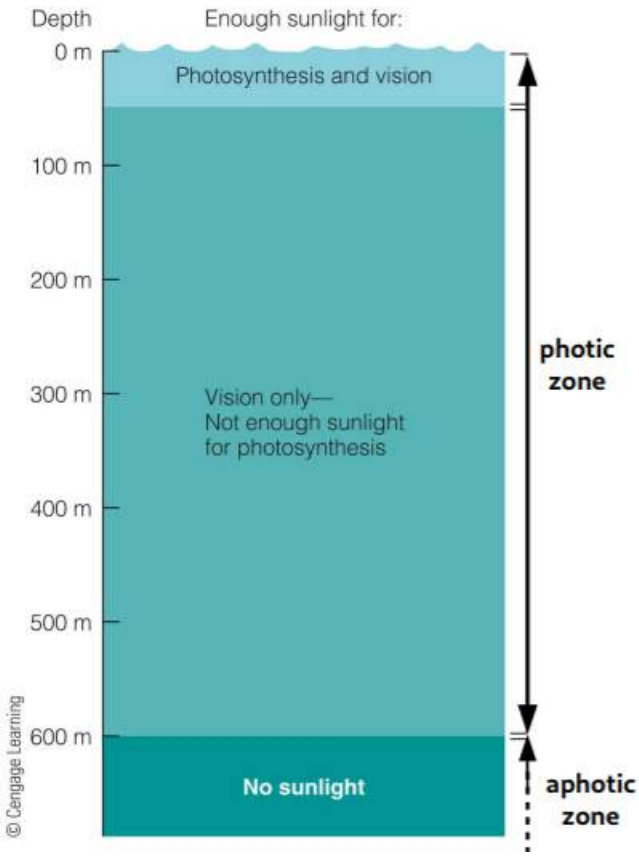


> - The red is absorbed very quickly, at the top of the water (*converted into energy*)
> - violet blue and green , especially the blue, reaches the deepest in the water
>
> > why do we percieve the ocean as blue?
> >
> > → the light inside the ocean is diffracted out onto our eyes and appears as blue
>
> > How would a red object appear at a few meter above the surface ?
> >
> > → as it goes deeper it loses its color ! divers can see that , or a red fish for instance
> >
> > → we can see the fish if we insert a source of light or *flash*

We classify the zones as

- Photic zone : thin film of lighted water at the top of the ocean
- Aphotic zone : dark ocean below the depths which light can penetrate

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</ul>
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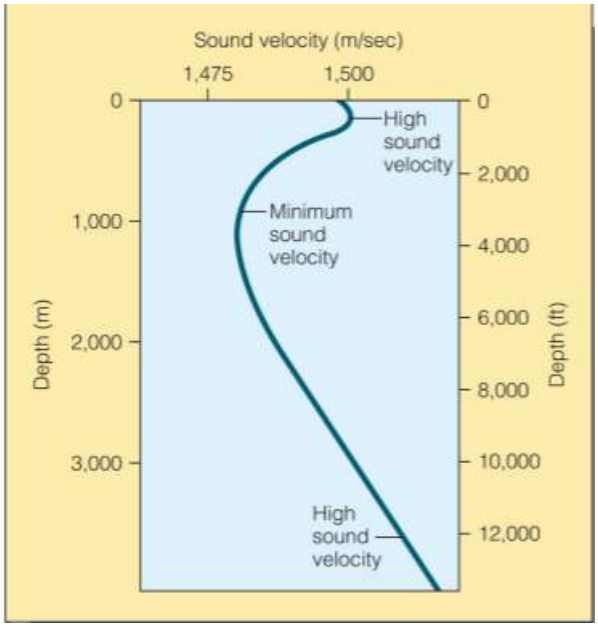
Propagation of Sound

[Definition] (*Sound*) form of energy transmitted by rapid pressure changes in an elastic medium

> in contrast to light sound travels very efficiently in water
>
> > average speed of sound in water is 1500 m/s !!! wtf
> >
> > $\longrightarrow$ omg this is why marine animals use sounds to communicate and share information wow
> >
> > $\longrightarrow$ this is because speed of sound increases with temperature and rpessure

$$\begin{array}{|l} \text{slow} \xrightarrow{S} \text{fast} \\ \text{cold} \xrightarrow{T} \text{warm} \\ \text{surf} \xrightarrow{D} \text{depth} \end{array}$$



> water is warm at the surface so weird wobble at the beggining,

Lecture 5

> quiz 1
>
> Unlimited time, unlimited grading attempts ; make to backup the answers.
>
> - review of basic skills , significant figures, scientifc notations ,units conversion , we saw that during first lecture ?
> - latitude longitude coordinates
> - on course materisal : Long answee questions , encourage to go back to the material; summary to explain something , schematic to draw

Today we finish Seawater proprety, and start the Ice slides.

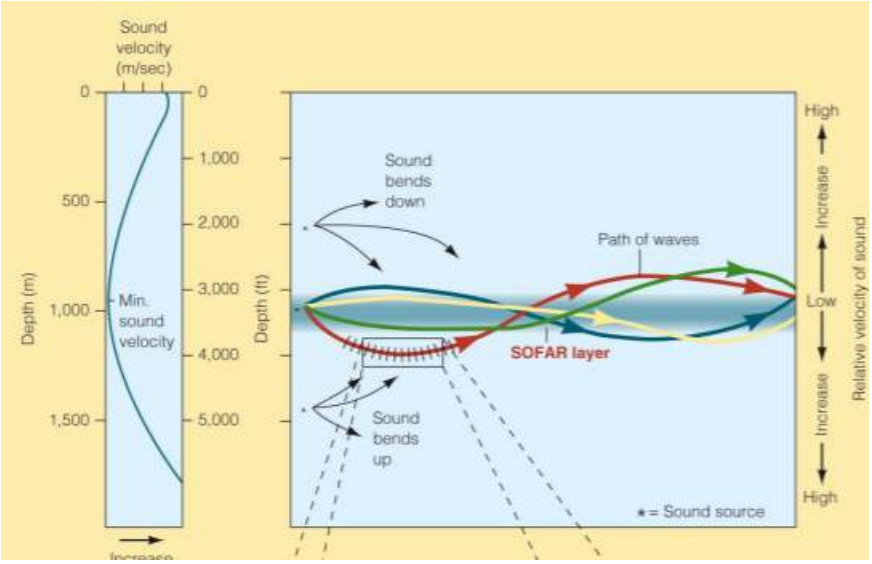
Recap from last time

- Freezing point at 0°C for pure water . Not the same for sea water(* below that*) .
- Exchange of heat (*Sensible heat*)
- Exchange of heat without the change in temperature (*Latent heat*)
- Propagation of light (*important to understand*) , is very quickly absorbed in the ocean (a couple meters below the surface), it warms up the water thereby.
- Red color absorbed in the first $1-2$ meter, and the blue propagating further down the color.
- Different regions on the water colon depending on light

Propagation goes much much faster in water

The typical profile of tthe velocity in water. At the local surface of water since it's really hot, the speed is really fast . A minimum is formed since it's hot above and cold belov. (*see graph last slide)*

- SOFAR layer : layer of minimum sound velocity usually efficient for long distances



Sound is layered because of diffraction → the different colors is the sound beign diffracted

```
road   \  beach
        \  .  . .
     x x .\.. . . .
 --> x x x .\. . . . .
     x x x x .\.  .  .  . .

change of medium, they slow down at the beach line, because.
```

> the mechanical wave spreads in all direction, SOFAR layer velocity is minimum and as it goes away the wave is bent back.
>
> > this is important given that the light can travel kilometers away this way
> >
> > - submarine detection
> > - mamlas communicating
> > - monitoring offshore eathquakes (*emits sound of course*)

[Note] this phenomenon happens at around 1 below surface beccause of the competition of warm and cold water , so it bounces up and down !! $\implies$ pressure effect.

> ☐ inside the water temperature as you go up, pressure as you go down

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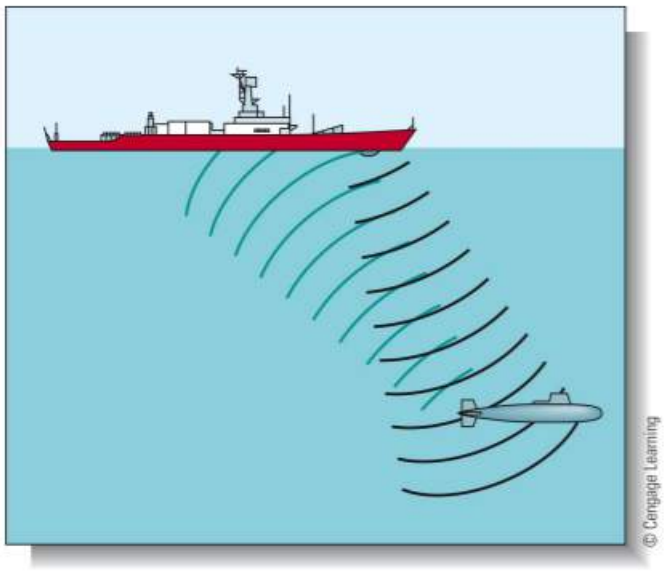
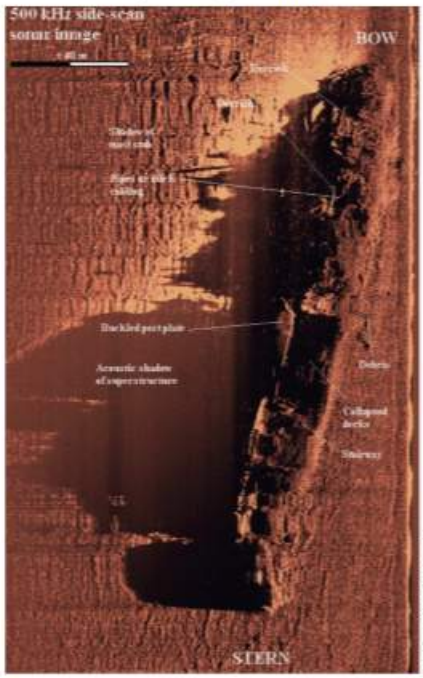
- **Sonar** : sound navigation and ranging (echo from the ocean)
  - sends pings waiting to hit something and come back , this way we can infer many information !!! like depth , geology , military importance

diment layers), archaeological studies, location of downed
os and airplanes



A sunk ship resting on the seabed



> on the right, a sheep underwater mapped through pings ??

[Application]

Problem : The echo sounder of a ship gives you a reading of 0.1 s. What is the water depth? Assume a sound speed of 1500 m/s.

$$T = 0.1s,\ S = 1500\ m/s$$

$$S = \frac{2d}{T} \implies d = \frac{ST}{2} = 75\ m$$

Sea Ice

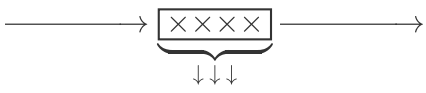
A. Sea Ice Characteristics

Can you tell the difference? What is sea ice, iceberg, ice cap?

> Sea ice, ice bergs, ice caps , ice sheet, frozen ground ?
>
> - all bottom part is the sea ice
> - in the background (mountains) we call those *Ice caps* , they are giant , and the glaciers (*Pure drinkable water btw*)
> - top right little piece there is an ice berg (*they come from the ice shell from the giant cube at top of anatartica they flow in the ocean by detaching*)

Sea Ice formation

- the freezing point for that water is $-1.8^{\circ}\mathrm{C}$, and the saltier the water, the lower the freezing point $\implies$ we find water at $-0^{\circ}\mathrm{C}$.
- **Brine** : droplets of highly saline water (Concentration of salts). These salts gets concentrated and then gets drained out through gravity in the ocean , so since they're going away the water (ice) becomes fresher.
- **Brine rejection** process of brine being expelled back in the ocean , which raises the salinity of near-surface water.



so salt increases above this ice cap

```
        ----
      /   ^    \
    /     | 4 km \
--->      |         ----      the ice cap
  |               |
```

Sea Ice growth

- Frazil : small needle-like ice crystals , typicall 3 to 4 mm in diameter, suspended in water.
- Pancake Ice:

Interaction between the sea ice sheets :

- Rafting : Current of winds pish around thin ice so they slide over each other
- Ridging: sea ice is push around into piles that rise and form small mountains above the sea level a couple o meters .(like convergence in tecktonic plates)

```
        ----
      /      \
-------         ---------
      |         |
       \     /      <--- ridges
         ==
```

- New ice : ice less than 10 cm thick
- Young ice : 10 to 30cm
- First year ice : ice thicker than 30 cm

  > this ice has not survived a summer melt season

- Multiyear ice : ice that survived a summer melt season 2 to 4 m

Some important features

Complex surface that varies dramatically across even short distances : ridges keels, cracks, snow cover ,etc

- Leads : long linear cracks

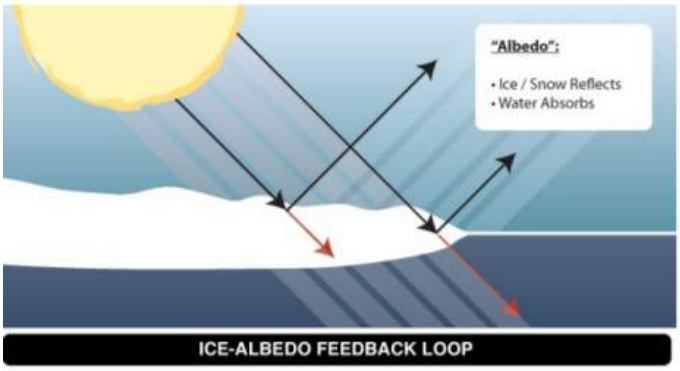
- Polynyas : irreagularly shaped areas of persistent open water

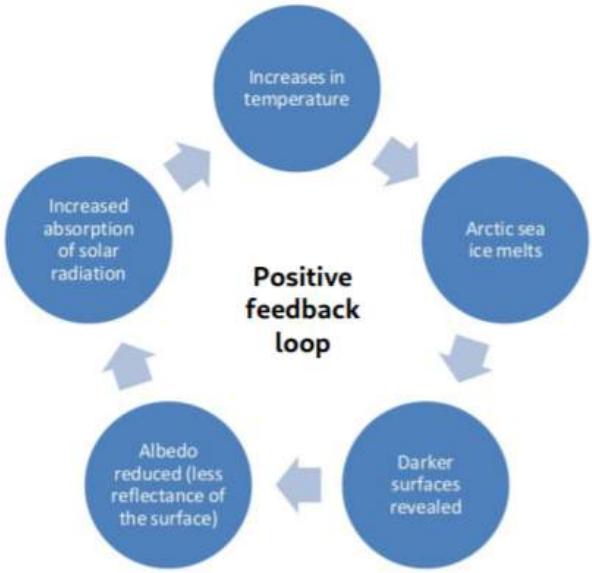
- Melt ponds : pools of melted snow and ice crated during summer melt

> This features are important for the climate and ecosystem because
>
> - Leads, polynyas and melt ponds absorb solar energy, leading to melting of sourrounding ice ,
> - Laads and polynias areimportant for wildlig (breathing,fishing)

Thermodynamics

- Ice-albedo feedback: see schematic





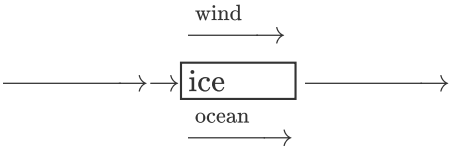
- Albedo non-dimensional unitless quantiy that indicates how well a surface reflects solar energy
  - $0 \implies$ perfect absorber
  - $1 \implies$ perfect reflector
  - Sea ice has high albeo $(0.5 \text{ to } 0.7)$
- Ice albedo feedback (*Schematic right*)

> in summer seaice starts smelting, albedo then decreases cuz we reveal the darker surfaces of the ocean, so more energy is absorbed, the surface of the ocean is haeated, so even more melting of more ice !!!
>
> > so a little energy = a lot of reccursive melting !

Movement of the sea ice

> continuously in motion ,(excep for *fast ice*)

- Fast ice : sea ice that is immobile and anchored to the shore or ocean bottom (fastened belt)



above the line is flat but there s actually a tilt

B. Processes, interaction and role in the climate

Sea ice interacts with...

- atmoshphere : via winds, precipitation , heat, etc
- Ocean : via currents, heat and salt exchange
- bacteria, animals ,etc

Role in the climate

- on the global mean temperature : because the sea ice has so high albedo , this keeps the surface cooler which mitigates the temperature of the whole globe
- On the global ocean circulation : salt expellled in the ocean , water propagates all around the world
- On gas exchange : sea ice at first order acts as a lead , which preents the exchange of the gas ??

[Question] How does sea ice influence sea level ?

> Doesn't contribute, it's already part of the sea lol. (*Floating on top of it !*)

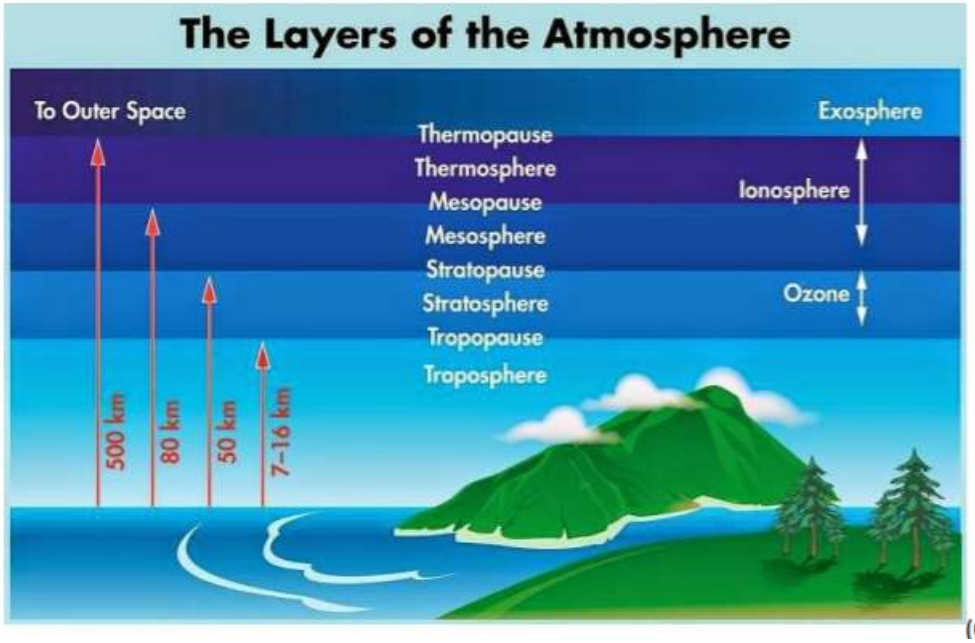
Lecture 6

Part 2. Atmospheric circulation

> Ocean stores CO_2

A. Composition and structure of atmosphere

[Atmoshphere] Layer of gases ad particles that envelops earth

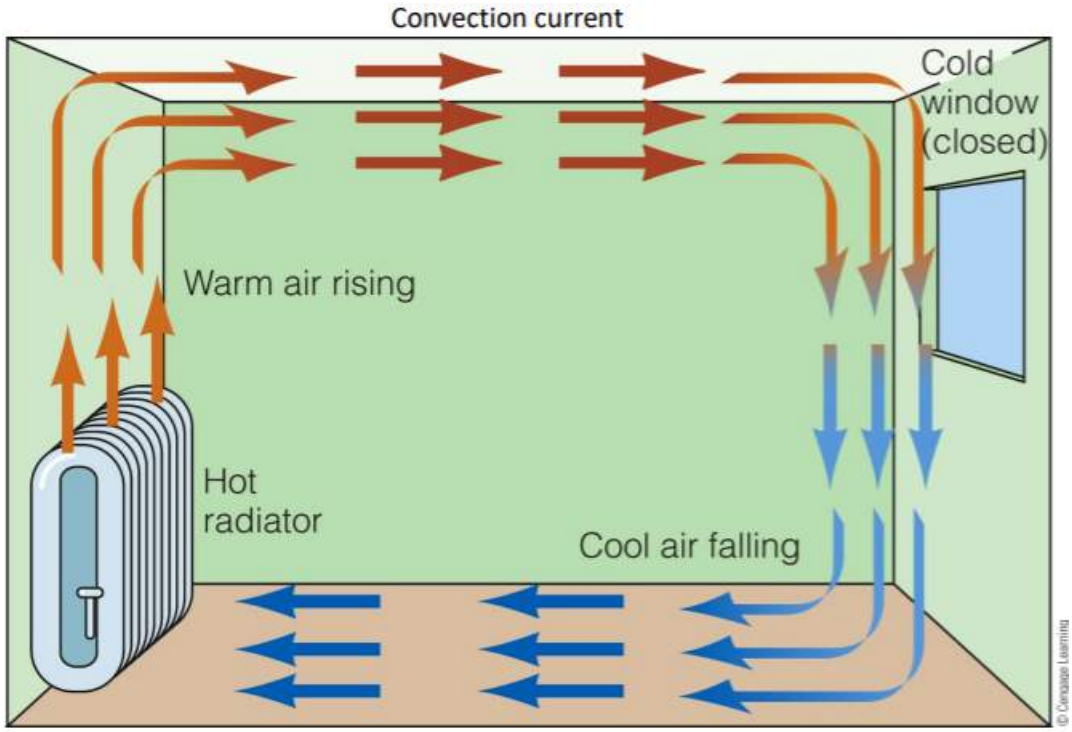


> - The troposhere is the lowemost and most important layer of the atmosphere
> - The stratosphere, dry ozone, quiet ,stable
> - Misosphere , very cold , $-100^{\circ}\mathrm{C}$, where metiors burm , aurore borealis
>
> In the atmosphere we have 78% nitrogen and 20.9% oxygen, also some other minor gases

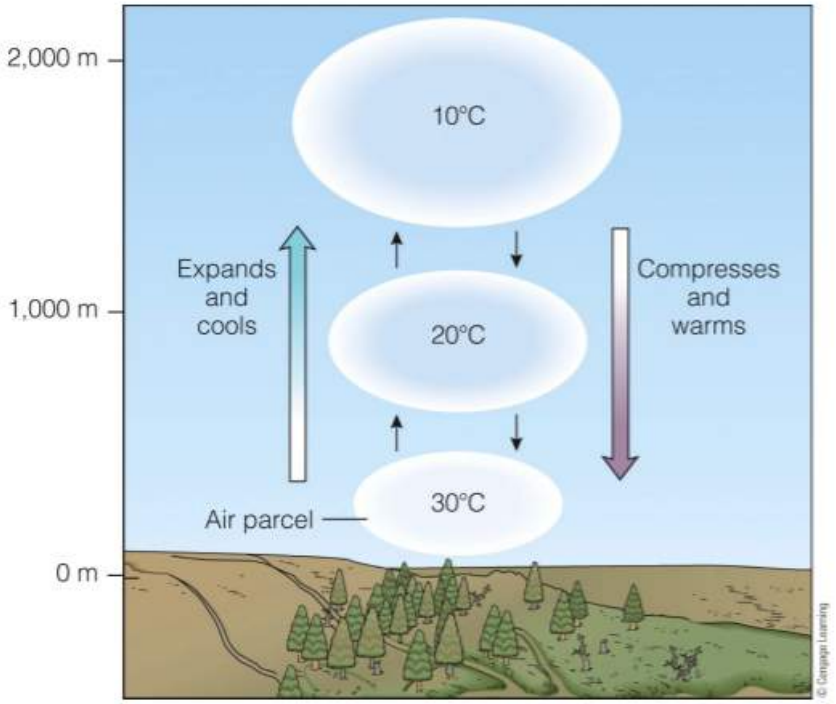
Up to 4% water vapor in the air, it condensates and becomes visible through rain clouds, snow, etc

Air has mass 1 cm of a column of dry air of the atmoshpere weights 1.04 kg.

> the density of air changes with
>
> - decreases with temperature
> - decreases with humidity
> - decreases with pressure



Because the radiator is warm it's less dense so rises to the top. Get's to the cold window, falls because decrease in density

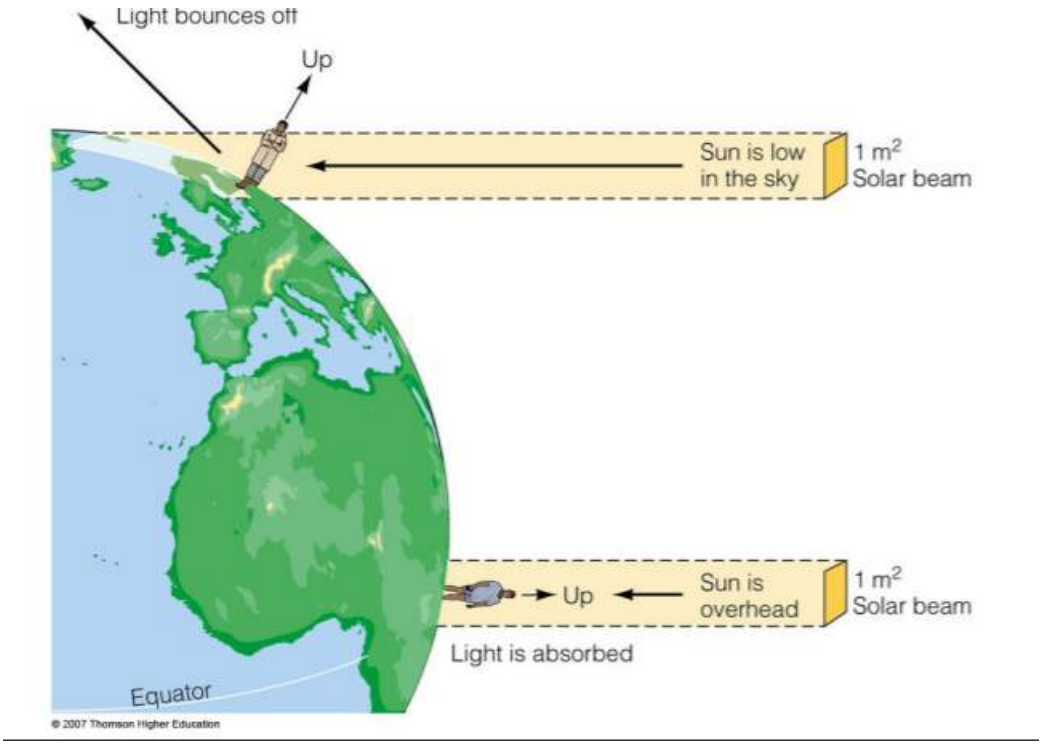


An air (water vapor) percel expands in volume and decreases in temperature as it goes up in the air

> it condensates , makes clouds and it makes rain

B. Solar Heating

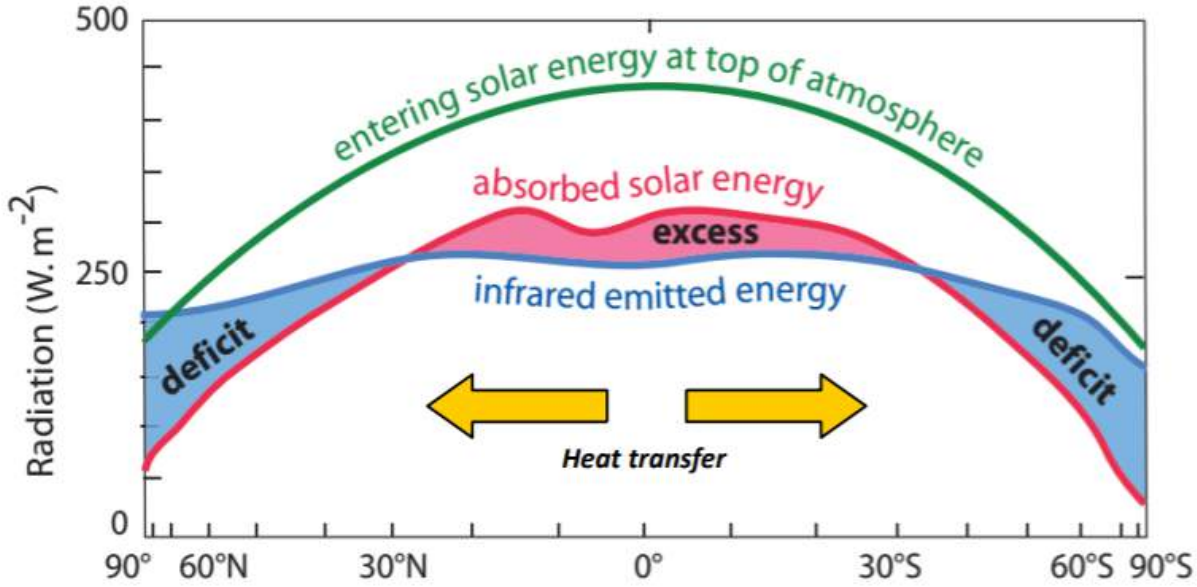
About 50% of the energy radiated towards Earth from the sun is actually absorbed by it, rest is released back



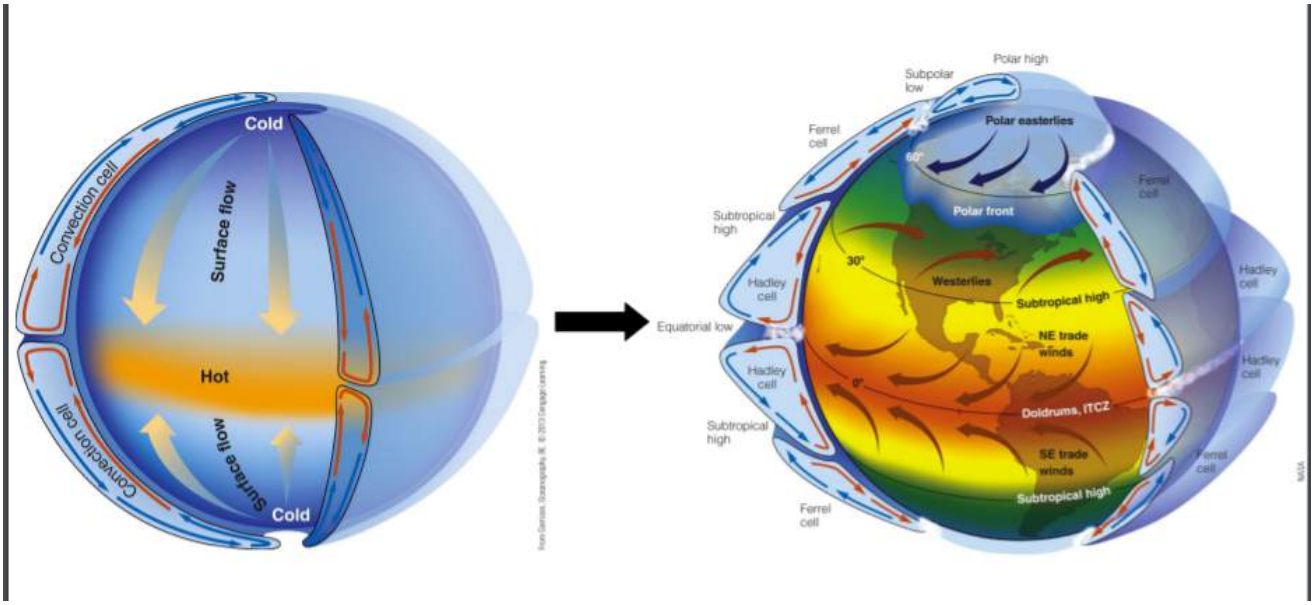
Given 2 beams of the sun at different altitudes, the upward beam has impact on a much higher area (*see picture*) compared to the bottom one.

> Moreover because the normal angle in the top picture is in diagonal, some of the heat is deviated (*bounces off*).

As a resul of this, we get the following diagram

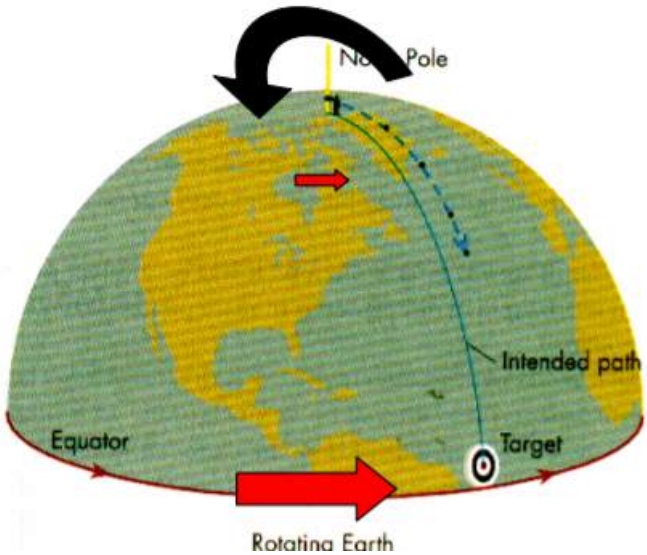


Notice the excess heat, at the poles it emits more energy than it absorbes (Deficit) while at the equator it absorbs more than it emits (Excess).



> IMportant to understand the convection cells and the direction due to coriolis

[Fact] The earth rotates eastward so there exists coriolis force

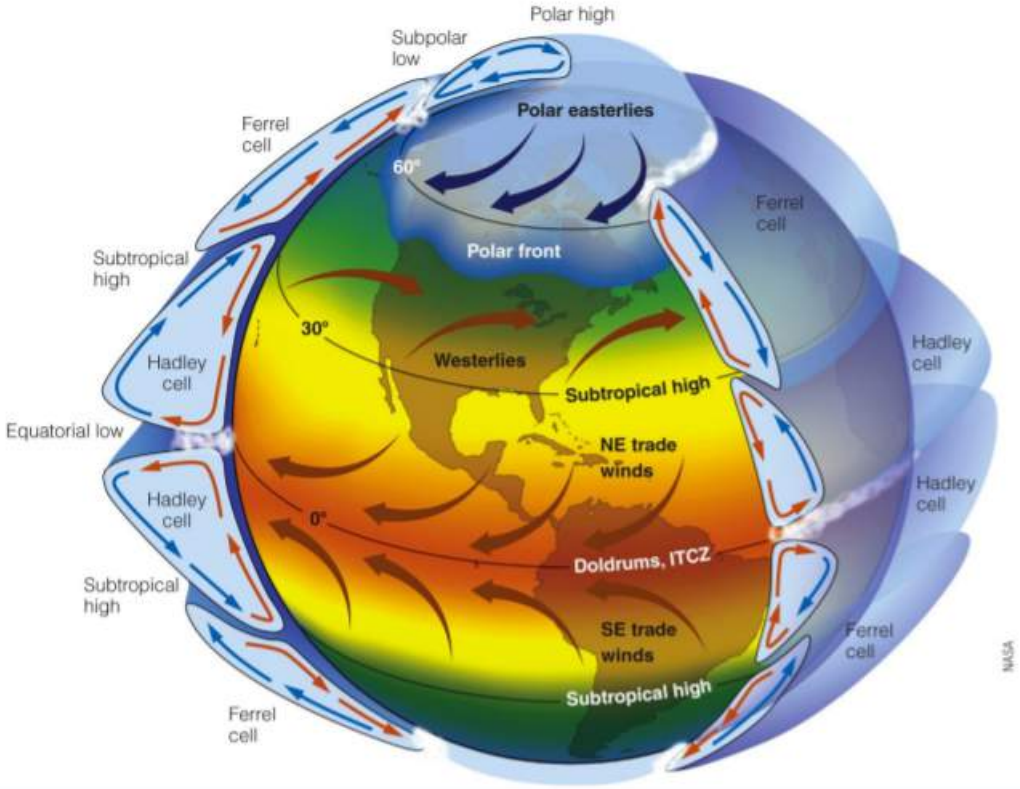


> If a cannonbal is thrown from the top to the target, then where will the cannonbal land ?
>
> Towards the left obviously
>
> $\toparrow$ this is called the coriolis deflection

> Similarly if we throw ball from equator to top,
>
> > difference in tangential velocity means the ball will land where we aimed ???

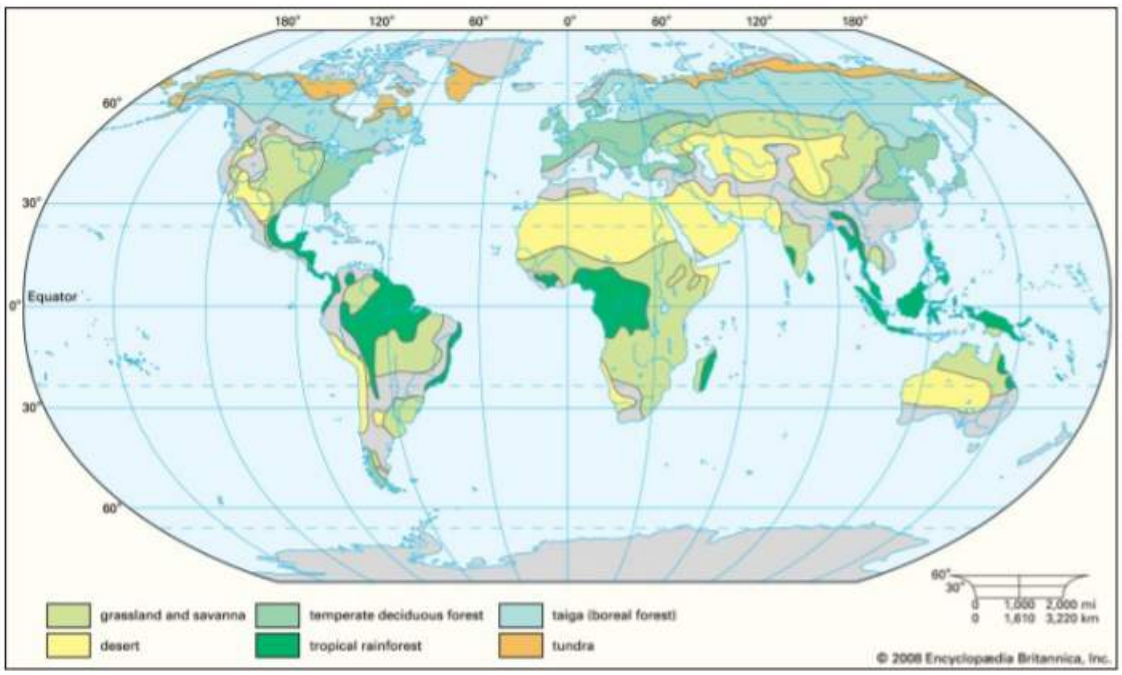
Because coriolis force we have cyclones and many other things?

- Hadley Cells (Tropics)
- Ferrel Cells (Mid-latitude)
- Polar Cells (Polar regions)



> Three kinds of cells (3 up and 3 down)
>
> > ascends → expands → cools → condenscantes
> >
> > Looking at the map, we're at intersection of a condensation point in the third cell so this is why for montreal we have big snow ?

- This is why we have tropical rain forests at the same angle on the map !!(Ascends)
- Same for deserts deserts deserts (Descends)



> in the picture above the tropical forests are at same line, deserts around same line, etc all because of ascending and escending

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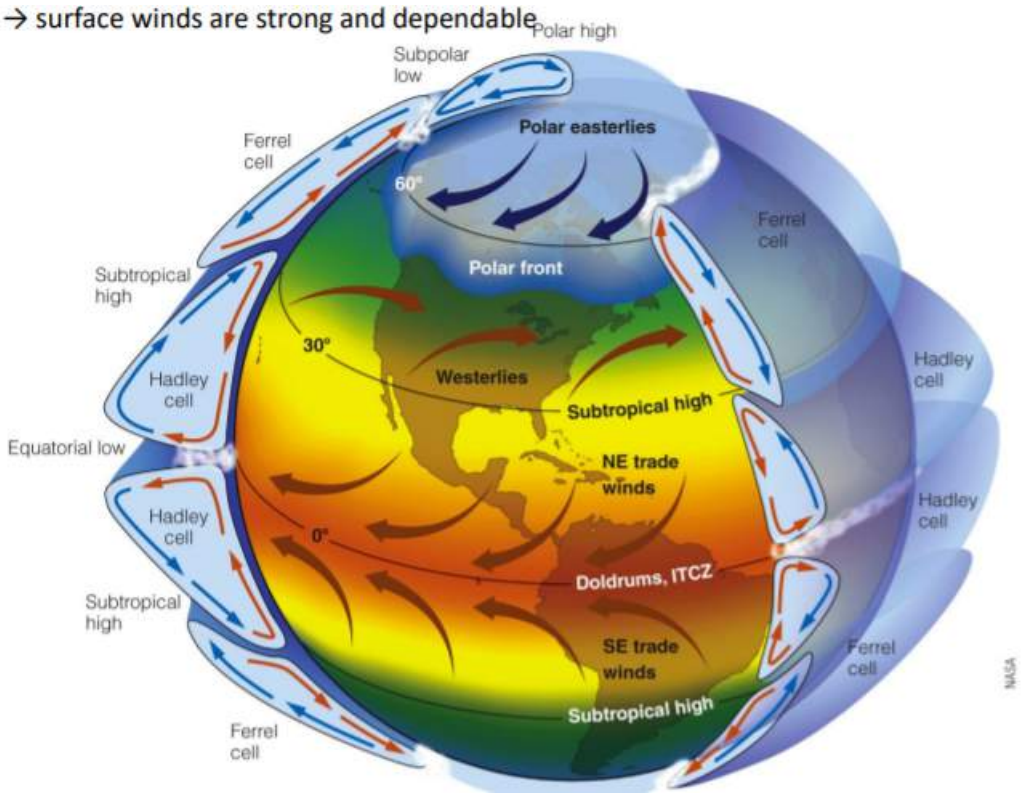
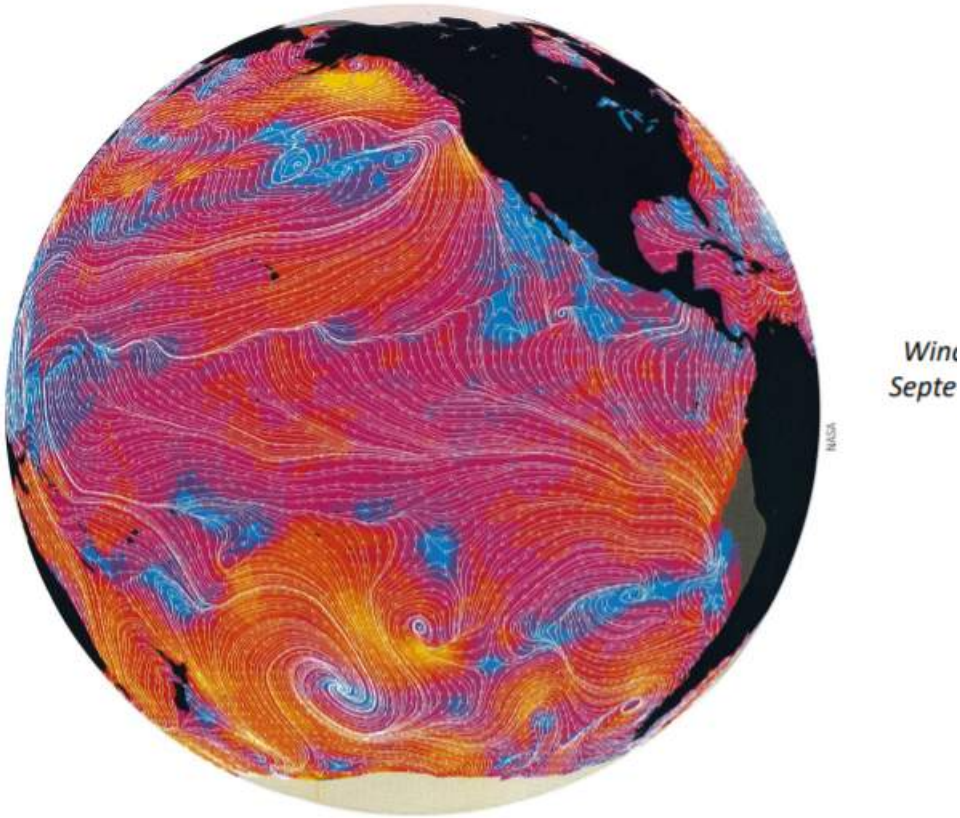
In between the cells : we have zone sof convergence/ divergence of air masses



- NE trade winds because a lot of winds for back in history pushing boats
- SE trade winds as well !
- Westerlies (strong) and subtropical high (even stronger in south becaus nothing to stop them like in the north rocky mountains and etc, look at a map lol there's nothing below the south continets)



Win
Septe

WInds flow, accurate with that we said around the middle, more messy at top and bottom

Lecture 7

Summary of what we have learned

> - Sea ice is part of the stratosphere
> - Brine rejection when sea forms
> - crystals form , liquid $\rightarrow$ ice $\rightarrow$ concentration of salt *brine*
> - newly water sinks into the ocean
> - this creates ocean circulation

> ice moves due : to wind, ocean below pushin the ice, coriolis force , internalized stress, etc

C. Studying sea ice

> go to polar regions in vessels
>
> > - (*IN SITU*) smaple the ice (disadvantage, can't sample everywhere so bias is introduced) we don't get good picture this way

> From 70s we started havign a better view since satelites started launching

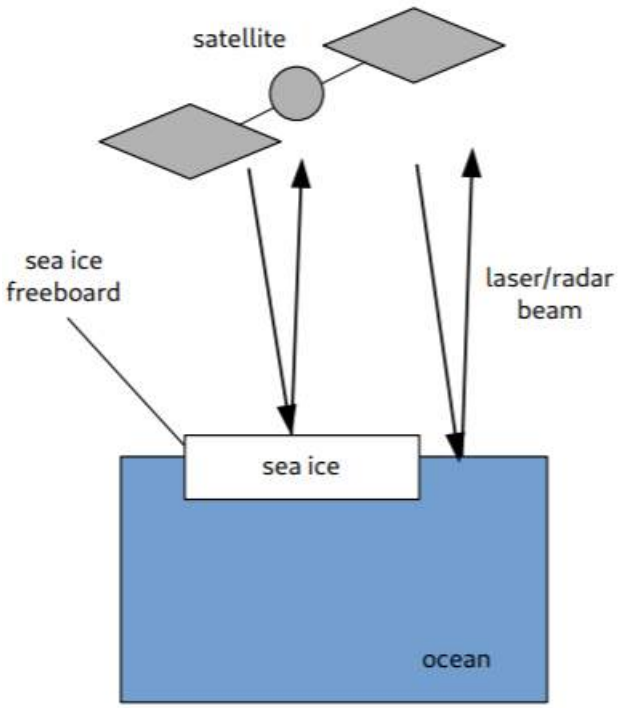
Before the 70s we usually sampled the ice.

Check where the whales go to see where the ice is at ? Because they feed there

Satelites obseraations (*remote sensing*)

> - microwaves which are emitted by the ice, is the usualy sensoring method.
> - Aso use visible light (must be during the day

We can infer the sea ice thickness from knwoing the sea ice freeboard location



Submarine observation (part of remote sensing)

```
------[_ice____]-----  <-- submarine gets the draft under
      /
     [] <-- submarine
```

> They are good to measure thickness of the draft

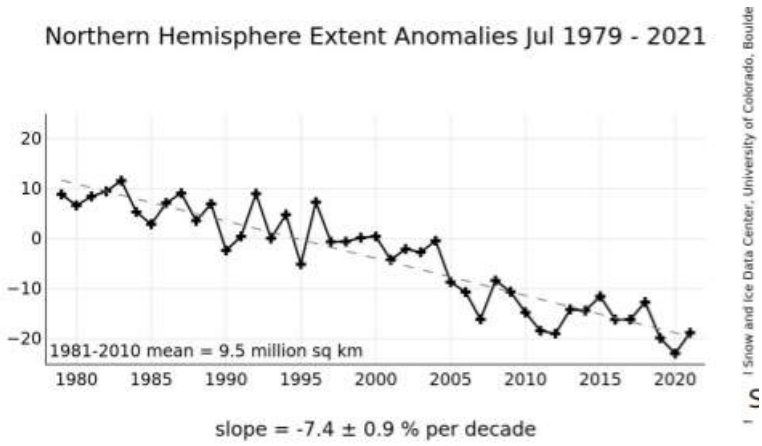
Artica vs Antartica ?

Arctic and Antarctic differ a lot...

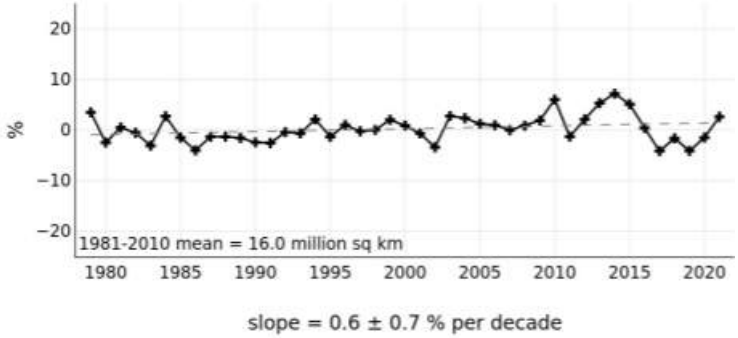
	Arctic	Antarctic
Geography	Semi-enclosed ocean almost completely surrounded by land	Land mass surrounded by an ocean
Freshwater content (ice cap and glaciers)	Lands in minority recovered by ice; 9% of global freshwater content (7 m)	98% of the continent recovered by ice; 90% of global freshwater content (56 m)
Fauna	Essential terrestrial (bears, wolves, foxes)	Essentially marine (whales, seals, penguins, krill)
Flora	Many species and high coverage	Few species and low coverage
Human presence	Occupied since 10,000 years; Native population (4 million)	Explored from the late 19th century; Scientists (~1,500)
Geopolitics	Claim for economic purpose	Dedicated to peace and science

- artic is surrounded by continents
- anatrtic is surrounded by ocean

> - if we were to melt all the ice : antartica 56m of sea level vs artic 7m of sea level
> - artic's sea ice is melting at dramating rate !



meanwhile, antartica,



> despite global warming, sea ice has been constant in anatartica, even slightly increasing. Why no melt ? Many theories...

---

4. Ocean basis and properties

Q How many oceans are there in the world ?

Accepted answers : 1 4 and 5.

Pacific, India, atlantic, artic, and a fifth : southern ocean So 5 oceans !

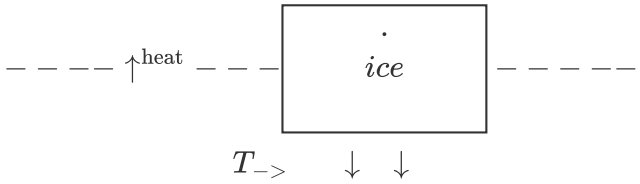
A. Density stratification

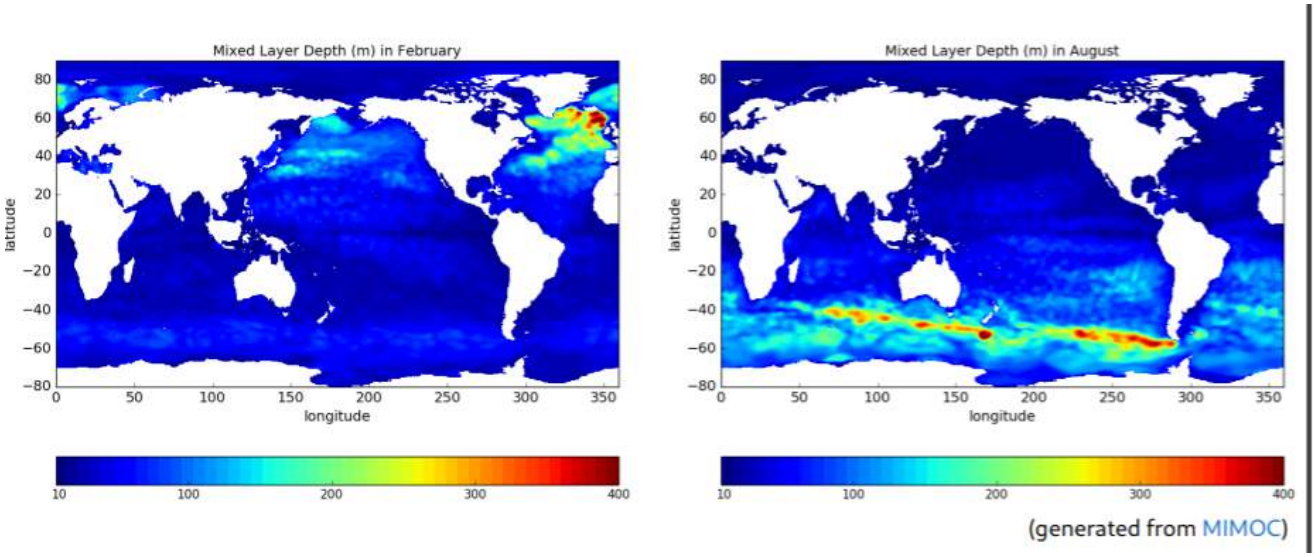
> Recall density is a function of salinity, pressure

We define 3 zone sin the water column according to density:

- Mixed layer : close to the surfacce. It's called like that because
- Pyncoline
- Deep zone

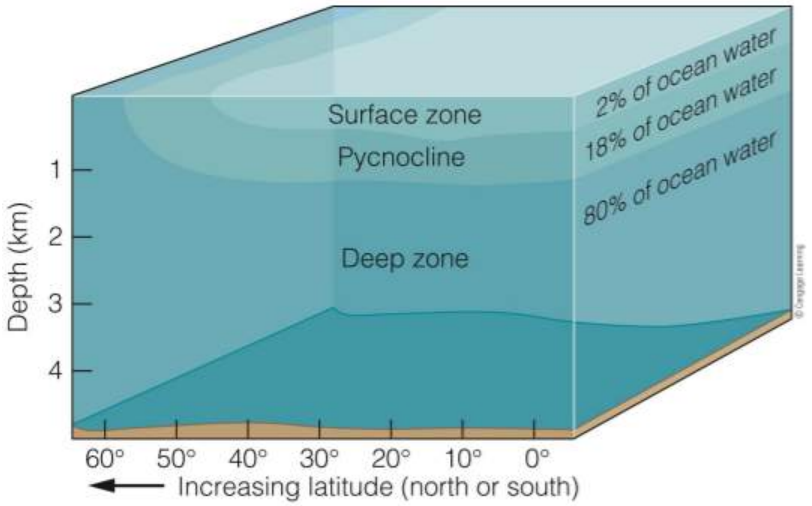
```
1          -->
2          -->    wind
3     T  _____________     ocean
4          mix mix mix             | mixed layer
5
```

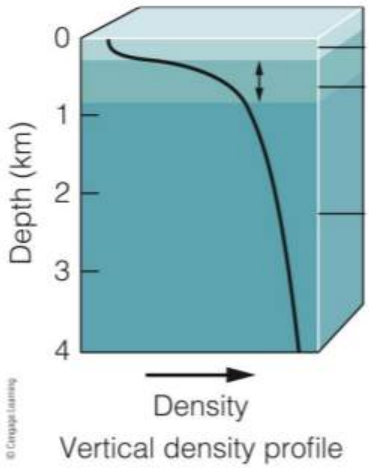




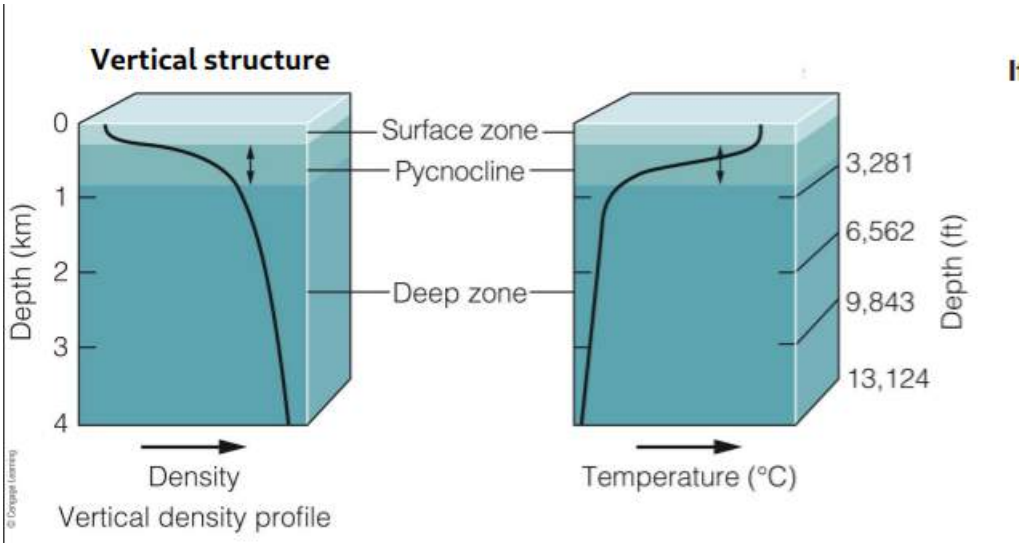
The deepest mix layers are in the southern hemisphere

> In winter we have the ocean giving up heat to the atmoshpher e,T decreases so density increases ... ?





> - depth incerases with density ?
> - surface zone is only 2%
> - fast density change in Pycnocline
> - Deep zone is the msot quiet part of the ocean (80%)



Thermocline : the zone i nthe ocean in which temeperature decreases rapidly with depth

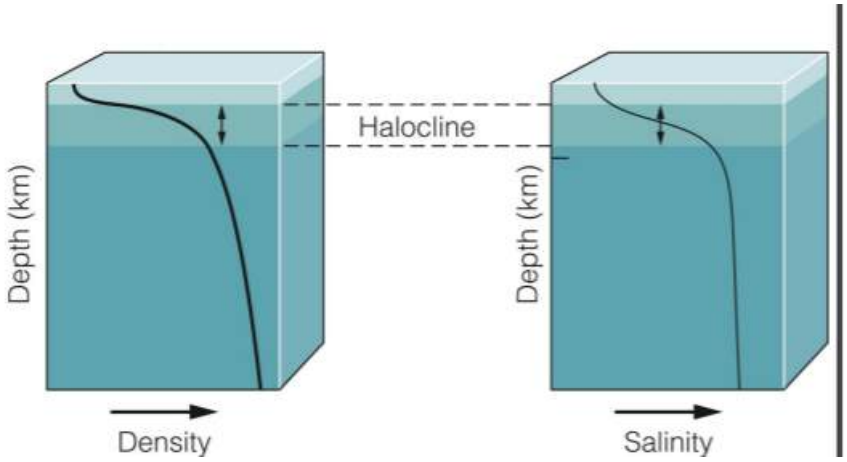
Recall that

$$\rho = F(T, S, P)$$

so as $T \uparrow \implies \rho \uparrow$

- lighter water is the warmest (*logic*)
- then temperature decreases rapidly with depth

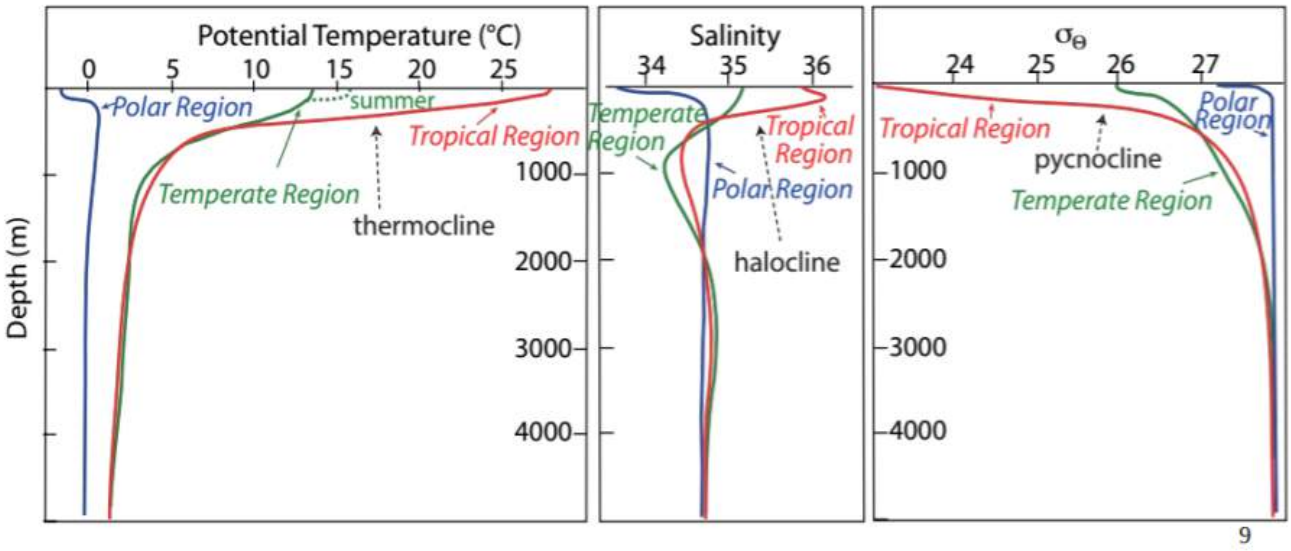
Q what if we think in terms of salinity ?



Halocline : zone in the ocean where salinity increasea rapidly with depth

> if we talk of density then pycnolcine, if temeprature then themocline and if salinity then halocline

Experimental data actually back up this model



> - tropical regions have very strong halocline and thermocline $\Longrightarrow$ strong stratificaiton
>
> [Important notion ↑]

[remark] The polar region line :

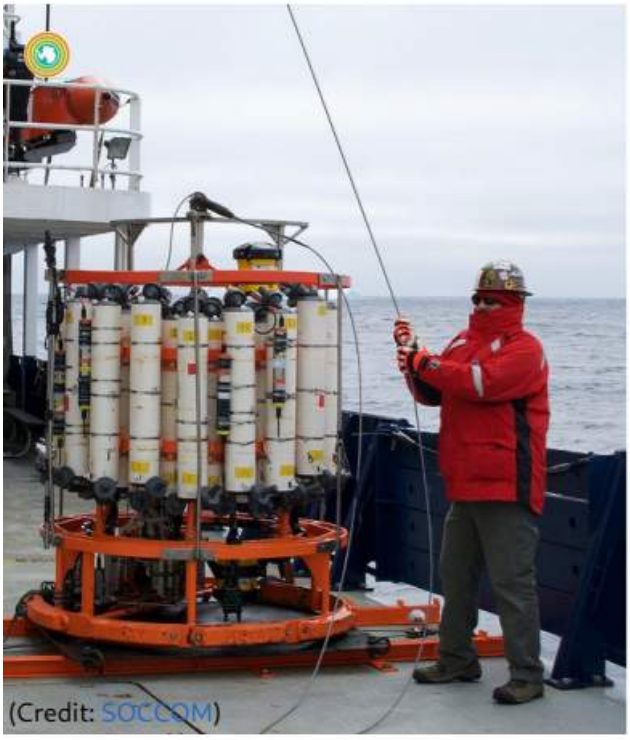
- has fresh water than stabilizes the functions on the graph (fresh water over saline water $\Longrightarrow$ sharp transition in the pynocline for the polar region $\Longrightarrow$ weak stratification) theremocline is absernt halocline
- the polar regions are more aeasily mixed ????

Measuring temperature and salinity

In Situ Observations :

- temperature : with sensors using thermistors (resistance varies with temperatuere)
- Salinity : how well electricity travels through the water (conductivity)

  salinity ↑ $\Longleftrightarrow$ conductiviy ↑



water flows inside the tubes, we trap the water in the column at some depth inside the ocean. Then at surface we open them and perform chemical analysis to see the salt content.

> recently we use Argo , sink down to 1km, then it drifts passibley with the current, thendown another 2 km , and is comes back tot the surface it measures temp, oxygen ,salinity, etc. And sends the data to the satelite at the same time.

Lecture 8

[Recap]

Three important znes

- mixed layer (conencts oceans with atmosphere)
- pycnoclien
- deep ocean

Temperature and salinity influence density (we introduced pycnolcine, halocline, and other one). We deisscussed vertical propfiles of salinity (density stratification). Slinity is important in polar regions, whilst the other one important for tropical regions. This relates to stratification ,the stronger the pycnocline the strogner the stratiffication,

> if stratification is strong you need a lot of energy to mix surface ocean with deeep ocean

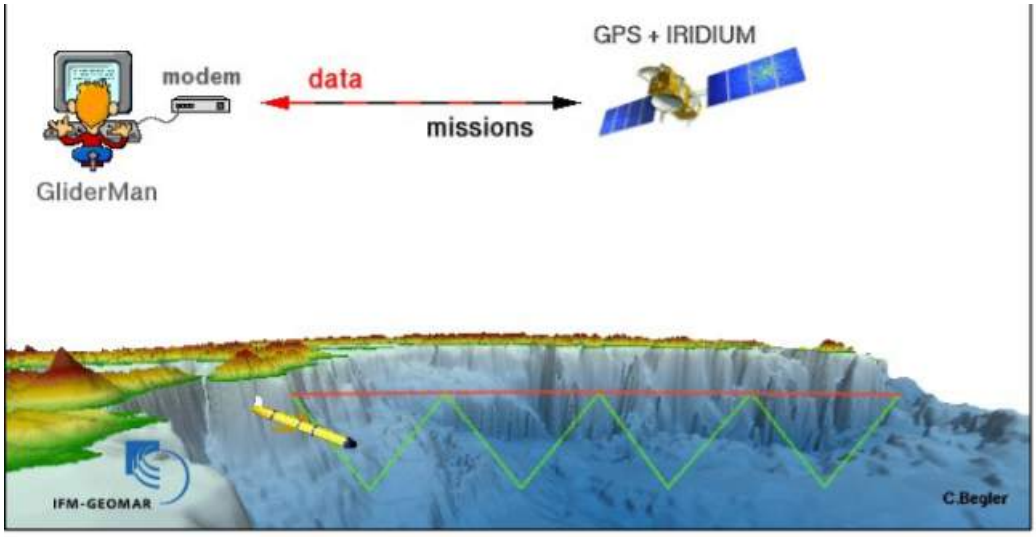
We saw how to measure the properties in the ocean. Temperature and conductivity to get salinity and depth are use through *Rosettes*.

> Argo floats revolutionized the domain, They allowed to fill the gaps in the ocean, where traditionally we needed research vessels like for instance polar regions during winter wind ,ice etc, → well algo floats can go there.
>
> - Also cheaper
>
> How they work is that they sink into the water, at 1 km they drift passively, they control the boueancy, they can't decide where they go though. Then dive again 2km and when they come back up they measure all the parameters.

How do they float on ice though ? Keeps going down until there's no ice at surface (cycle), until they surface

> so we actually lose track of some of these floats !

Another type : Gliders



Similarly to floats, they have all sorts of sensors for many different measurements. They also communicate their position and data when they reach the surface

main difference : the movement, they zigzag, so they can explore a whole layer in the ocean.

Another type : Sail Drones:

- powered by wind
- sails for months
- measure presure radiation,
- conductivity temeprature depth (CTD)
- camera on board
- Recently one did the whole antartica ocean for 12 months !

Another type : Seals, Tutles equip animals with sensors.

Latitude

- their trajectory is monitored
- like gliders or algo floats, they take different measurements of properties
- Particulary, they find the cracks that others can't find
- they dive deep

> Note The satelite can't get signal through water, just like GPS, well they use GPS.

Satellite observations

[Definition] *Remote Sensing* : science of obtainign inforamtion abouut objects or areas from a distacance. typicall from aircraft or satellites.

- surface temperature of the ocean (sicne 1970s), important for monitoring global warming
- we didnt't have salinity for a long tiem. But recently it was done ! (2011), from a space mission.
- Other variables like current voloicty, sea ice concentration and thickness, chlorophyll.
- DISADVANTAGE: only information about the surface.

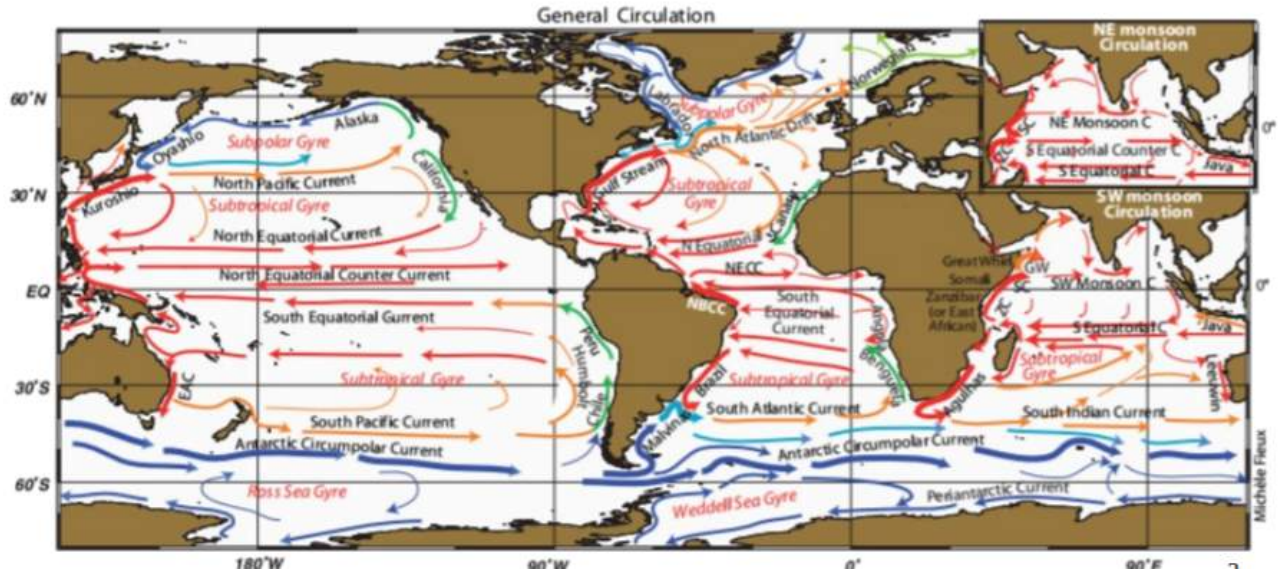
C. Distinctive features of the five oceans

Part 2. Ocean Circulation

2. Wind-driven circulation

Oceans currents are produced by 2 main currents :

1. Friction of the wind at the surface of the ocean.
2. Density differences produce thermohaline currents.



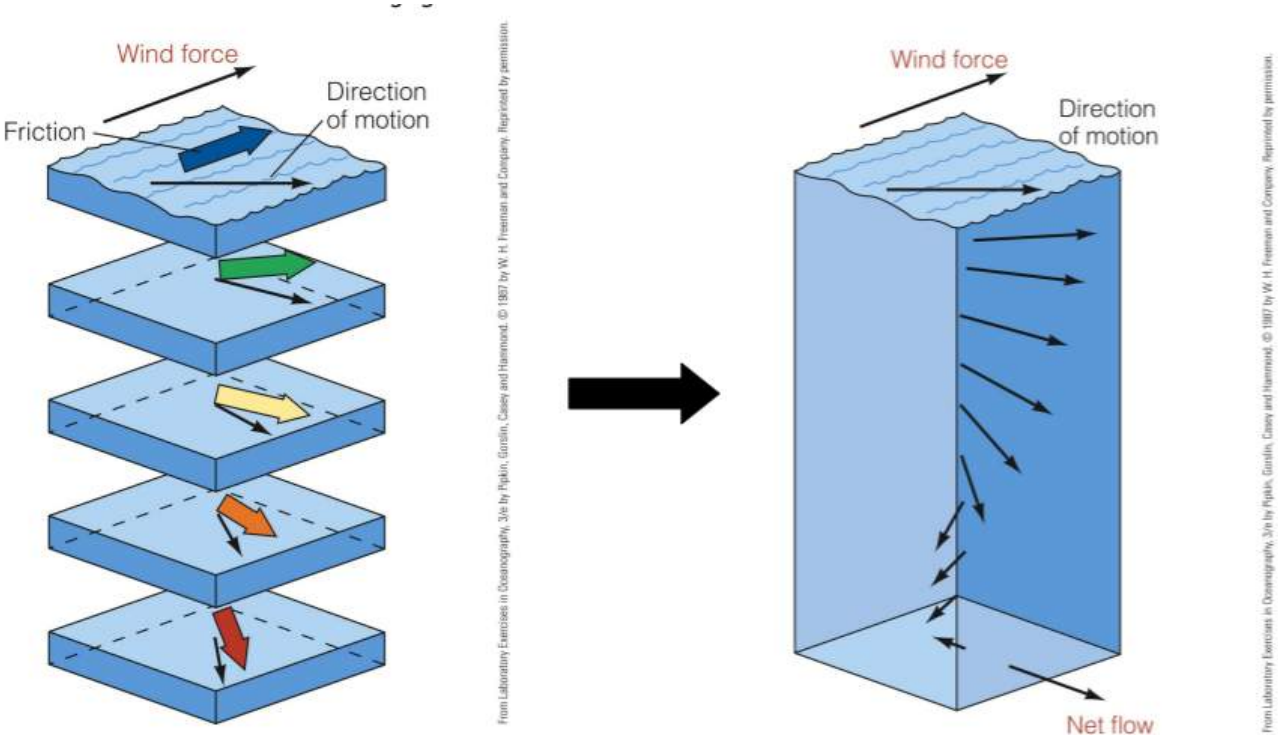
> the circulation is much much complex, but the map above is an average of the main path ways of water.

A. Direct wind forcing

In the late 19th century ,expedition boat was done to explore the arctic. To get measurements. He on purpose get stuck into the ice to drift with the sea ice.

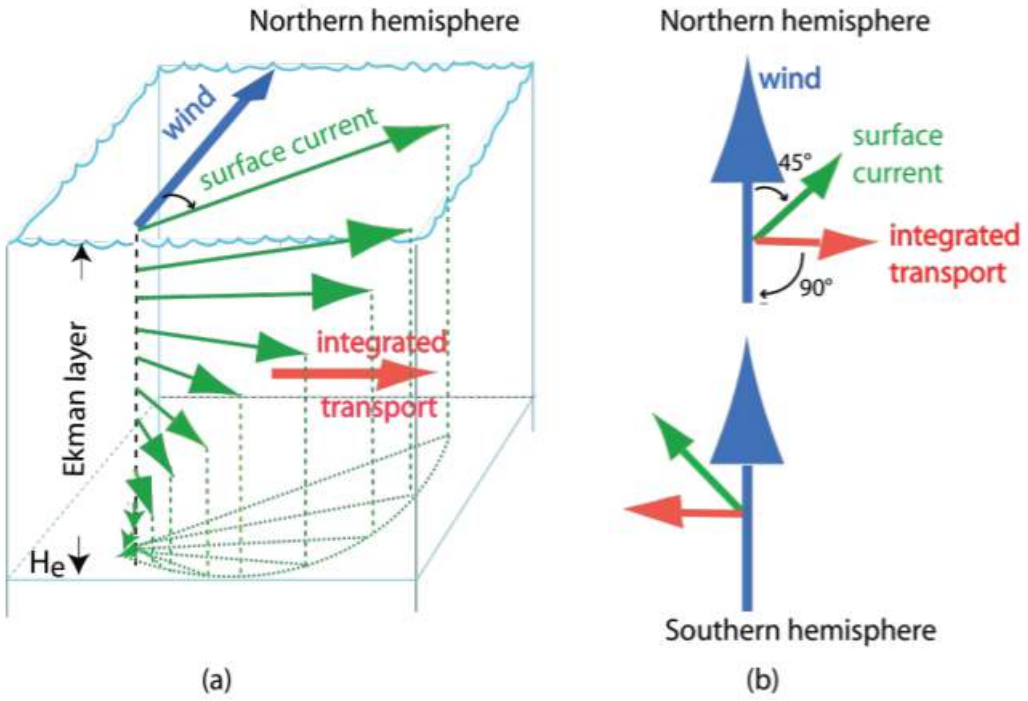
> he noticed ice drifts to the right of the wind, not in the same direction ! → because of CORIOLIS FORCE

Ekman equations were developped then. Resolving yields that the motion of the current look like a spiral.

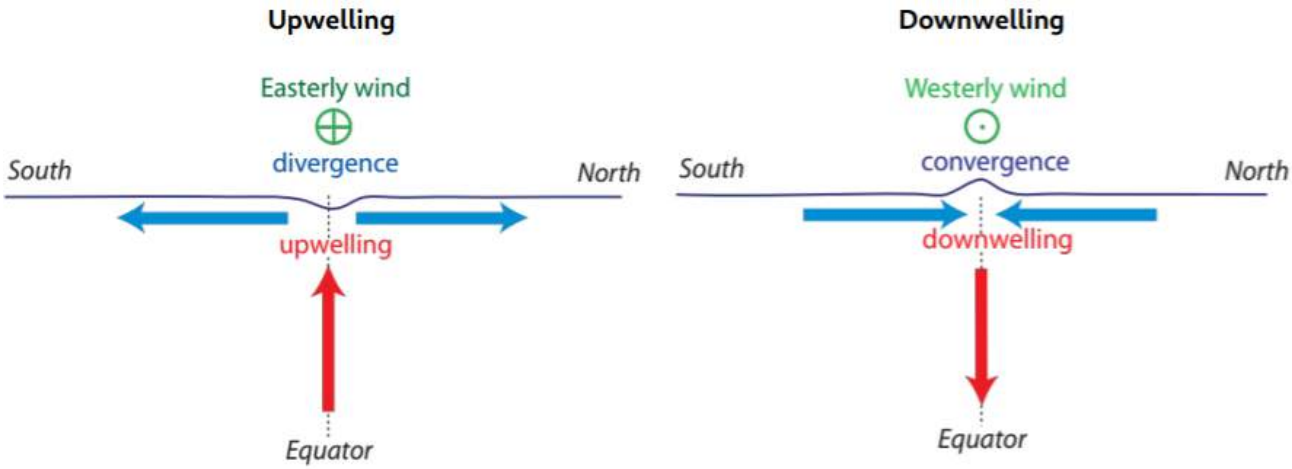


↑ Ekman's spirals

> [Remark] Coriolis force applies only to objects at movement, not stationarry ones
>
> - arrows get smaller and smaller, cuz at some point there's no more wind energy penetrating throught the water column.

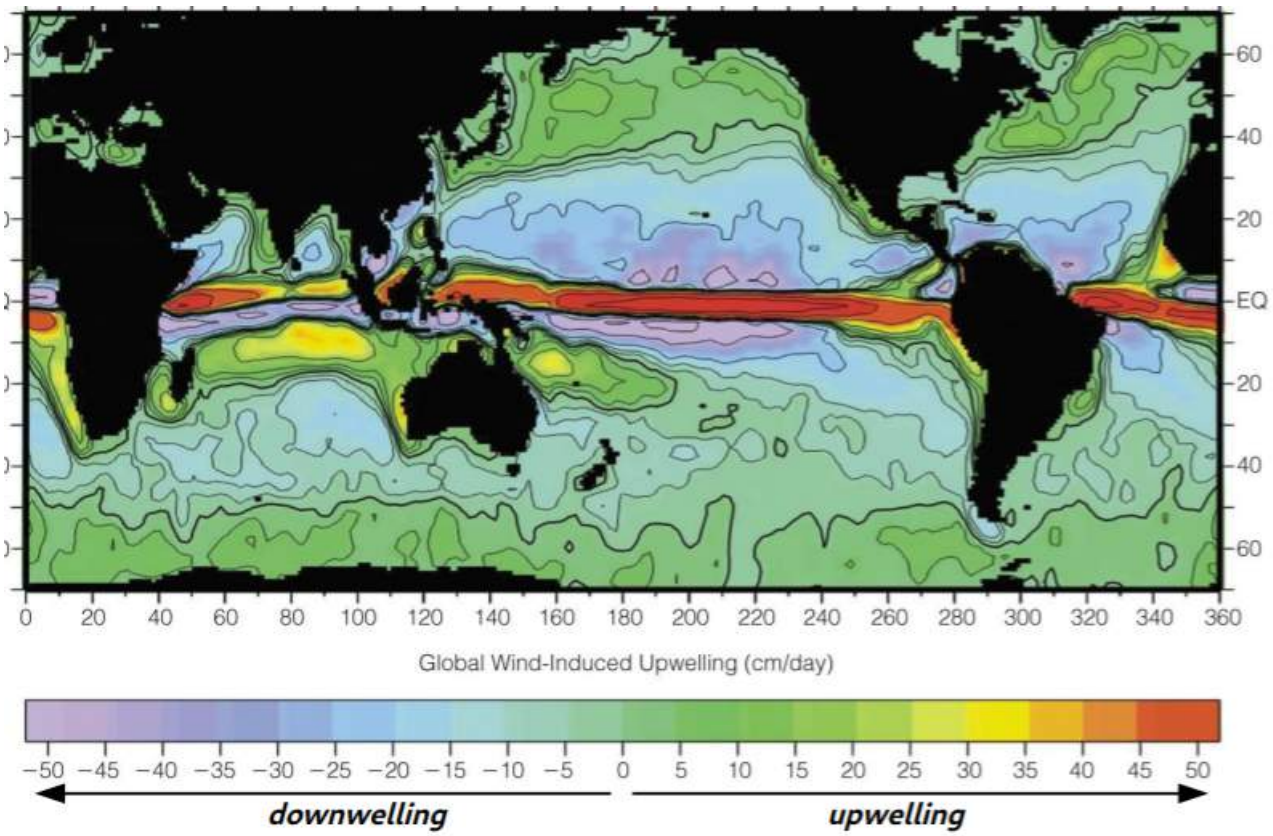


> the sum of all these vectors (integral) is called the Ekman transport.
>
> > integrated transport : I give you the wind so I can tell the water moves in that direction .



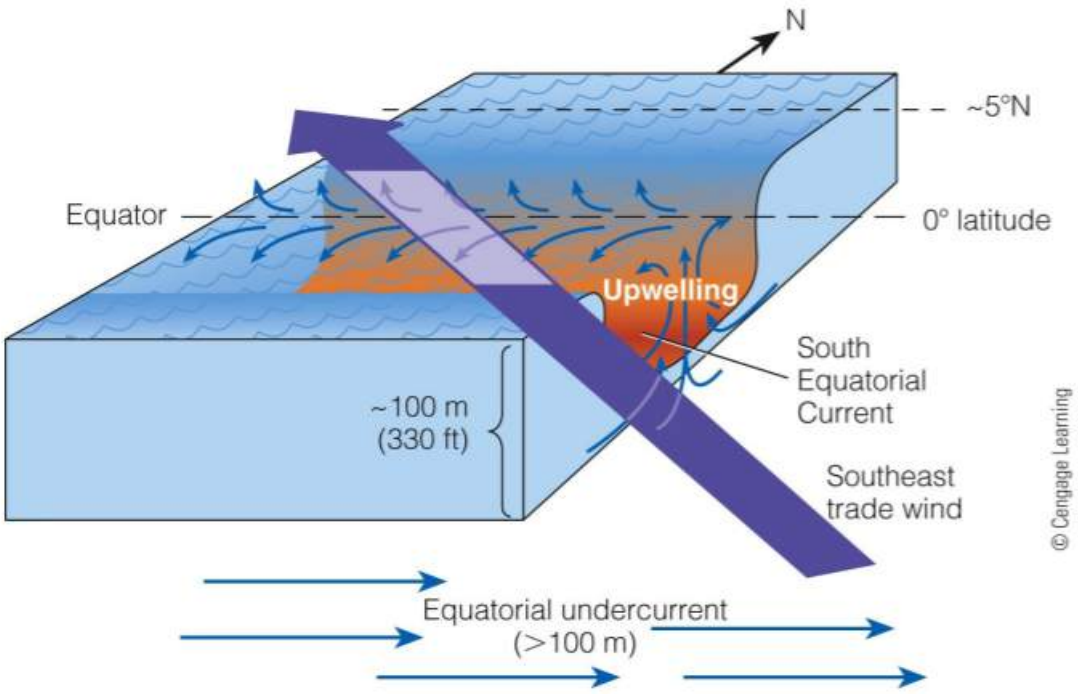
> - Upwelling arrow goes up from below since it's generated by the diverging vectors
> - Note on the image above inwards and outwards vector points.
> - mass continouity makss the wind go up if converging winds from both sides
> - wind spreads of the surface (diverging) when hittin the surface.
> - [Remark] This creates the convection cells !!!

> [remark] VERY IMPORTANT CONCEPT deflection right in Nothern hemisphere and deflection to the left in the southern hemisphere.



↑ computed only knowing the wind !

> at the equator (red line) arrow goes left, and half upwards from there, arrow goes right
>
> > can we infer the vertical direction from the map above ?
> >
> > for top arrow (since were in norther hemisphere then arrow down) for the middle arrow, arrow up for the same reason, so it's a converging point in between the two arrows. (⊗)
> >
> > > if another left arrow added at the top , then diverging ⊙ n between the two arrows.

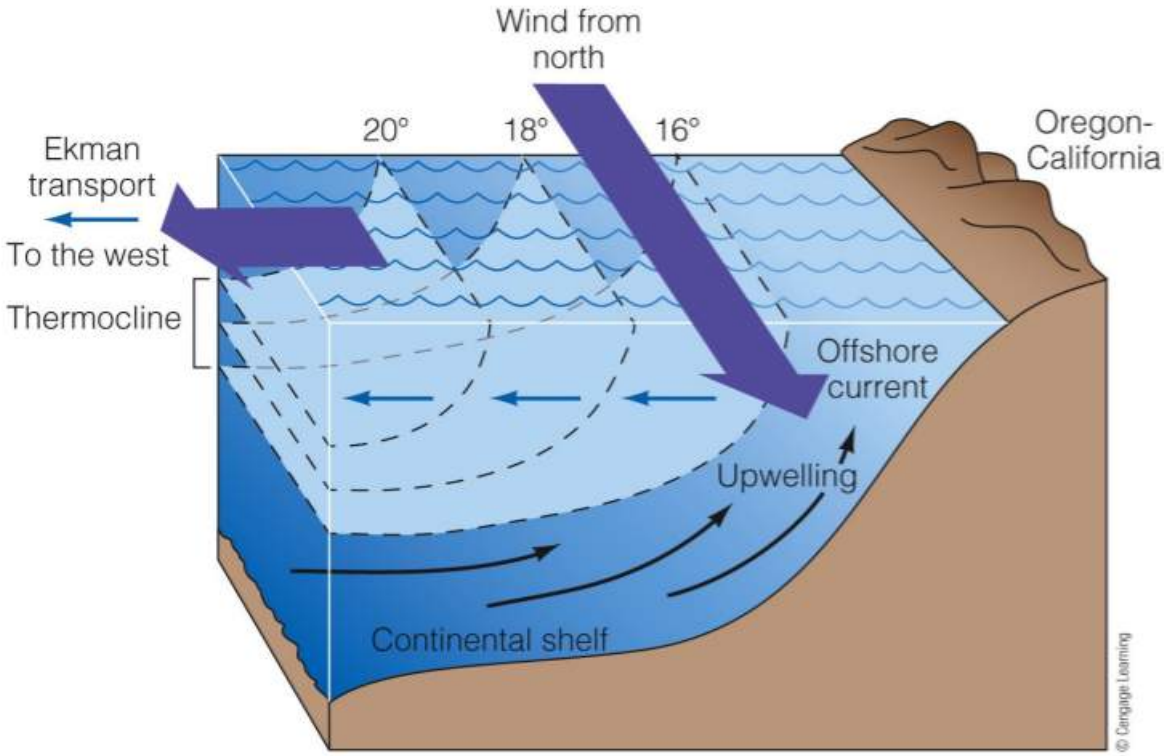


Schematic to see how this happens. Note that upwelling here goes as far as 100 m in the ocean.

- equatorial upwelling
- southern ocean upwelling

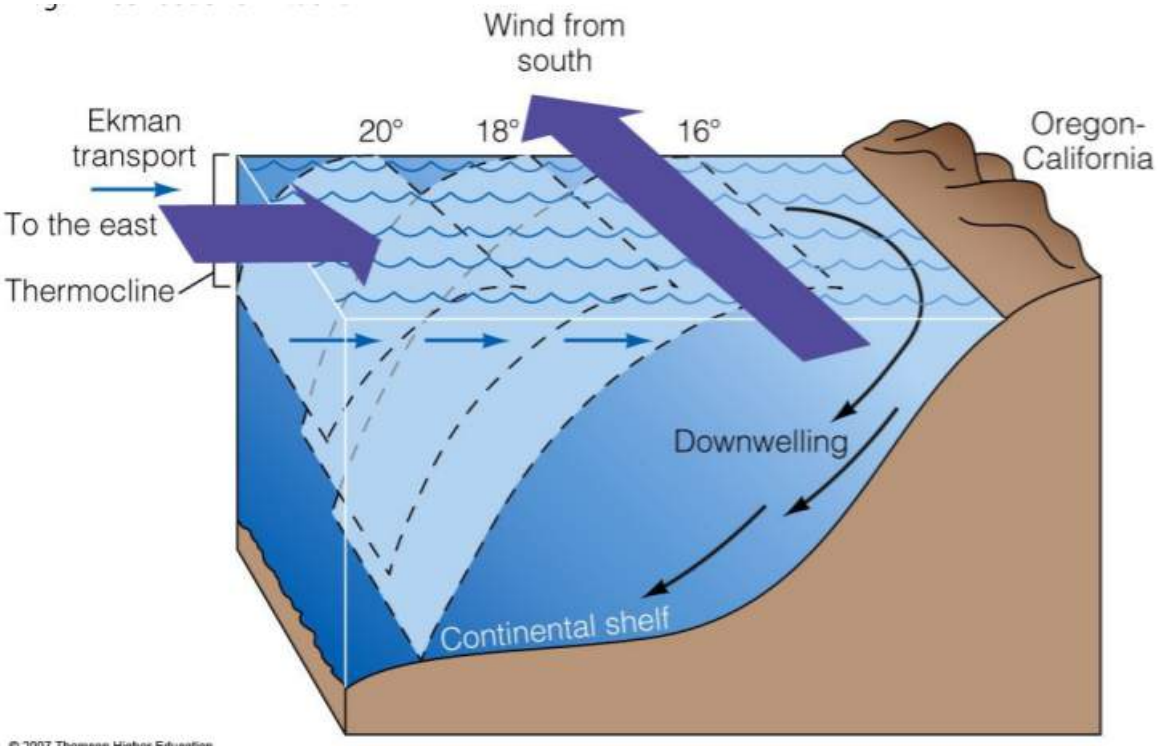
We talked about how2 convergig motions induced a vectical motions. You need not necessarely the 2 arrows for upwhelling/downwhelling, for instance :

→ Due to the Coriolis effect, Ekman transport is offshore
→ Winds blowing offshore can induce coastal upwelling too



water from below is pumped to replace the water above. ??

Simialrly,



Lecture 9

Recap:

- We talked about the Ekman Spiral (change of intensity and direction due to energy pwowered by the wind, dissipated through friction).
- If we integrate the velocities of the spiral , we find the net average transport is at right angle to the direction of the wind (right in norther hemisphere and vice-versa)
- Divergence of ekman transport creates an upwelling, similatly convergence water is pushed down, downwelling.
- If we know the direction of the wind then we can infer the ekman transport.
- massive divergence in southern ocean
- don't necessarily need to have convergence and divergence to have upwards / downwards motion. Can also have this near a coast.

[Definition] *Gradient*

$$\ominus \longrightarrow \oplus$$

A field that goes from lower to higher concentration

[Definition] *Pressure gradient*

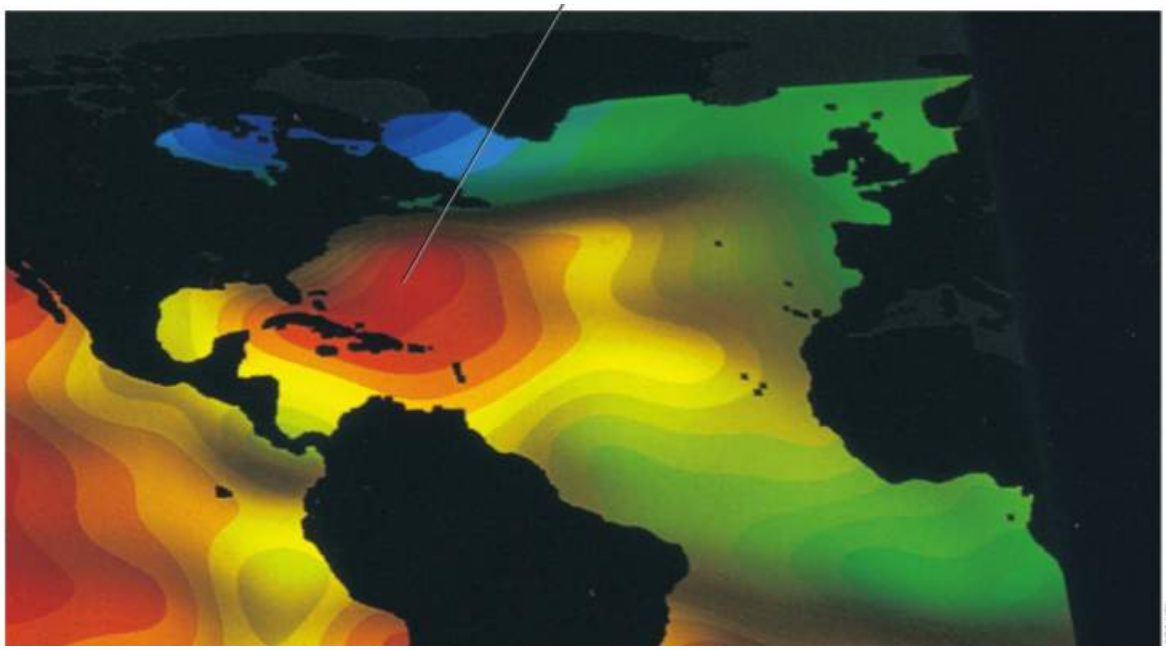
$$\ominus \xrightarrow{P} \oplus$$

B. Resultant geostrophic currents

(see written notes for schematics)

[Definitnon] Geostrophic gyres: Gyres resulting from geostrophic balance.

- Center of the dome is the highest pressure point.



C. Main geostrophic gyres and currents

five of the six great current circuits in the world ocean:

- North Atlantic gyre
- North Pacific gyre
- South Atlantic gyre
- South Pacific gyre
- The Indian Ocean gyre

[Definition] West Wind Drift (The ANtartic Circumpolar Current).

- It is not a gyre, just a long circuit around the antartic continent.
- It is the biggest current transport current. 600 times that of the amazon current

> For the boundary currents, the western parts are to the east on the map (wtf).

[Definitnon] Transverse Currents

> notice between eastern and western boundary currents ?
>
> - Eastern boundary currents in blue are cold
> - Western boundary currents are in red are warm
>
> They flow from low lattitude (lots of solar energy so water gets warm (equatior is in tropic)) it brings up the heat towards the higher latitude. The ocean is cold up so when water flows towards the lower latitudes it brings with it cold water
>
> > This is a redistribution of heat @!! Currents transport heat.

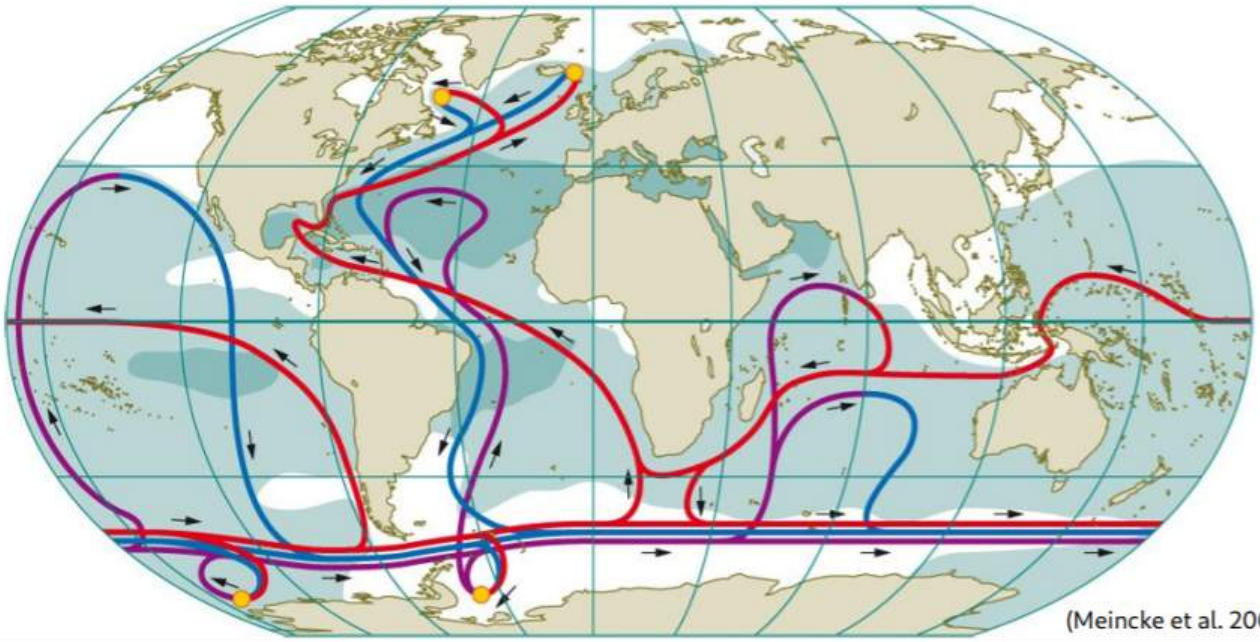
Part 2. Ocean Circulation

Part A .Density induced water movement

Recall that

1. winds produce surface currents
2. Density differences produce thermohaline currents

Oceanic general circulation results from a complex combination of thermohaline circulation and wind-driven circulation



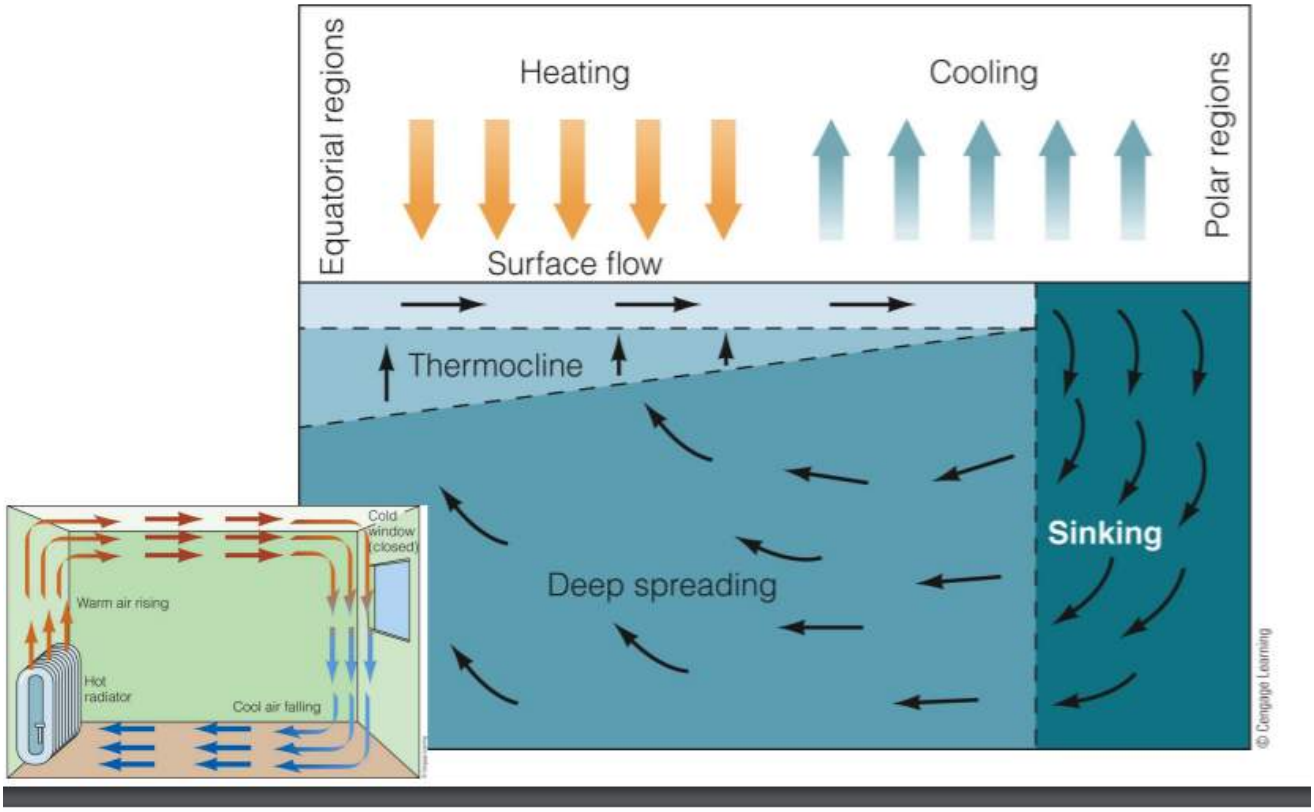
(Meincke et al. 200

So wind circulation and thermocline circulation

Ass 2 Q2.

- What processes reduce the density of the surface layer ?
    1. precipitation
    2. heating by the atmosphere or short waveradiation raise temperature
- What processes increase the density of the surface layer
    1. evaporation increases salinity and decreases temperature
    2. direct conduction woith the coldre atmospher edecreases temperature
    3. Freezing of seawater increases salinity just below the sea ice formed.

Horizontal pressure gradients

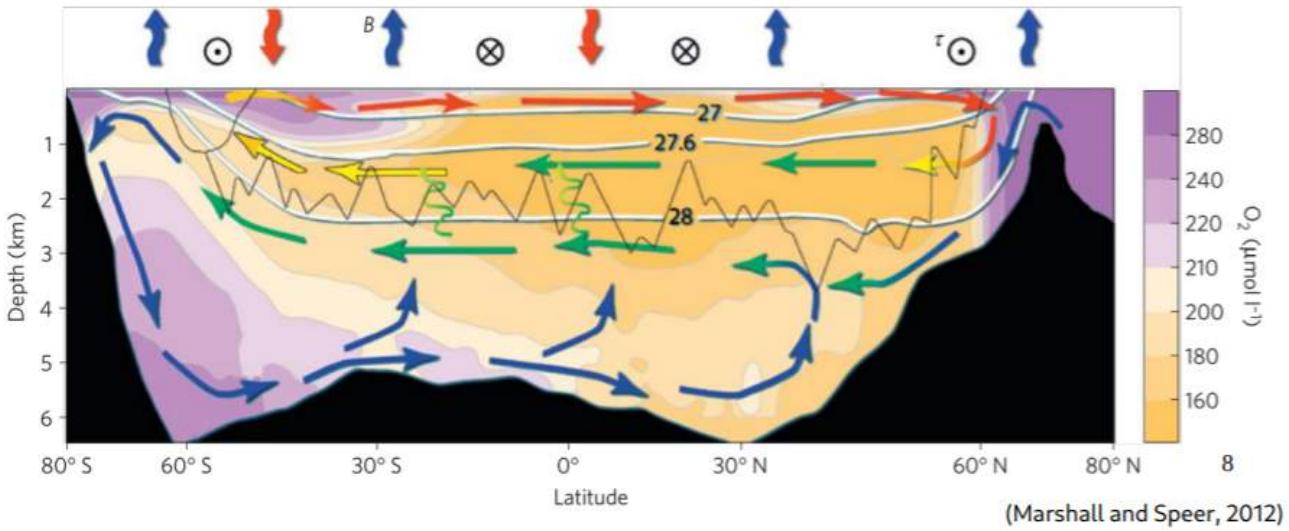


> light water induces small rpessure and dense water induces high pressure. Difference in density implies difference in pressure in the horizontal which drives the motion in the horizontal.

[Definition] *Thermohaline circulation* Water circulation produced by differences in temperature and or salinity and therefore density.

- *therme* (heat) and *halos* (salt).
- the whole ocean is involved in slow thermohaline circulation

[Definitinon] *Water Masses* : A body of water indentifiable by its salinity and temperature and teherefore density or by its gas content or another indicator



(Marshall and Speer, 2012)

B. Formation and Propagation

Lecture 10

Recap

1. discuss why there are difference in density between different regions because difference in salinity and stuff. Processes with atmosphere and ice
2. between basins and hemispheres differences in density , leads to different types of motions .creates virtual motion in the water
3. difference across horizontal between different basins then this has an effect on pressure at a depth , then the water is forced from the higher pressure to the lower pressure so large movements induced by difference in density

> this is what powers the thermocline pressure, it's a global circulation , very slow circulation that goes all over the globe.

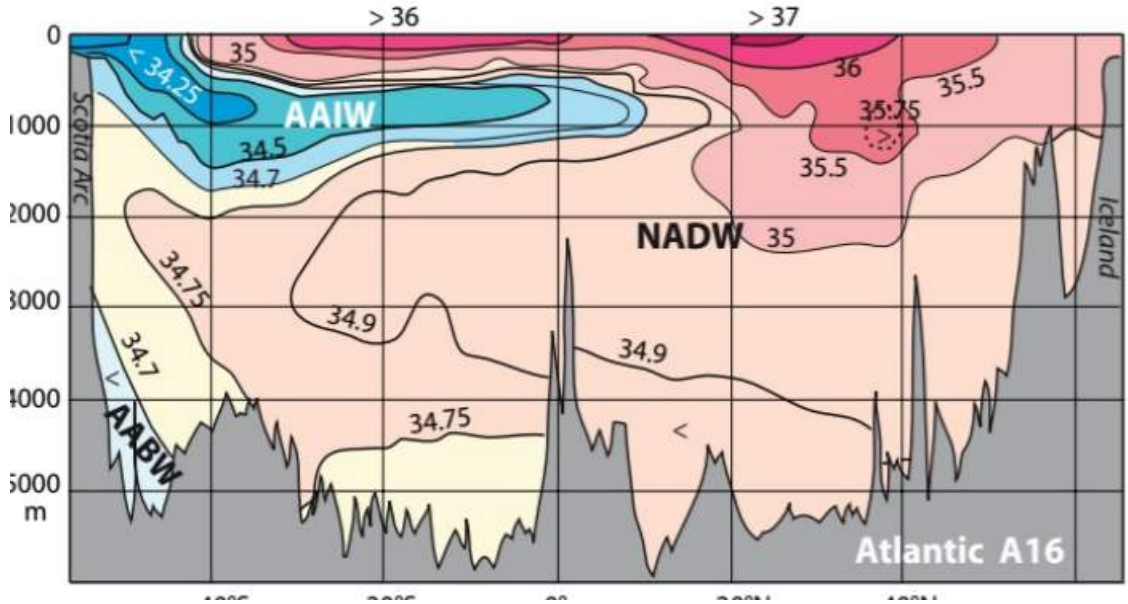
Water masses are bodies of volume of water with specific properties. The water masses get denser and sink in the deep ocean, according to the density they will go at different depths.

> temperature and salinity is conserved for centuries and millennia in these water masses.

Water mass is an important concept.

research vessels see different waters with same properties so they infer that it must be the same water mass propagating.

B. Formation and propagation (continue)

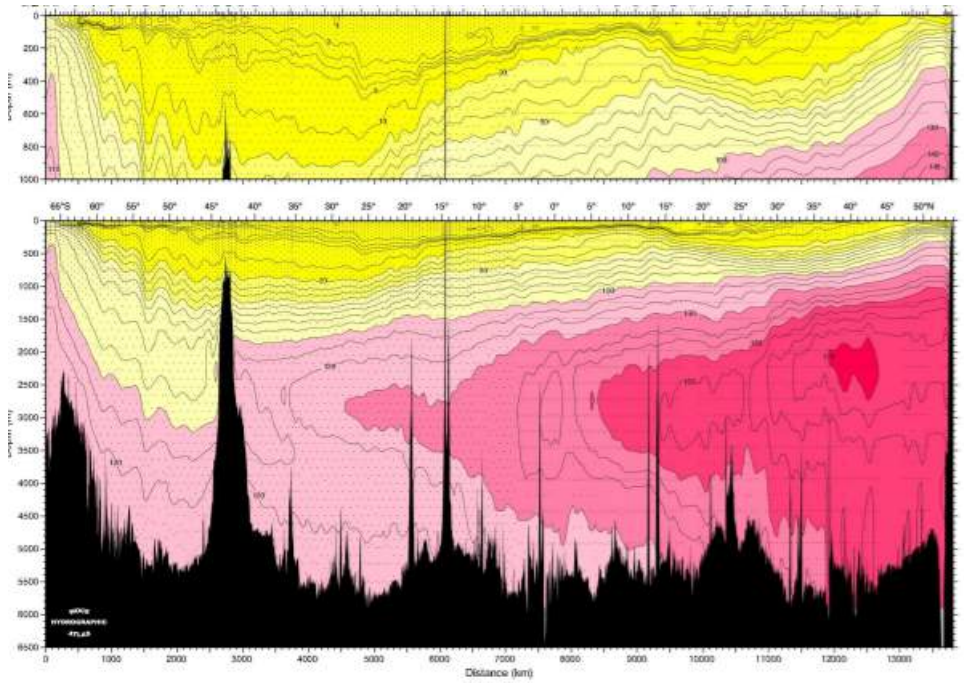


- the blue water here is dense , stabilizes around 1k them slides towards the equator as we said before. This particular water mass has a signature
- Not the blue water subducts between the pink water; the denser goes below the lighter one,they organize according to denisty.
- they AABW and bottom is bottom water , all around Antarctica , brine rejection makes them saline, but mostly because they're cold.

Trackign water masses with tracers

we can track the water masses using tracers.

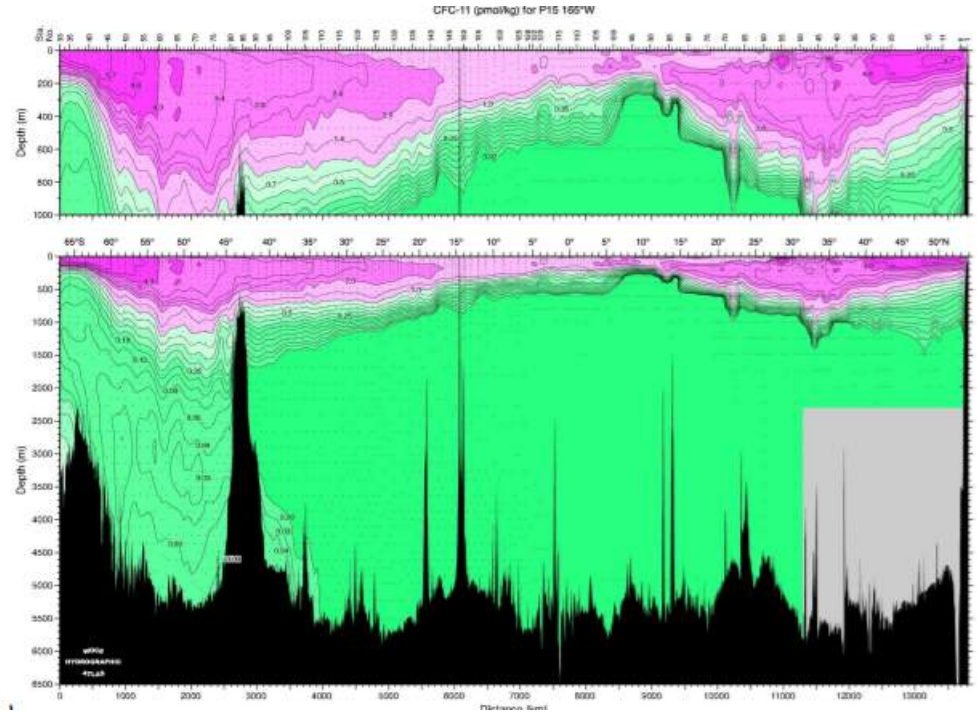
- conservative tracers : temperature and salinity
- biochemical tracers (non-conservative) : oxygen , silicate, nitrate, phosphae, etc



↑ the water masses in the north pacific are older since they have more silicate

> older water masses need not be at the bottom necesarely, there exists places where we form waters that directly sinks in the bottom of the ocean. For instance in the arctic region the water is dense, the water is young and sinks immediately.
>
> > this is actually the contrast between the northern hemisphere and bottom hemisphere on the picture.

- chemical compounds tracers : carbon =-14, chlorofluorocarbons (CFCs)



> - higher concentration near the sense does it make sense and why ? because

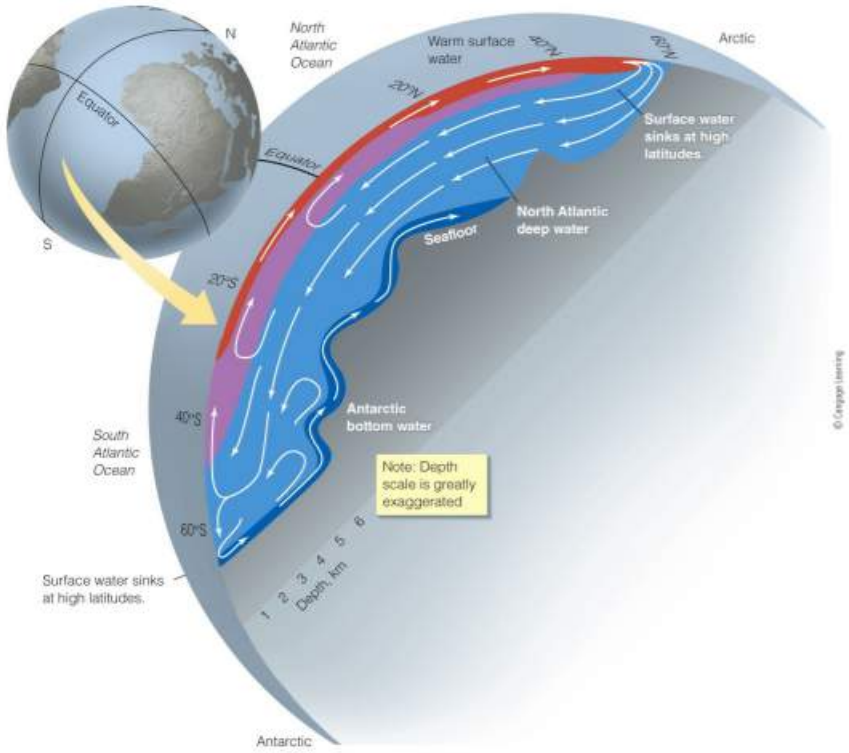
> - Why in the bottom low concentration ? we find in the left portion (antartctica because the fresh water sinks it's dense) for the other part there's no CFC because they didn't have time (CFC have been injected since 1940s, the waters are too old compared to that).

[Remark]

it's in the pacific that we find some of the oldest waters in the ocean $\Longrightarrow$ makes sense !!

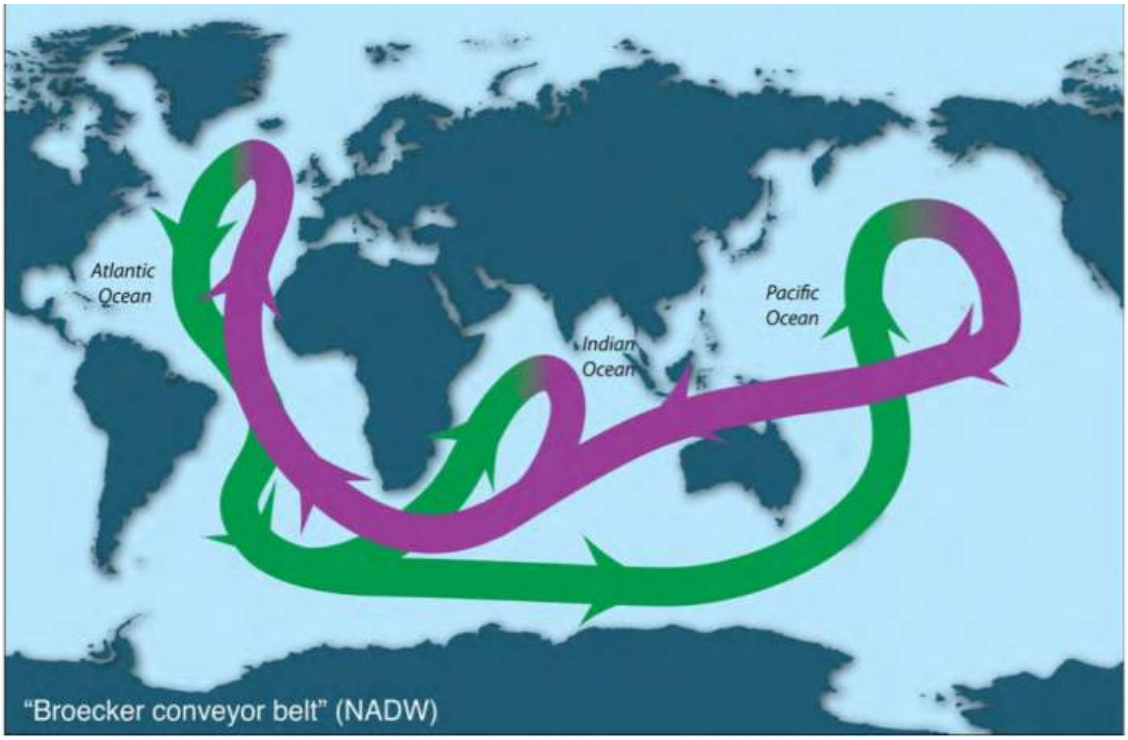
C. The Great Conveyor Belt

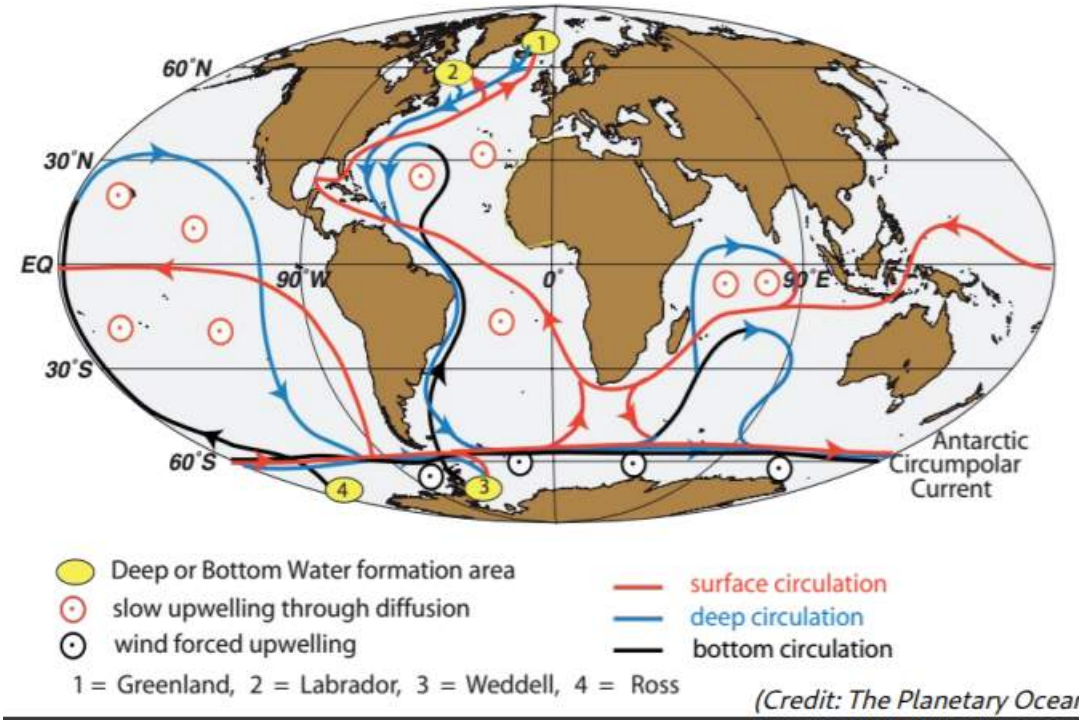
[Definition] the general circuit that water masses accomplish around the world !ocean.



at the poles water sinks then go through the globe as bottom waters ? something like that lol

> the time to traverse the full conveyor belt is very long : <u>about a thousand year</u>
>
> > this slowness is actually very important for the climate
> >
> > - dissolved gasses
> > - heat between low and high latitudes (so thermohaline circulation)
> > - nutrients for biological organisms



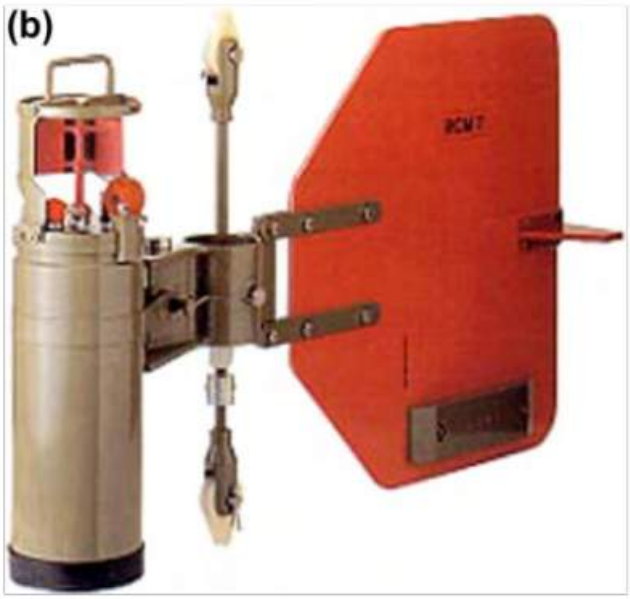


- yellow dots are places where it becomes deep or bottom water formation area
- the deep water upwells to the surfaces through 2 processes
    1. slow upwelling orange dot
    2. wind forced upwelling black dot.

> check written notes for schematic of how the dots work.

D. Studying currents

Current meters



(Source: From 4)

> currents are recorder internally using this. It's a sensor for speed (rotor) and sensor for direction (vane, tail)

- ADCP

  instrument that uses Doppler effect to measure current (more recent in history)

- Drifters

  Anything instrumental made of stuff that can tell us about the circulation. For instance

  - floating carts
  - traces of opportunity,(*remains of ships, containers and their content, plastic, oil, radioactive compounds*) lol.
  - floats : just drifting at the surface

Drift of tennis shoes lost in May 1990 in the North Pacific Current

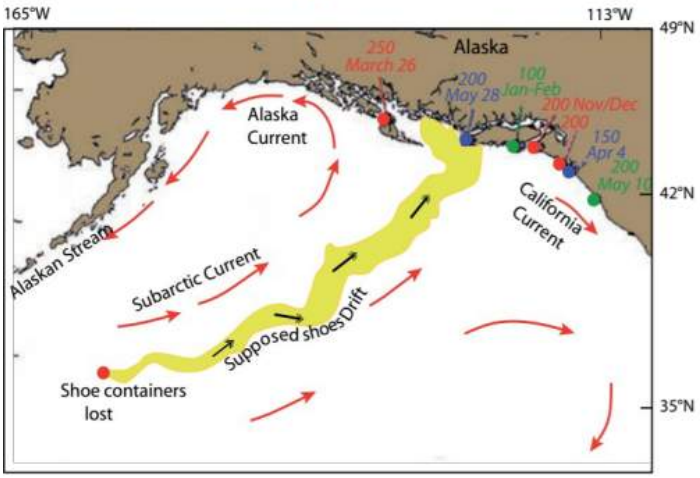
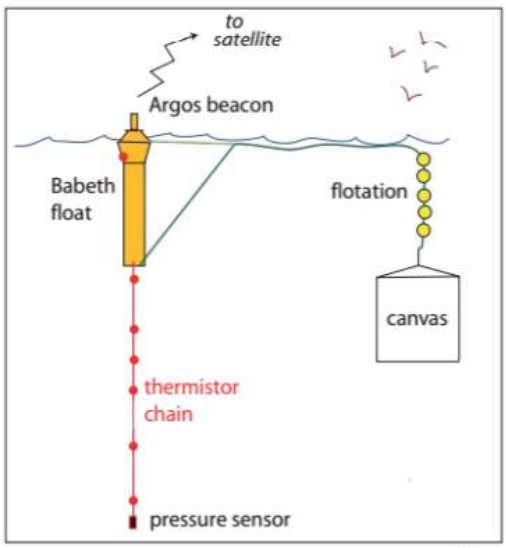


Diagram of a drifting buoy



Waves

> What are waves ?
>
> Oceanic waves are one of the several kinds of waves. There is also other types of mechanical waves
>
> - seismic waves
> - sound waves

[Definition] Disturbance caused by the movement of energy from a source through some medium (solid, liquid ,gas)

Lecture 11

> no class on Tuesday no class on Thursdays but midterm on Friday

Midterm revision

Friday October 15 McDonald 280 for me

- 10 short answer 10 minutes (5 points)
- 4 long answer with schematics 40 minutes (10 points)
- 2 problems (*REASONING*) 20 minutes (4 points)

---

1. Part 1 The physical setting , all 4 parts
2. Part 2 Ocean circulation , no waves

Review both assignments

Lecture	Important concepts, theories and phenomena
Ocean topography	Plate tectonics
Seawater properties	Heat capacity, density
Sea ice	Albedo, ice-albedo feedback
Ocean basins and properties	stratification
Atmospheric circulation	Coriolis effect, convergence/divergence
Wind-driven circulation	Ekman transport, upwelling/downwelling, geostrophic balance
Thermohaline circulation	thermohaline circulation, conveyor belt, water masses

Not complete list above btw

- know how to explain these concepts
- know how to draw associated schematic.

> - density extremely important

> do not memorize numbers, but do understand magnitudes
>
> > focus on the WHY

> place things on figure in some questions, so hand in both booklets.

In situ float stuff must be known

- know the basic geography of the basic oceans
- no name of the currents

Assignment 1

$$\text{ecosystem/animals} \not\subset \text{climate}$$

marine sediments : deposits of insoluble particles that have accumulated on the sea floor, living or non living organisms , for example the phytoplankton or zooplankton, when they die the sink down and that creates sediments on the seafloor.

- the older the crust the thicker the sediment layer (logical, cuz more time for the particles to build up on the layer)
- closer to river : since rivers are hotspots for sediments (they carry a lot)

Easter coast of India thickness

- because presence of river
- thin in the middle of the ocean and thick close to the coast.
- along the coasts exists the shelf and there is the highest chlorophyll concentration, upwelling bringing up nutrients

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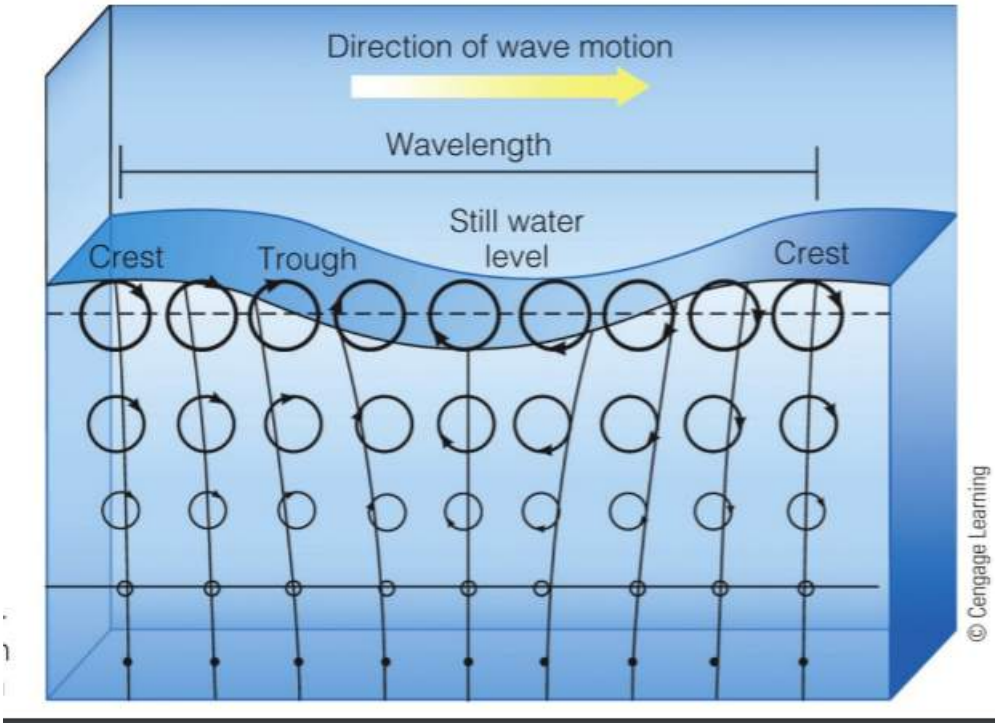
Back to lecture on Waves

> An object doesn't move with that way there is no *transport inpact* the object floats on top locally in a sinusoidal manner.



[Definition] *Progressive wave* : A wave of moving energy

[Definition] *Orbital wave* : A progressive wave in whcih particles oft he medium move in closed circle

> - the progressive waves can occur internally in the ocean as well not just at the surface
> - the diameter decreases with depth
>
> we can actually calculate at which depth the orbital motion is almost negligible that is at half wavelengthof the wave on top !

How fast are waves ?

[Definition] *Celerity (Speed)*

$$C = \frac{L}{T},$$

where L is the wavelength and T the period.

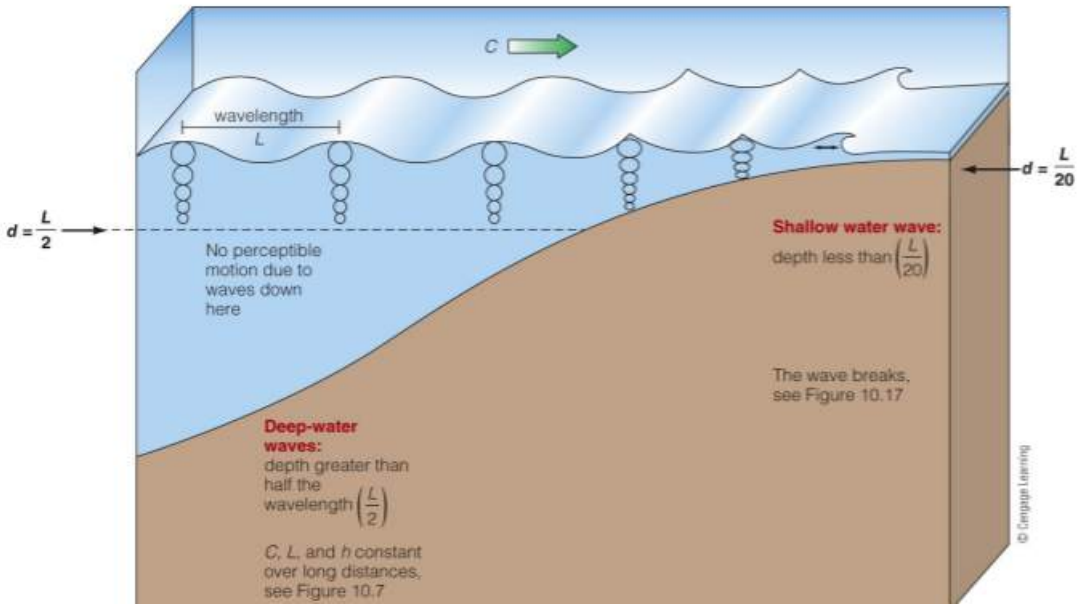
Classifying waves

- Disturbing force (wind for instance blowing the ocean)
- Restoring force (force that competes against the disturbing force)
- typical wavelength

Table 9.1 Disturbing Forces, Wavelength, and Restoring Forces for Ocean Waves

Wave Type	Disturbing Force	Restoring Force	Typical Wavelength
Capillary wave	Usually wind	Cohesion of water molecules	Up to 1.73 cm (0.68 in.)
Wind wave	Wind over ocean	Gravity	60–150 m (200–500 ft)
Seiche	Change in atmospheric pressure, storm surge, tsunami	Gravity	Large, variable; a function of ocean basin size
Seismic sea wave (tsunami)	Faulting of seafloor, volcanic eruption, landslide	Gravity	200 km (125 mi)
Tide	Gravitational attraction, rotation of Earth	Gravity	Half Earth's circumference

Influence of water depth



we saw that orbit decrease with depth and $1/23$ of the diameter at half wave length.

> note on the picture above that the depth impacts the shape of the waves they get flattened as the depth is larger ($\geq d = L/2$)

[definition *deep water waves* : waves moving through water deeper than half their wavelength $L < 2D$, they dont feel the orbital motion of the wave

[Definition] *shallow water waves* : waves moving through water shallower than $1/20$ of their original wavelength $L > 2D$.

Lecture 12

Part 1 : Coast and shore : where land meets the ocean

[Definiiton] (Coast) larger zone affected by the processes that occur at the shore

[Definiiton] (Shore) The place where ocean meets land (boundary)

Canada has the largest coast in the world (300k km approx.)

- more than 40% of the planet's population live within 100k of a coast

The location of coasts depend primarly on

- global tectonic activity
- volume of water in the ocean (if water rises the coast shrinks)

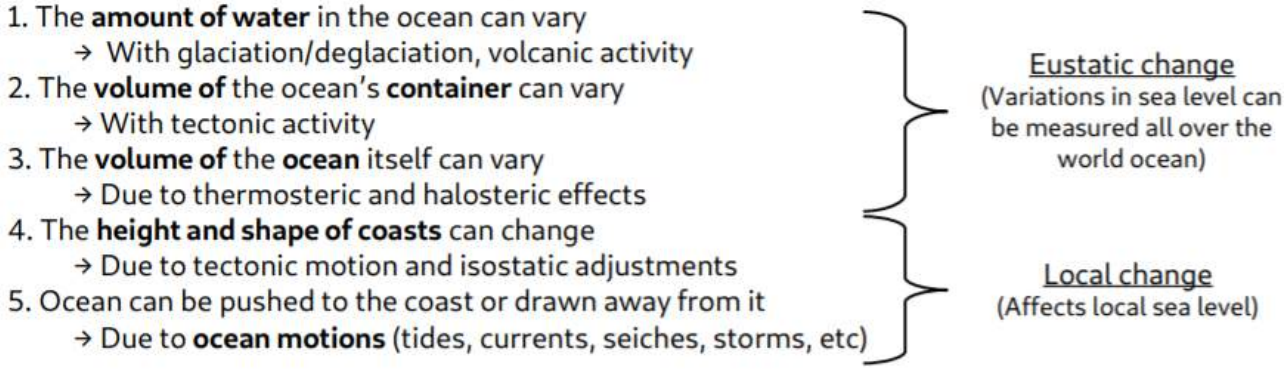
The shape of the coast

- uplift and subsidence (ice melt or something ?)
- erosion and deposition of material

Part A : Factors shaping caosts

Sealevel strongly influences the location aond shape of the coasts

5 factors that influence sealevel :



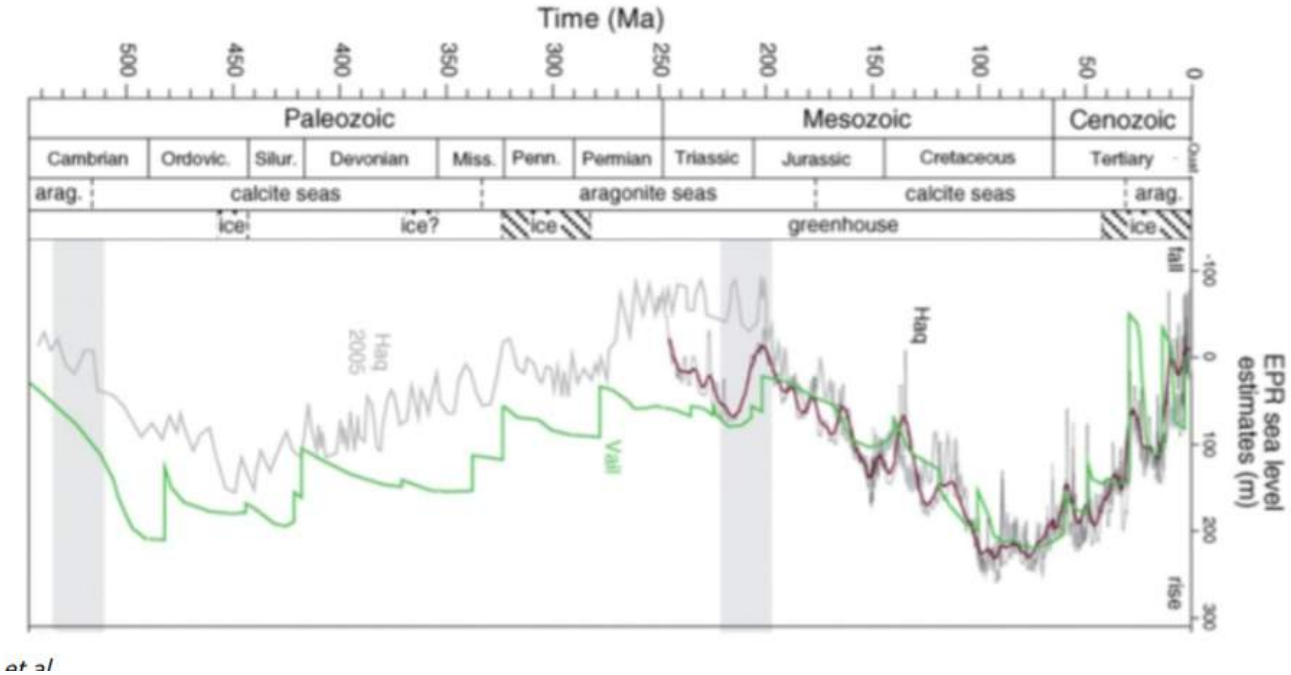
- if ocean is a bucket of wate rif we shrink th ebucket water will overflow. Volcanoes and what not changes the shape.
- If we heat the ocean density will increase so will take up more space (thermostatic). Same with the salt (halosteric)

> local changes (compared to global changes)
>
> - ice sheets melting for instance
> - tides (moon), storms (floads), etc. (rapidly occuring processes (compared to tectonic activities which take millions of years)

Do you know by how much global sea level can vary on geological time?

Over the past 2 million years it changed only around $+6$ to -125 m compared to now

![](



et al

Recap : location is defined tthough slow tectonic process and fast sea level state, tides and storms. The shape we see classificaiton of coasts

Classification of coasts

- Erosional coasts : A coast in which erosive processes eceed deposttional ones
- Depositional coasts : A coast in whcih processes that deposit sediment exceed erosive processes

Part B. Erosional and depositional coasts

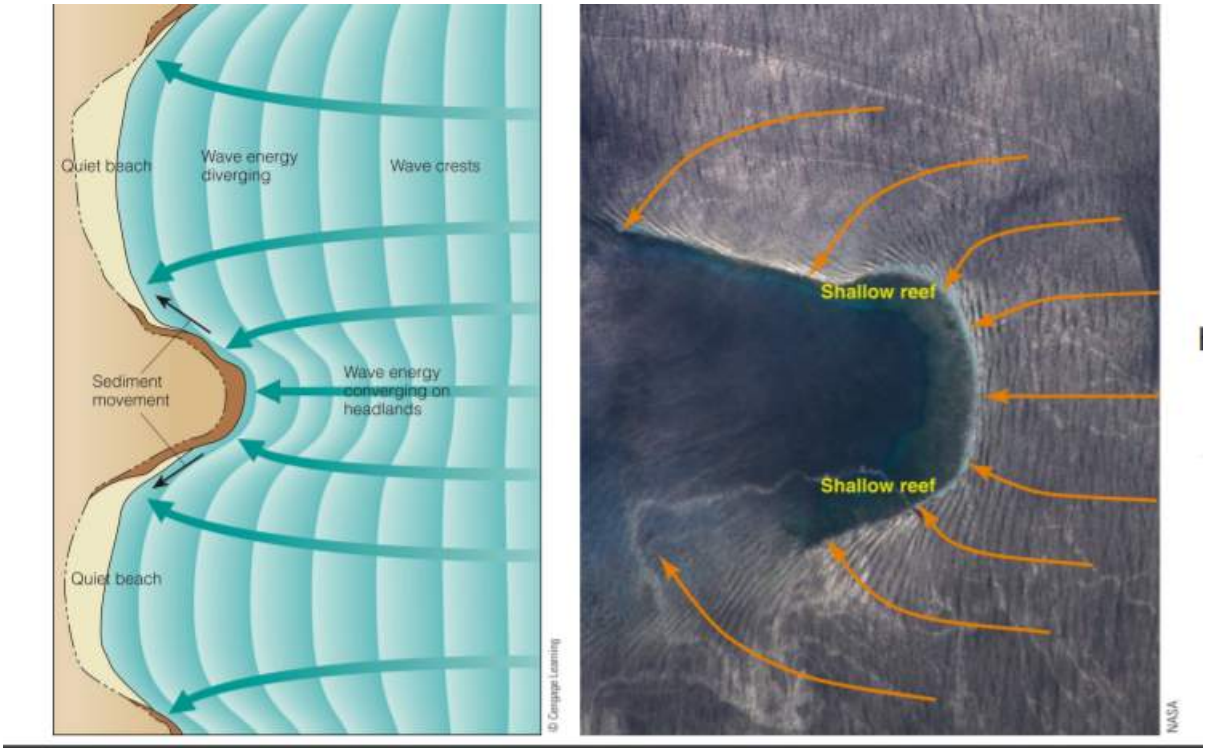
Erosional processes

erosional coasts are relatively new coasts

> both the ocean and the land work on eroding the coast
>
> - from land: steam erosion, wind driven grit, glacial activity, rainfall, dissolution by acids from soil
> - from ocean: crashin waves, action of marine organisms, idssolution of minerals by water

erosion is rapid on high-energy coasts and slow on low-energy coasts

> erosion can strengthen the shore lines so all erosion coasts will become depositional coasts



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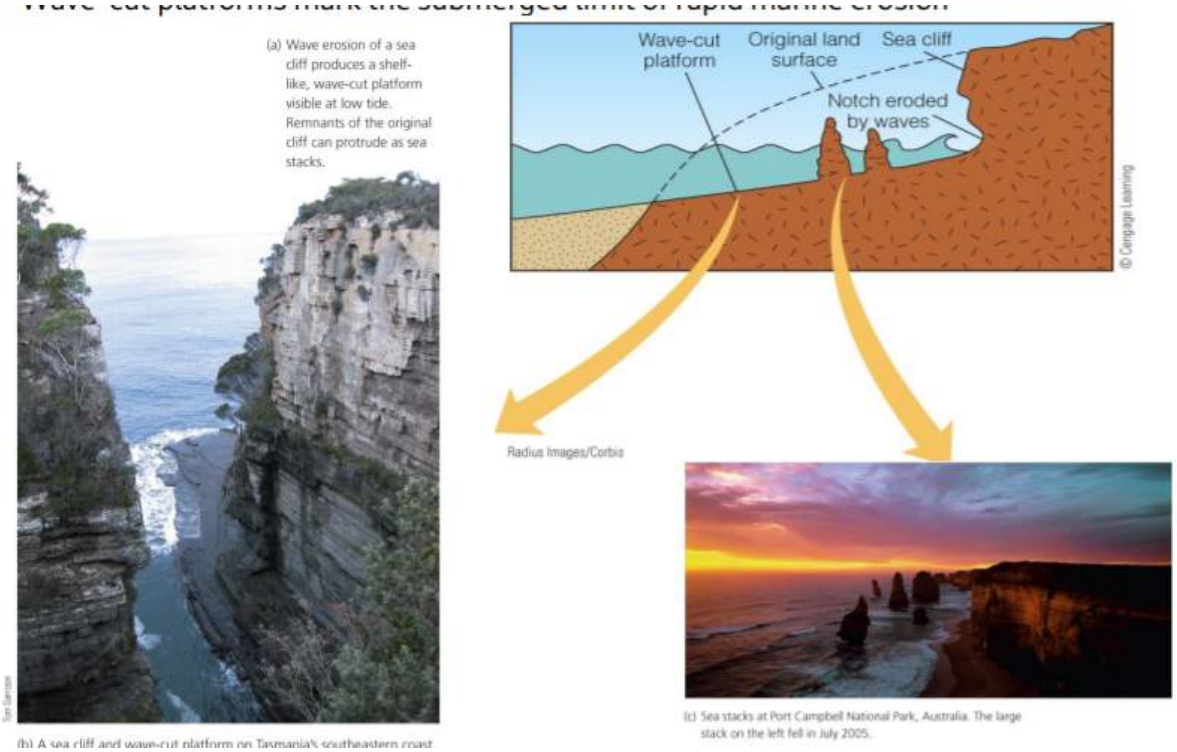
the erosional coast especillay when young is very complex

[Definition] (seal cliff) : A cliff marking the landward limit of marine erosion on an erosional coast



> can lead to complex features like caves and arches.

Depositional processes

steady and growing coasts

> beach is the most common depositional coast
>
> - most dominant process is sediment and coral accumulation

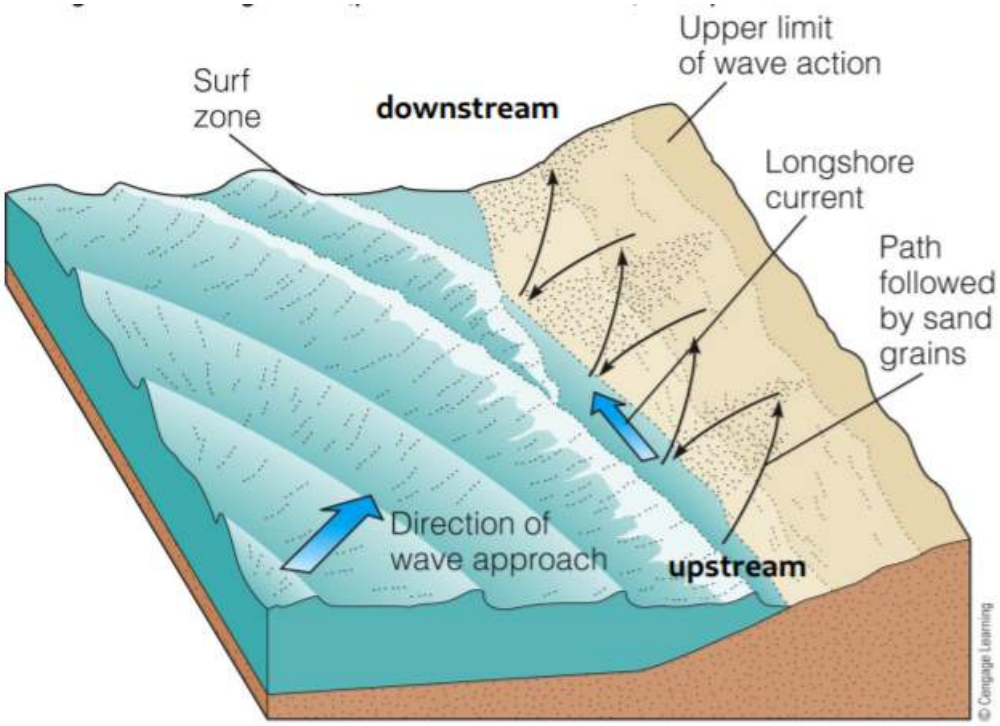
Cast steudy : Beaches

[Definition] (Beach) : A zone of unconsolidated (loose) particles extending from below the water level to the edge of the coastal zone

beaches result from sediments (e.g. sand and gravels) is transported to places suitable for decoposition

> in the winter, the becah is jsut a bunch of rocks, no more sand (it is taken away) because of great storms waves that take the sand away

> the beach undergoes a big transformation year long



The wave approaches at an angle and transports sediments (and takes the sand). The sand goes up and down up and down and effectively it is being transported side ways.

The direction of the longshore drift is in the white arrow's direction. Note how there is more side on the upper sides than lower sides, so the sand is transported upwards.

[Definition] (rip currents) Strong current that moves away from the shore

Part C. Different shapes of coasts

Coral reefs and mangroves

[Definition] (Coral reefs) : A mass of calcium carbonate assembled form coral organisms, algae, mollucs, etc. They remain below sea elve or extend above it

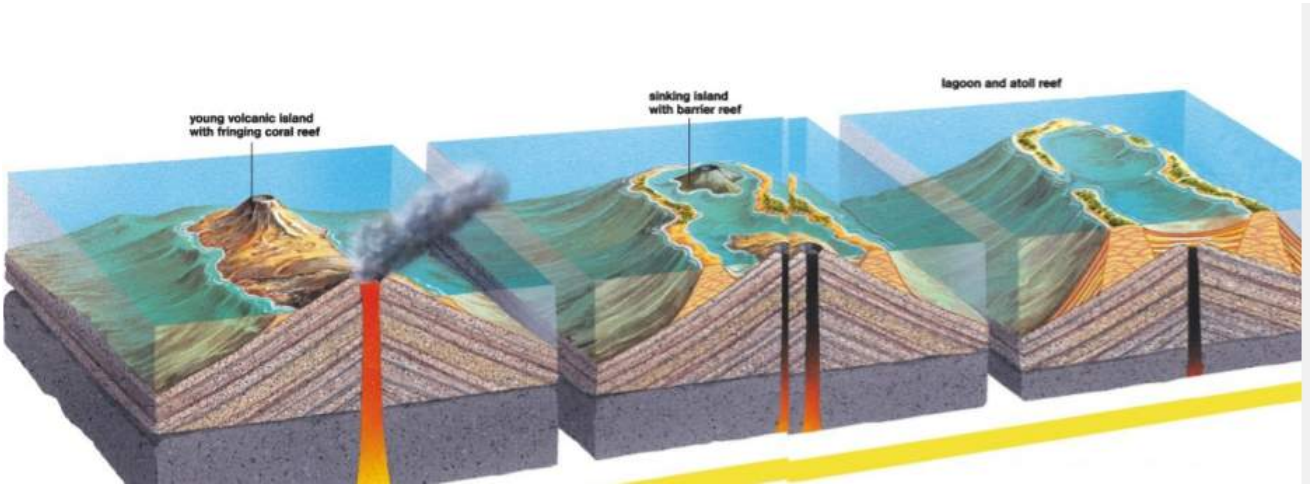
[Definition] (Mangroves) : Trees tha tcan grow in saline water. Root systems trap and hold sediments around the plant

Great Barrier Reef, Queensland, Australia

Mangrove trees

Atolls

[Definition] (Atoll) : A ring-shaped island of coral rreefs and corals debris (almost) enclosing a shallow lagoon from which no land protrudes

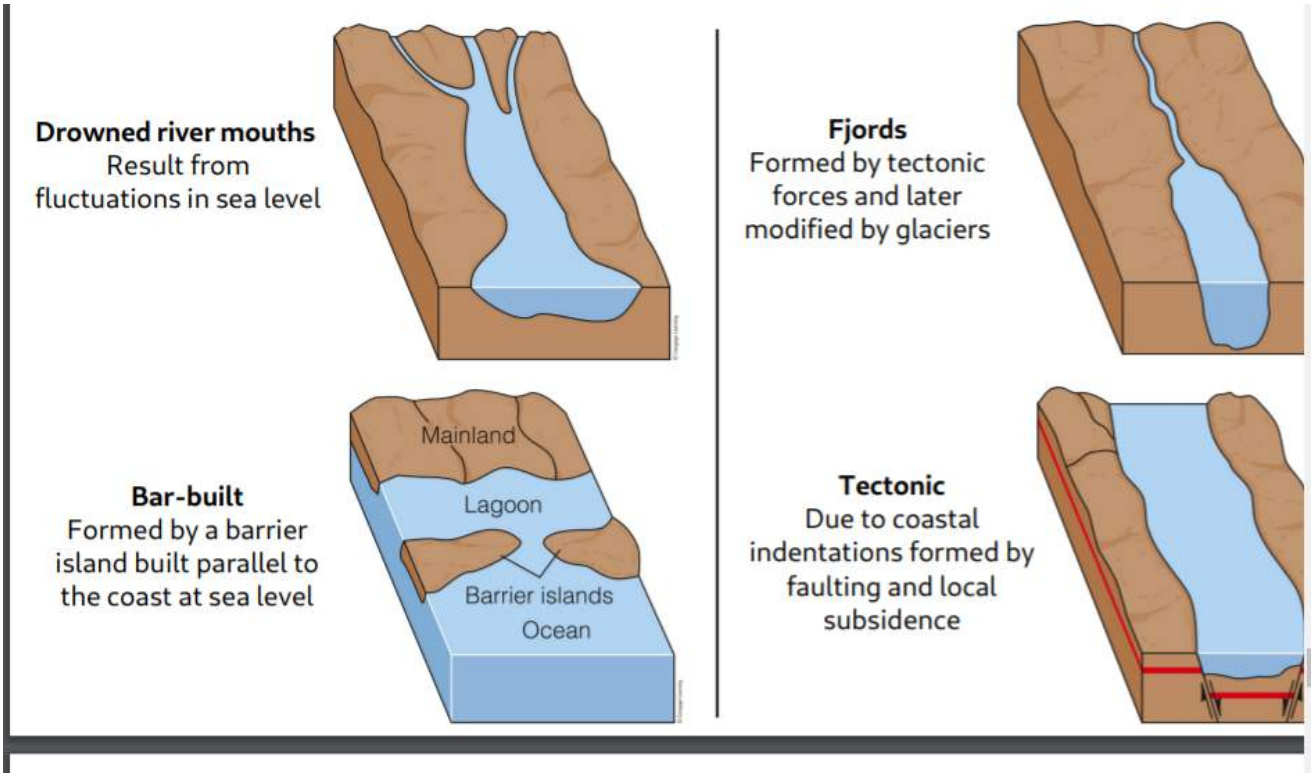


> the corals grow faster than the plates sink down. So corals can grow faster than plate tectonics bsically ?

Estuaries

[Definition] (Estuary) : A body of water partially surrounded by land where freshwater from a river mixes with ocean water

- high biological activities so many people live near them for isntance fish and what not.



They are determined by the formation?

From quebec to sept-iles we have the *St Lawerence estuary !*

Lecture 13

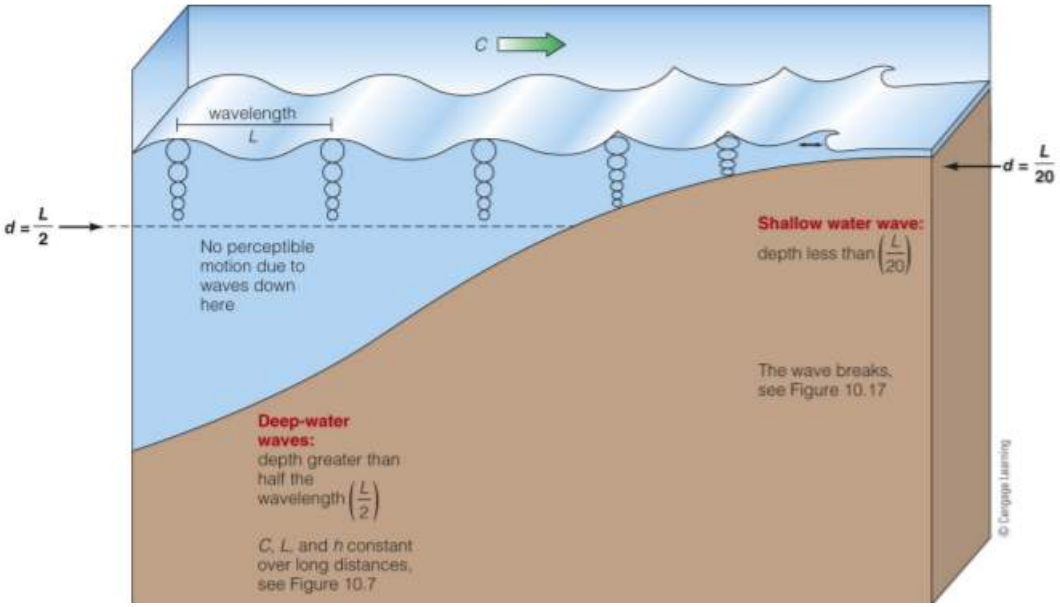
> In Lecture 12, we looked at waves, and we saw the orbital movements that progress as we go deeper

We also described main characteristics of waves, important to know (deepwater wave or shadow wave, wavelengths).

We defined the celerity of the wave as

$$C = \frac{L}{T}$$

we also talked about different types of waves and where they form. Different type of waves form with different types of characteristics and from different forces : wind, gravitational attraction , etc.



$$< d = \frac{L}{20} \longrightarrow \text{shallow wawater wave}$$
$$> d = \frac{L}{2} \longrightarrow \text{deep water wave}$$

is the delimiting line where no perceptible motion due to wave.

[Exercise] Which waves can be deep water waves ?

Table 9.1 Disturbing Forces, Wavelength, and Restoring Forces for Ocean Waves

Wave Type	Disturbing Force	Restoring Force	Typical Wavelength
Capillary wave	Usually wind	Cohesion of water molecules	Up to 1.73 cm (0.68 in.)
Wind wave	Wind over ocean	Gravity	60–150 m (200–500 ft)
Seiche	Change in atmospheric pressure, storm surge, tsunami	Gravity	Large, variable; a function of ocean basin size
Seismic sea wave (tsunami)	Faulting of seafloor, volcanic eruption, landslide	Gravity	200 km (125 mi)
Tide	Gravitational attraction, rotation of Earth	Gravity	Half Earth's circumference

given a depth of 4 km :

waves	wavelength	deep/shallow
capillary	$\mathcal{O}(1\ \mathrm{cm})$	deep since $1 < 2 \times 4$km
wind wave	$\mathcal{O}(100\ \mathrm{m})$	deep
Seiche	$\mathcal{O}(10\ \mathrm{km})$	shallow
Seismic	$\mathcal{O}(100\ \mathrm{km})$	shallow
Tide	$\mathcal{O}(20000)\ \mathrm{km}$	shallow

For tide :

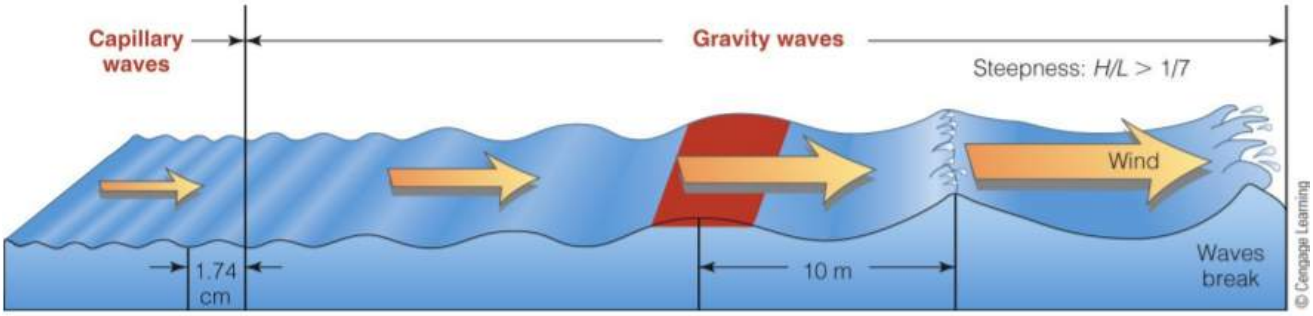
$$\frac{1}{2}\ \text{circumference} \implies \frac{1}{2}2\pi R \quad \text{for } R = 6000\ \mathrm{km} \implies \mathcal{O}(20000)\ \mathrm{km}$$

Part B. Deep-water waves

Wave generation by wind

Wind waves grow from capillary waves

The ripples grow in wave length progressively until they become wind waves.



> As they grew into wind waves theres gravity flatteing it, and wind producing deformation , this creates a competition and by extension an oscilliation
>
> > pretty much like a mass oscillating on a ressort (ressort force and gravity (eventually reaches equillibrium state because of evergoing friction))

Sea is a chaotic region of wavelengths. Different heights and lengths etc.

[Definition] *Wave steepness* : Raito of wave heightt to wavelength

$$\frac{H}{L}$$

Factors tha tinfluence wind wave developpement :

wave size increases with :

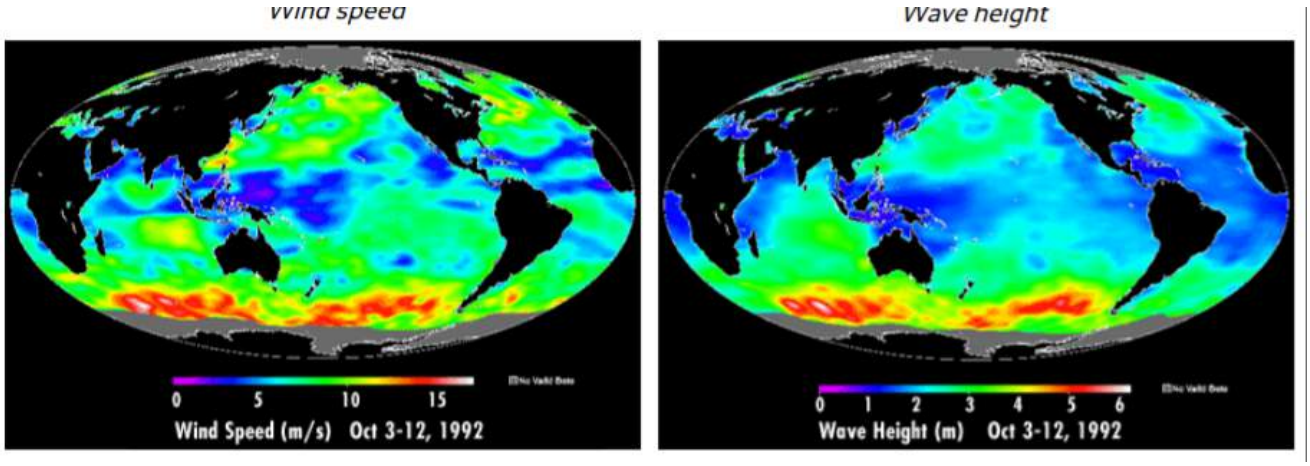
1. Wind strnegth : average speed of the wave
2. Wind duration : The longer the wind blows (storm) the longer the wave will have time to fully develop

   ex: high winds over short period of time, nope, need more time
3. Fetch : THe inenterrupted distance the wind blows withour a signifcant change in direction

   ex. cyclones dont grow many high waves compared to wind pushing unidirectionaly.

[Q] what is the region which typicall ahs the largest smallest waves ?

- largest : souther ocean
- smallets : around the equator and the torpics



↑ *observe the good correlation between wind speed and wave heigth.*

[Q] what is the region with the greatest potential fetch?

- in the southern ocean, very strong westernly winds around there, they blow all around the continent and are ininterrupted.

[Q] what are the chances to have fully developpes sea in a cylonic storm ?

- very low since no fetch of course

Wave dispersion

[Definition] (*Dispersion*) Separation of wind waves by wavelength as they mowe away from the fetch

organisaton of waves according to their wavelengths :

$$\text{long} \rightarrow \text{intermediate} \rightarrow \text{short}$$

[Definition] (*Swell*) Mature windwaves of one wavelength that form orderly undulations of the ocean surface.

this long train of waves form the effecg of swell.

[Q] Which waves do you think would announce first a storm for an observer far from the storm? Long waves or short waves?

- the long ones they travel the faster !

The celerity of deep water is

$$\boxed{C = \sqrt{\frac{g}{2\pi}L}} \implies C = 1.25\sqrt{L} = 1.56T$$

Comes from the formula

$$C = \sqrt{g\frac{L}{2\pi}\tanh\frac{2\pi D}{L}}, \qquad L << D$$

[Problem] Consider a wavelength of 20.0 m travellign over an ocean floor witha depth of 3000.0 m

1. is it a deep or a shallow water wave ? deep since $20 \times 2 < 3$ km
2. what is the celerity of the wave?

   $$C = \sqrt{\frac{9.81}{2\pi} \times 20.0}$$

   but also , and better <

   $$C = 1.25\sqrt{L} = 1.25\sqrt{20} = 5.59 \text{ m/s}$$

3. Wha tis the period of the wave ?

   $$T = \frac{L}{C} = \frac{20.0}{5.59} = 3.58 \text{ s}$$

Interference

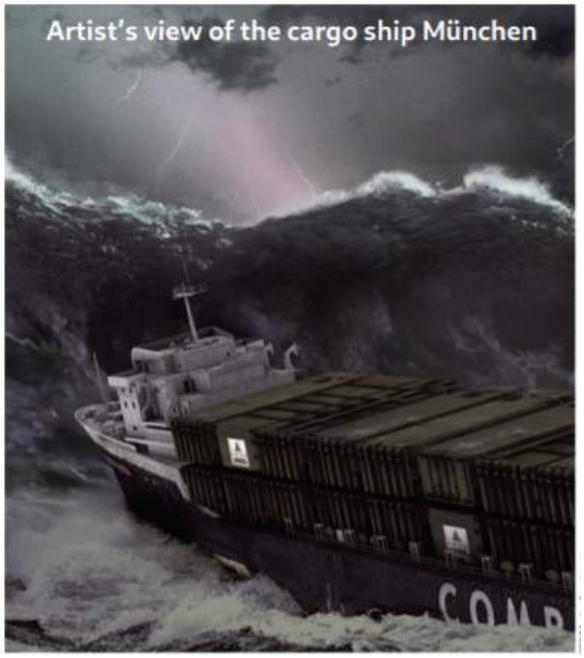
[Definition] (*interference*) : interactoion between waves, resulting in addition or substraction of wave energy

- constructive : addition, producing larger wave
- destruvtive: susbtraction , producing smaller waves.

[Example]

- surf beat : result of constructive interference. (quiet water then desctructive interference)
- rogue wave (freak wave) : unexpected huge wave that suddenly emerge (rare events). it used to be thought it's mytology lmfao !!

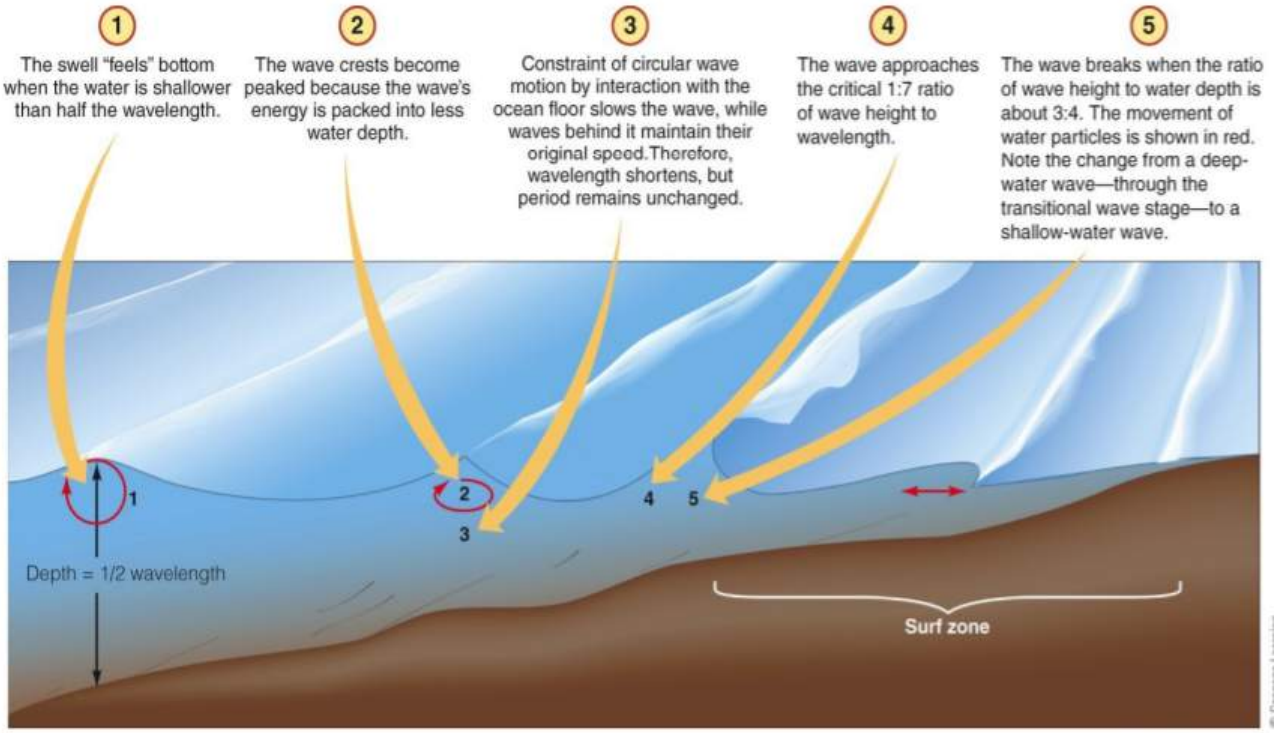
→ Results from constructive interference



Lecture 14

> Last time we saw the difference between deep water waves and shallow water waves
>
> - deep water waves don't feel the ocean floor
> - if in contrast it feels the ocean floor then it's a shallow water wave.
>
> 2 criteria of distinction :
>
> - wavelength (greater less than)
>
> capillary waves are small and are transported in wind waves, so for the deep water waves we primarly consider the wind waves.
>
> important concept : ocean swells formation process of dispersion.

Transiti!on from deep to shallow water waves



friction slows down the wave. the bototm of the wave is slowed down by friction of the ocean floor while the surface wants to go faster so it tilts, and increases steepness. decceleration and slowing down

the wave peaks and gets steeper where the steepness is H/L .

> the wave approaches the critical $1:7$ ratio of wvave height to wavelength, it can't go higher than that otherwise it breaks.

[Definitiion] (*Surf*) : Region betwen the reaking waves and the shore.

> waves don't necesarelt break their energy can dissipate through the ocean floor .

The celerity of shadow waver waves is

$$C = \sqrt{gD} \qquad \text{where } D: \text{ water depth}$$

[Problem] Consider a wave of wavelength 20.0 m travelling over an ocean floor with a depth of 3000.0 m

1. What is the tallest this wave can grow before breaking ?

$$\frac{H}{L} < \frac{1}{7} \implies H = \frac{L}{F} = \frac{20.0}{7} = 2.86\ m$$

2. At what water depth would it become a shallow water wave?

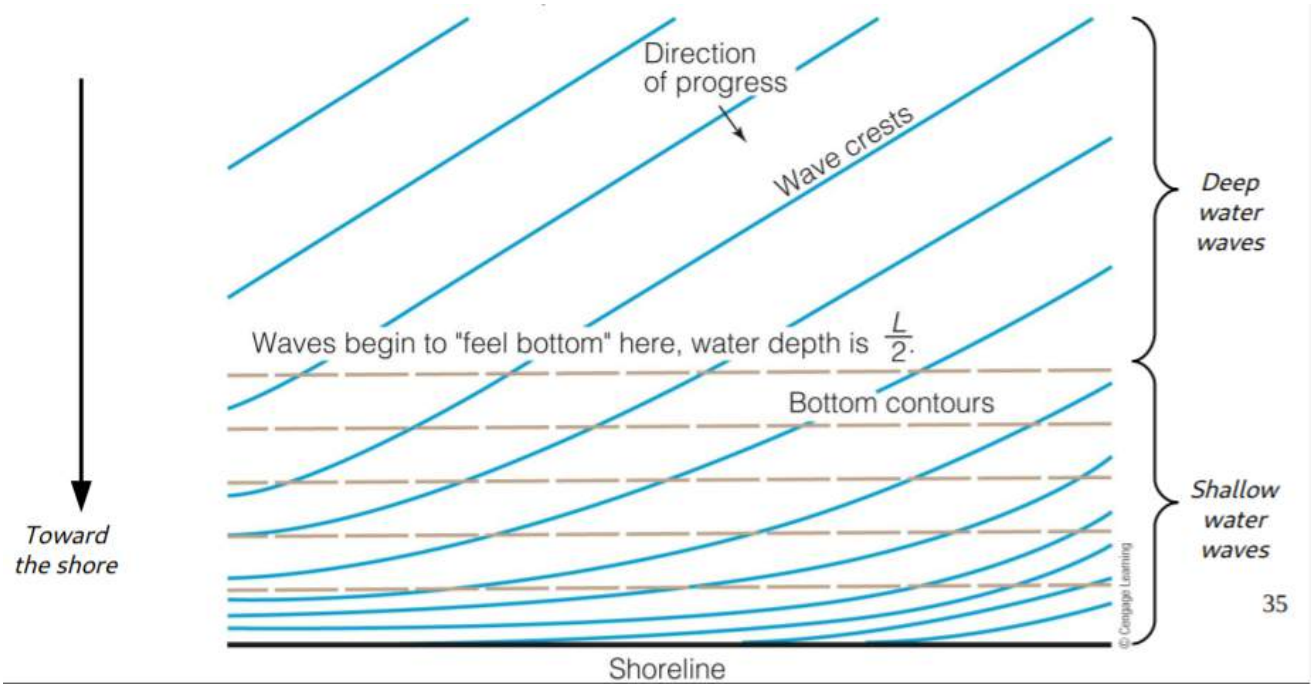
$$L \geq 20D \implies D \leq \frac{L}{20} = \frac{20.0}{20} = 1.00\ m$$

3. What would the celeiry of the wave be in water with a depth of 0.90 meter ?

$$\begin{aligned} 0.9 < 1 \implies \text{shallow water wave} \implies C &= \sqrt{gD} \\ &= \sqrt{9.8 \times 0} \\ &= 2.97\ \mathrm{m/s} \end{aligned}$$

Refraction

[Definition] (*Refraction*) Slowing and bending of progressive waves in shallow water



The train of waves approaches at an angle (no reason). on top we have deep water waves they dont feel the deep water ocean. As they go down they start feeling the sea floor so they transition into shallow water waves. The celerity starts decreasing.

> givne a specific line (wave) it starts on top at C_1 then as it enters in the shallow it has celerity C_2 where $C_2 < C_1$. The direction bends so the slower the wave the more it bends and lags behind. this is the refraction .This is wahat causes this wave to bend (recall sound refraction in ocean with the SOFAR layer).

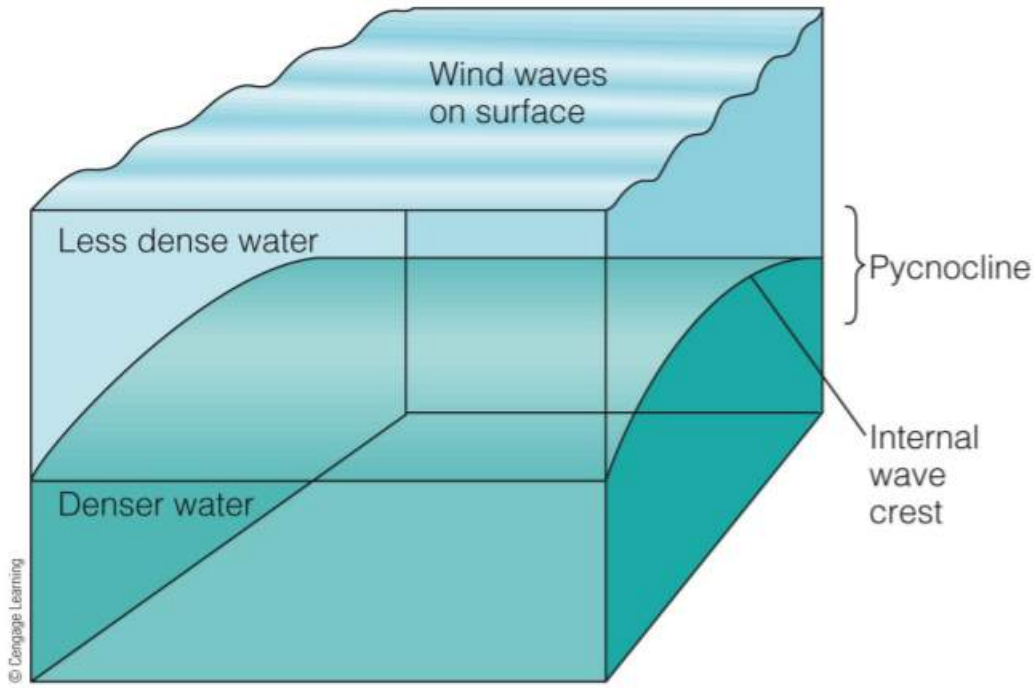
this results in a interessting property , the wave arrives at the shore lien almost parallel.

↑ middle left is the shore, from top they arrive in a certain direction, and they progressively bend (bottom) as they approach the shore.

Part D. Some distinctive waves

Internal Waves

[Definition] (*Internak wave*) Subsurface wave forming at the boundary between water layer of different densities.



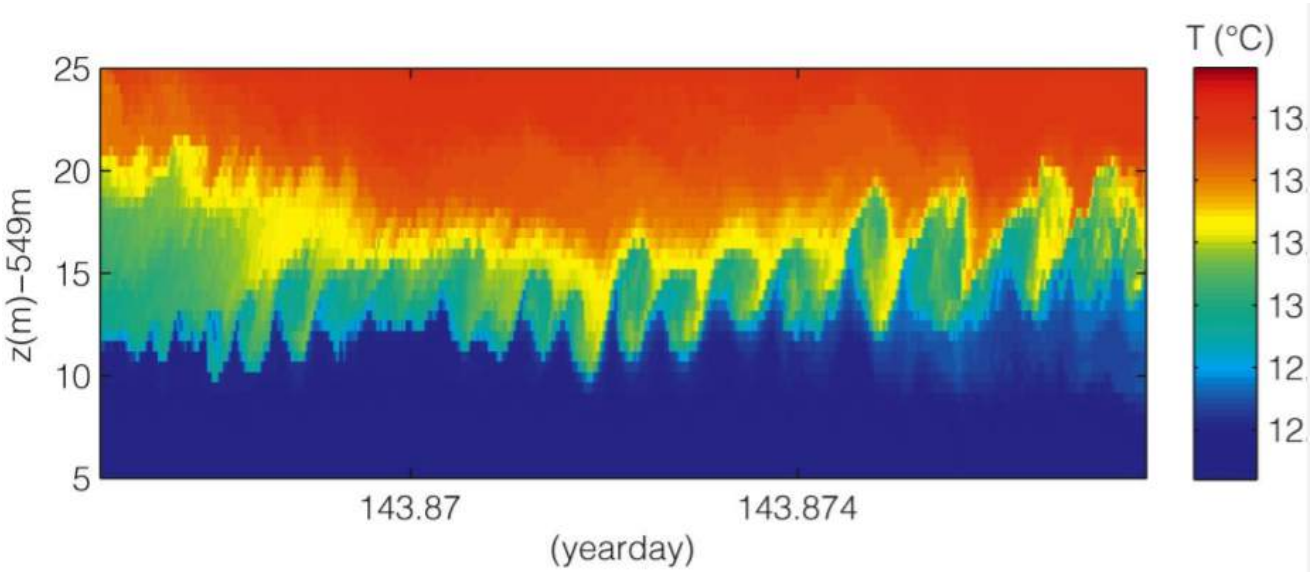
> they occur at about the pycnocline (where we have a strong change in density)

```
-------- surface

 (wave)==>    _     <- current has turbulence ,make wave
             / \
       _____/   \___    <-- topography feature
```

[Importance] of internal waves :

1. they can mix nutrients into sruface water and can trigger plankton blooms. (or bring some oxygen and carbon to the surface)
2. they can affect submarines and oil platforms

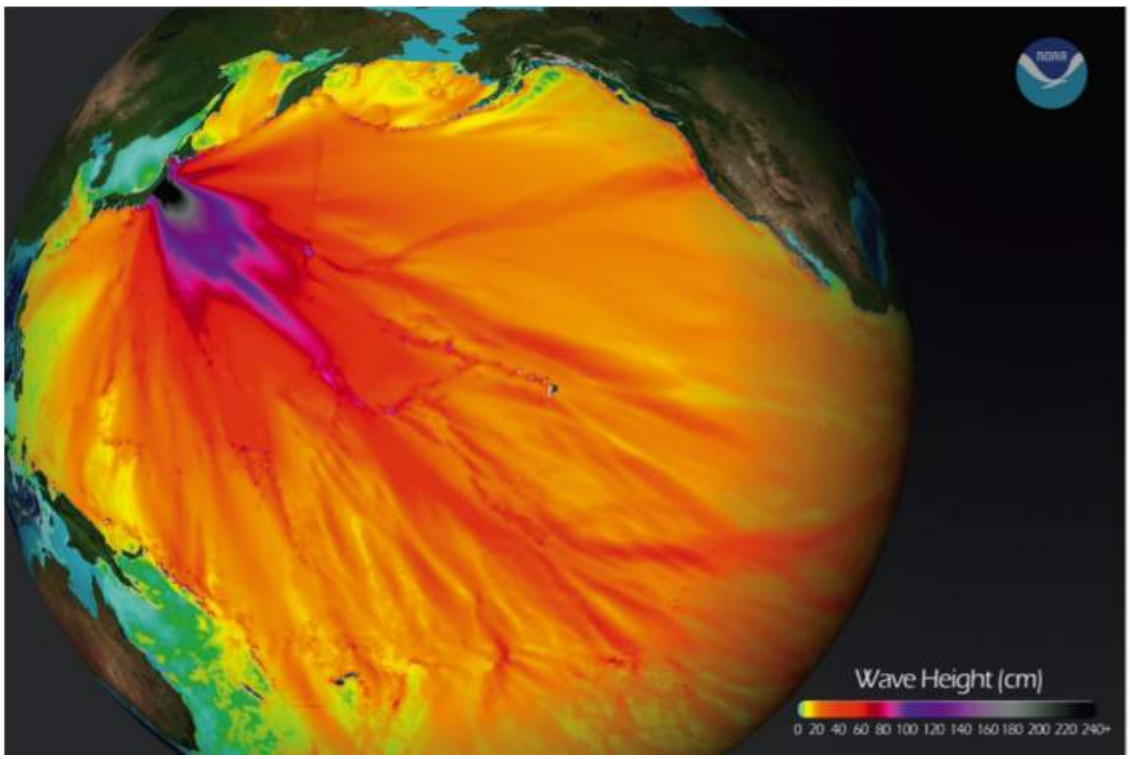


- ↑ perturbation in the temeprature (so also salinity and density and everything) by the internal waves, we deduct from this they have around ~ 10m height.
- this affects the thermoline circulation

Tsunami

[Definition] (*Tsunami*) Long wavelength (up to 200 km) , shallow water progressive wave caused by the rapid displacement of ocean water.

- up to 200km wavelength progressive waves.
- they are always shallow water waves because their wavelengths are so long.
- Causes :
    1. diveregence of tectonic plates creates a water dropl.
    2. Can also be caused by land slide (big chunk of land falling on water).
    3. Iceberg (same idea big chunk of ice falling in water)
    4. subduction of a plate tectinic into another causes stress, when that stress is released it causes a big pressure upwards makigna tsunami.



↑ the propagation of the tsumami is heavily influenced by the topography, because shallow water waves so only depends on depth (refraction invovled, this is why the propagation is not homogenous)

- note in the picture above,the wave heightincreases as it approaces the coast because the energy gets focused. the wave slows down, gets steeper gets higher (height increases as it approaches the coast)

[Problem]

1. Given that a typical Pacific abyssal depth is about 4,600 meters, how fast did the 2011 tsunami travel? (distance japan-hawaii is 6600 km)

$$C = \sqrt{gD} = \sqrt{9.8 \times 4600} = 212.3m = 210 \text{ m/s}$$

2. How long did it take for the tsunami to hit Hawaii? How about Canadian coasts?

$$C = d/t \implies t = d/C = \frac{6.6 \times 10^6}{2.13 \times 10^2} = 3.11 \times 10^4 \ s = 8.6 \ h$$

Once a tsunami is generated, its steepness is extremely low (so it passes unoticed by ships). As it approaches the shore the period of the wave remains constant its velocity drops, and the wave height greatly increases.

> so in the middle of the ocea a boat will be on top of a small height tsunami for like 8 minutes ! So it pases unoticed (it's not a big wave in the middle of the ocean).
>
> > only as it approaches the shore the height increases substantially.

If the through arrives at the coast first then the shore water will receed and reveal all the rocks on the seafloor (can be like 100m).

> multiple crests not just one ! if one tsunami passes by, expect another one

- several crests
- water receeding

Lecture 15

Tides

> - Affected by the moon
> - tides are shallow water waves (long wavelengths)

Tides are Waves

Definition of tides

[Definition (*Tide*) Periodic, short term changes in the height of the ocean surface at a particular place, caused by a combination of gravitational force of the Moon and Sun, and the motion of Earth.

> - tides are the longest of all waves
> - forced waves: waves that are never free of the forces that cause them.
> - 18000 km wavelength WTF !!!

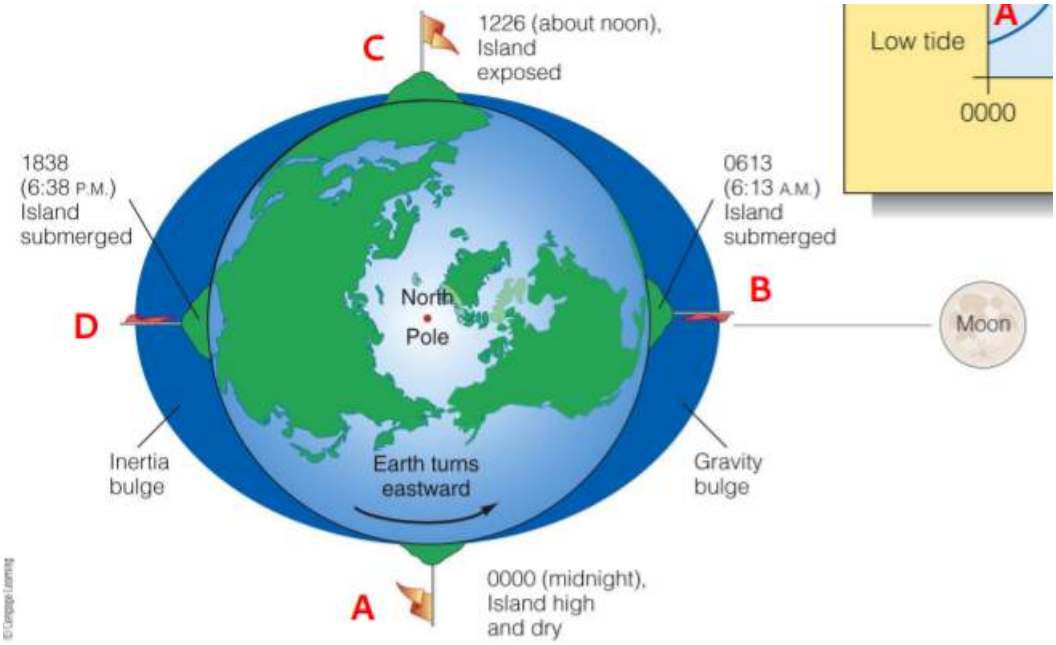
Impact of tides

- influence coastal marine life (aquatic $\iff$ not aquatic)
- currents can transport and erode sediment (back and forth movement at the coast) they can even shape the coast through that perpetual back and forth movement.
- mixing and ocean circulation in general (friction $\implies$ turbulence $\implies$ upwelling and so on)

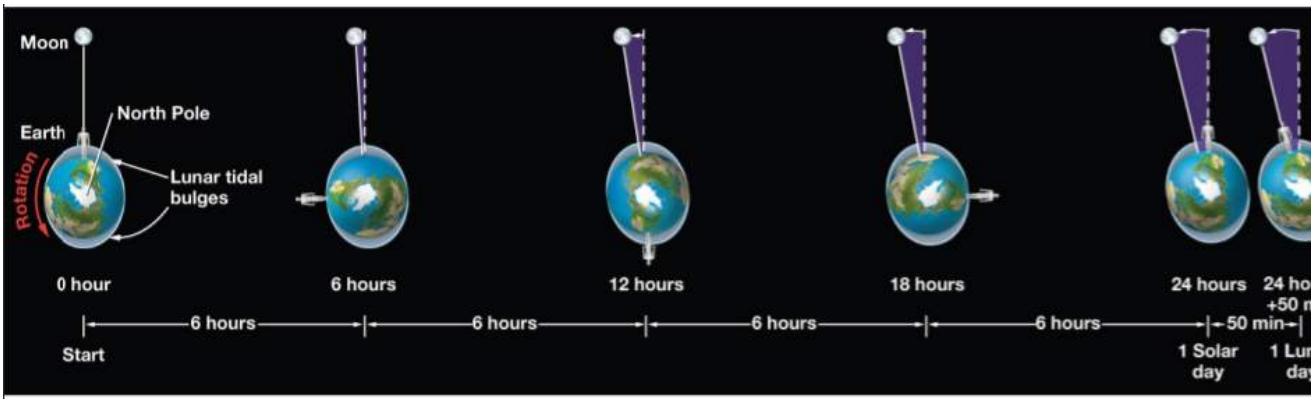
B. Equilibrium theory of tides

Introduction

> - centrifugal force pulling earth away from the moon
> - gravitational force pulling earth into the moon



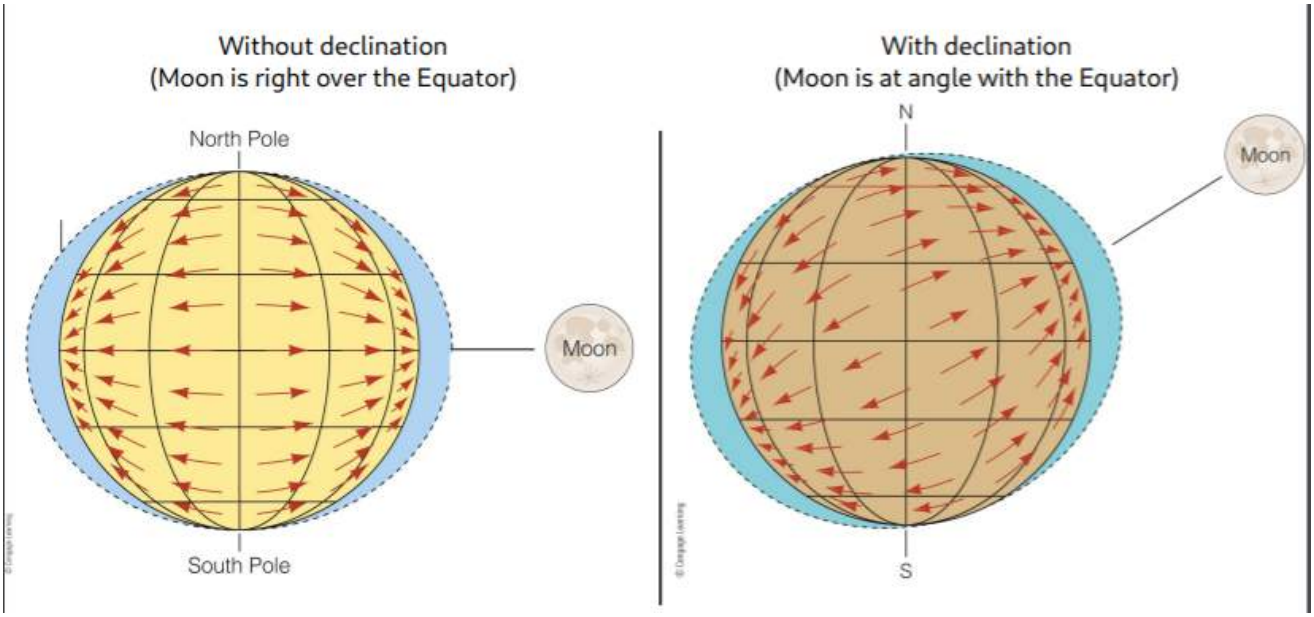
> [important the tidal cycle is not 24h long because a lunar day is 24 h and 15 minutes long (not a solar day of 24 h).



Note that the moon moves a little bit after each 6 hours. After a full circle the moon has moves eastward by about 50 minutes.

Case B : Moon & Earth only, WITH inclination of moon

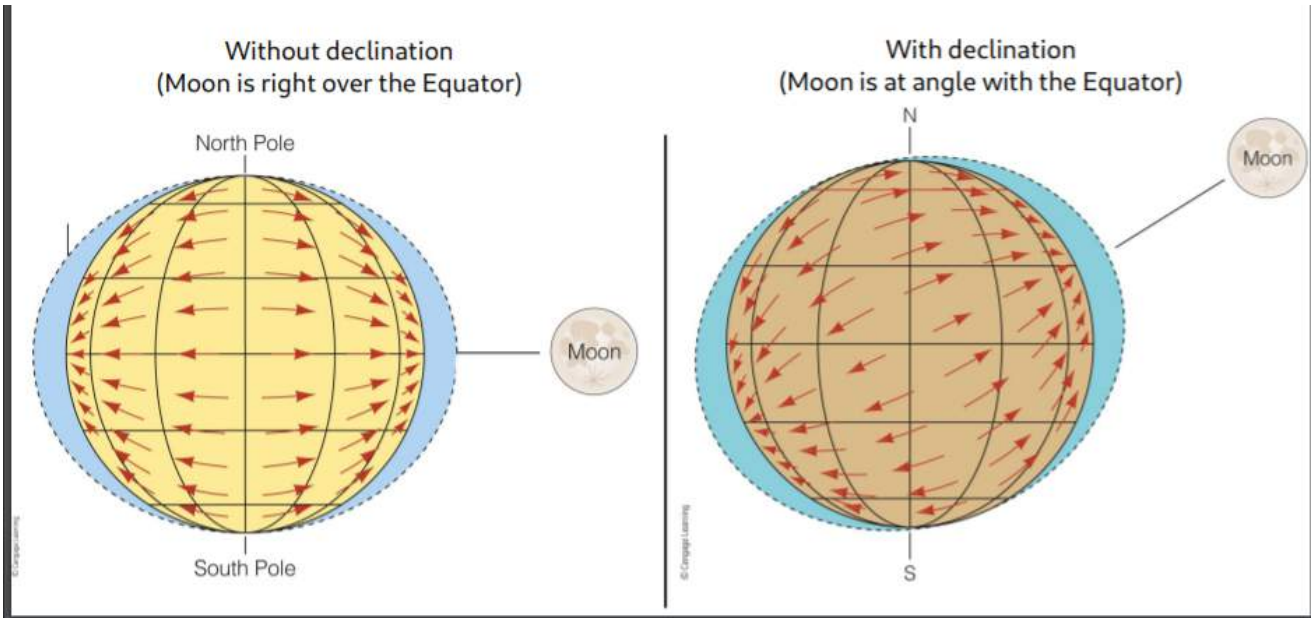
The moon does not stay right over the equator, Every month it moves from as high as 28 to -28 degree above Earth's equator.



Lecture 16

Case B : Moon and earth with declination

The moon is at an angle with the equator actually



Case C : Moon, Sun and earth without declination

[definition] Tides caused by gravitational and inertial interaction of the Sun and Earth

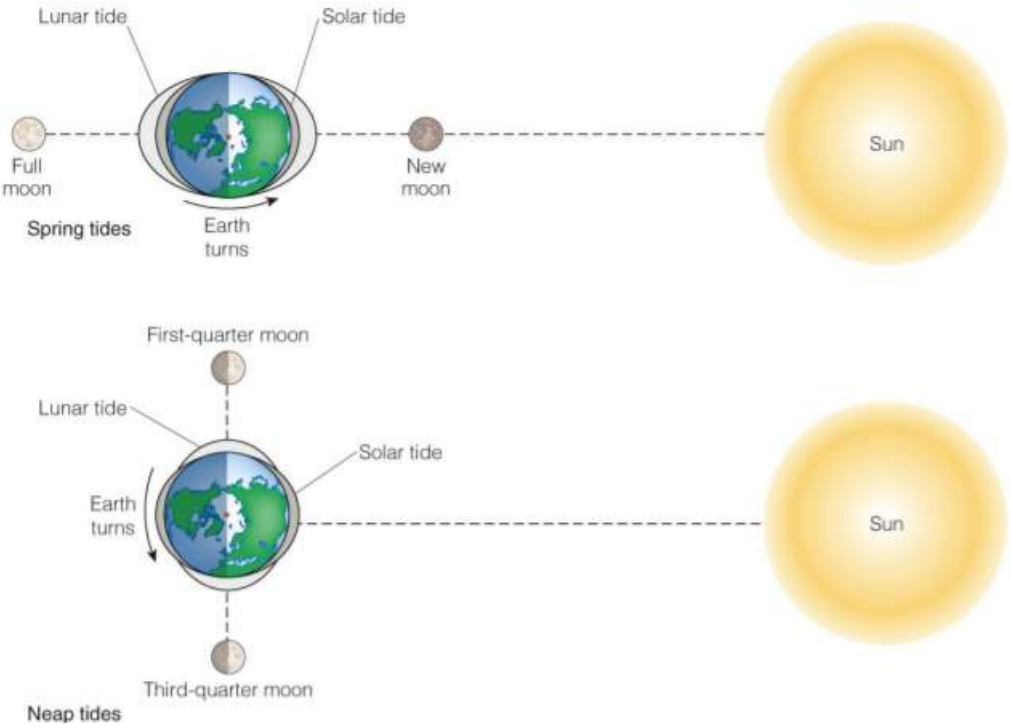
> solar bulges tend to follow the Sun through the day

[note] the sun's influence on the tides is only 46 % that of the Moon's

- because while the sun is more massive than the moon it is far farther
- *solar bulges smaller than lunar bulges*

> the 2 bulges live together at the same time

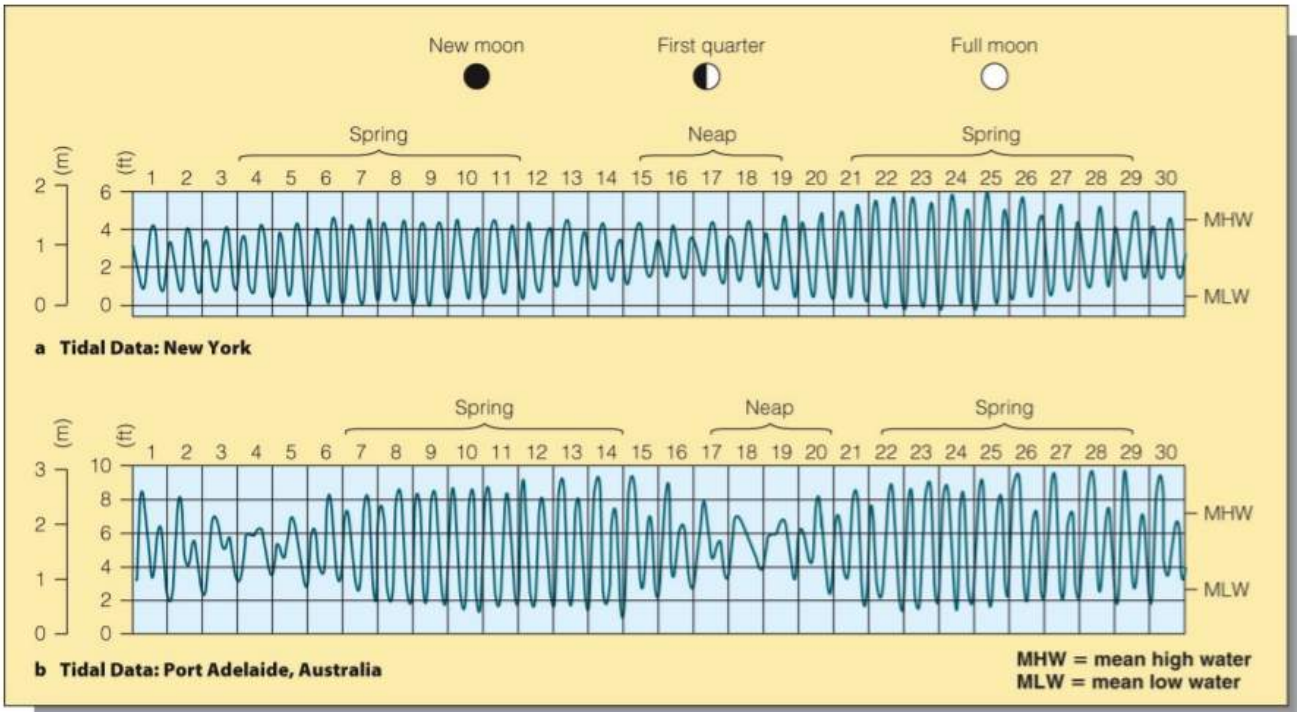
[definition] (*astronomical tides*) Tides caused by intertia and the gravitational force of the sun and moon



> ↑ not in the second schematic the solar pull does not affect the height of the lunar pull.

[definition] (*spring tides*) : occur when Earth, Moon, and Sun are all in a line

[definition] (*Neap tide*) : Occur when Earth, Moon, nd Sun form a right angle



C. Dynamic theory of tides

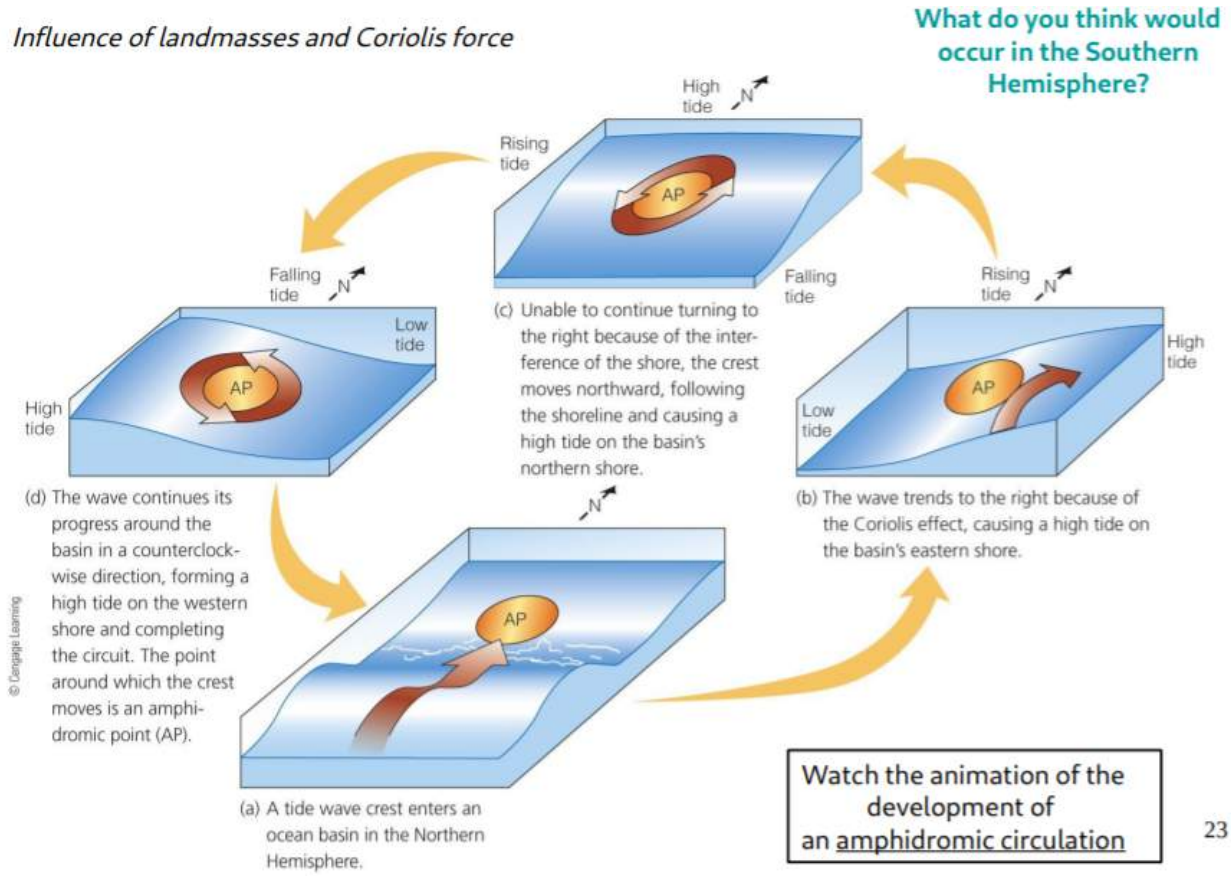
> theory introduced by Pierre Simon Laplace in 1775

Newton knew that his explanation was incomplete. He found that maximum lunar tides give 55 cm and solar tides 25 cm, i.e., less than a meter, but we could observe that they can go over a meter easily.

Assumptions by Laplace in newer model

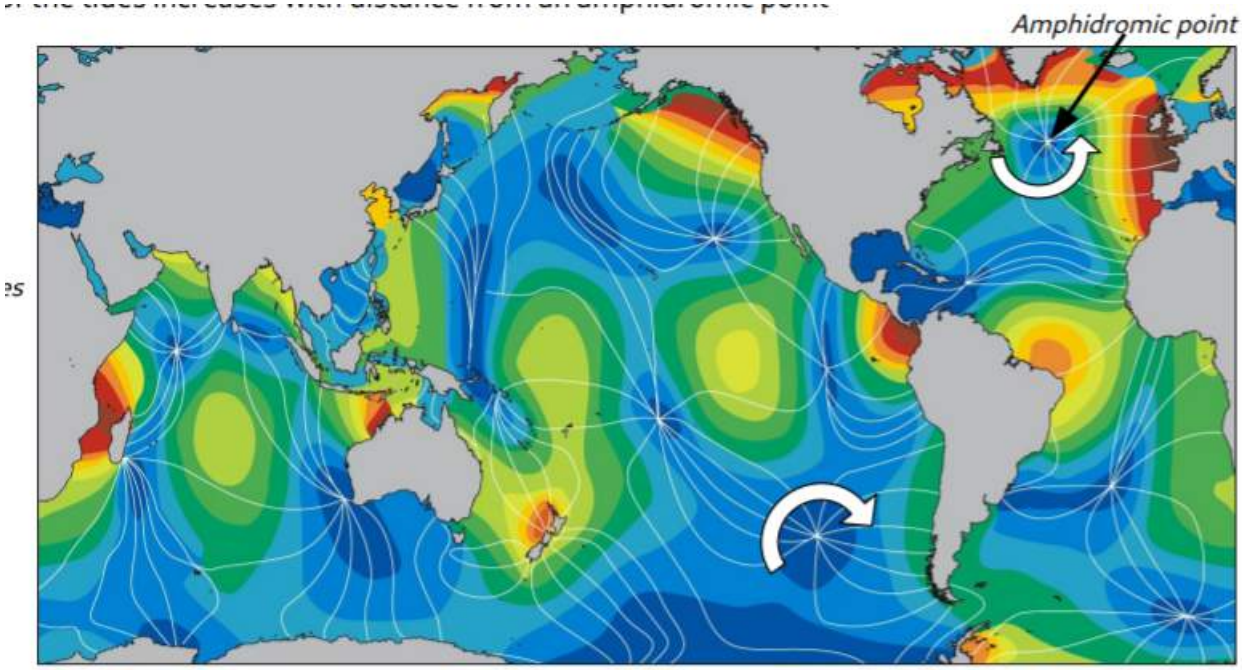
- the effects of finite ocean depth: tides are shallow water waves (they feel the sea floor)
- the interference of continents: tidal wave propagation is impeded by landmasses

- the effect of Coriolis force : tidal waves are deflected by Coriolis force
- Basin resonance: tides are influenced by the shape and dimension of basins so that they can be amplified.



> ↑ Asia to the left and America to the right. Coriolis deflection towards the right producing a high tide

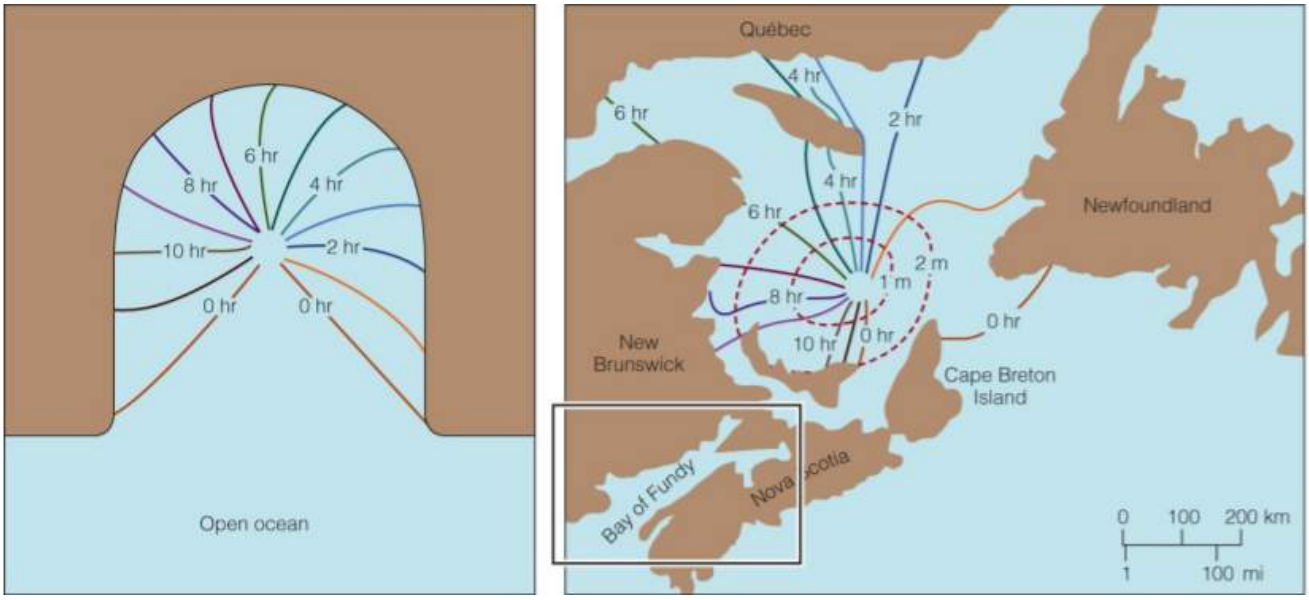
[definition] (*Amphidromic point*) : A no-tide point in the ocean around which the tidal crest rotates.



> blue is low and red is high tides.
>
> We see that where we have the highest tides is along the coasts. But because the height increases with distance from the amphidromic point.

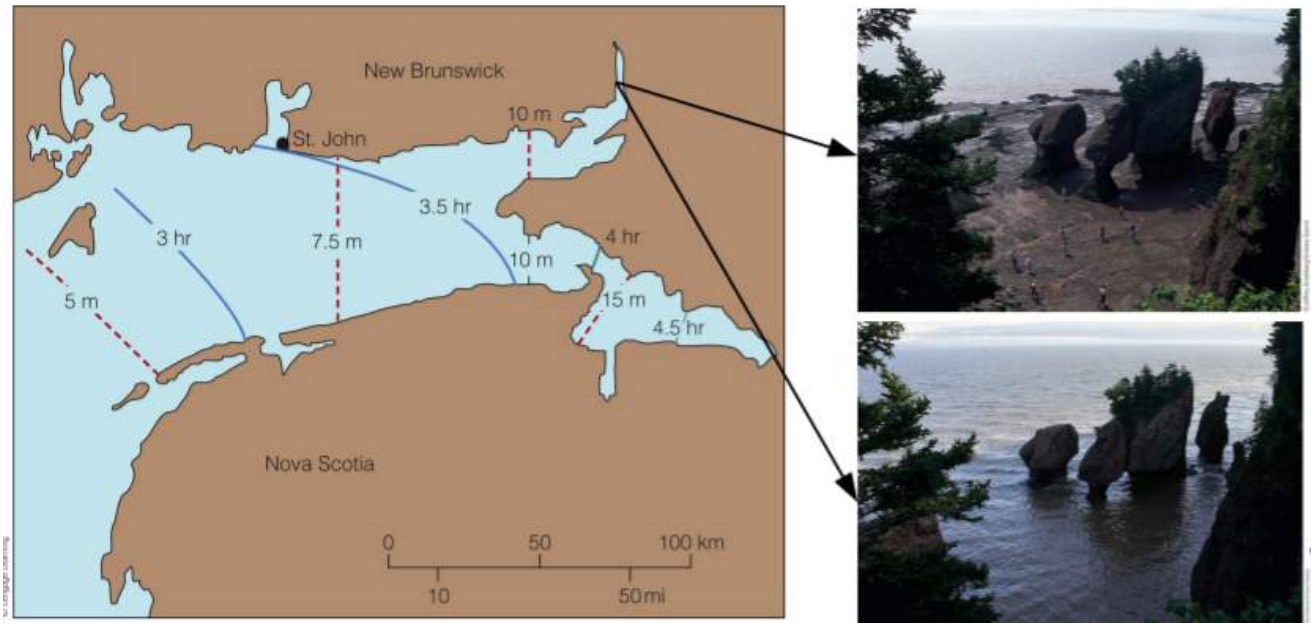
Tidal patterns and types

[definition (*tidal range*)] : the difference in height between consecutive high and low tides.



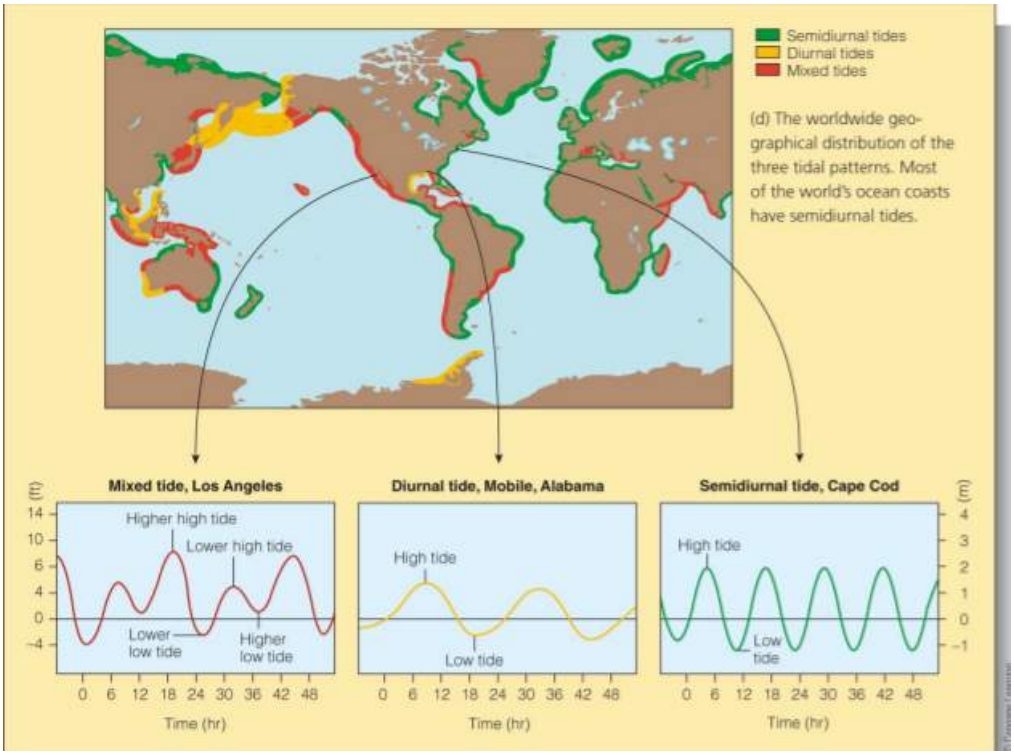
↑ mini amphidometric develops around quebec

[Example]



the amphidometric system can't develop here not enough space, this produces very high tides since there's no spreading

the major types of tides



- semi-diurnal tides : a tidal cycle with two high tides and two low tides each day, with the high tides of nearly equal height
- diurnal tides: a tidal cycle of one high tide and one low tide each day
- mixed tides: a complex tidal cycle, usually with two high ties and two low tides of unequal height per day.

Tidal currents

[Definition] (*tidal currents*) : mass flow of water induced by the rising or lowering of sea level owning to passage of tidal crests or troughs

> dynamic movement between flood current and ebb current

Prediction of tides

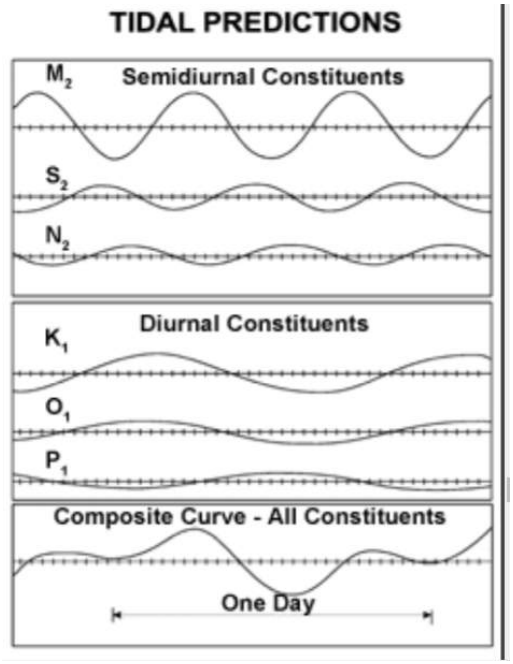
most tides can be predicted.

[Q] are we able to predict all the tides ? Yes and no lol

> there are 7 tide altering forces (we discussed 4 today).
>
> > - we need prior knowledge of the tide, so that we can project on the future

essentially we are able too, but there's too much information to consider.

Harmonic analysis

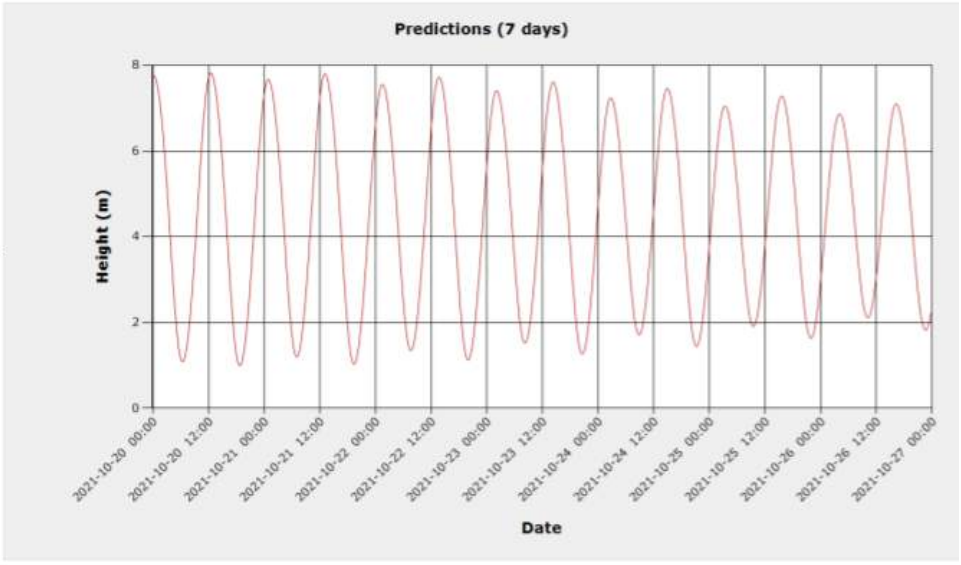


above is all the signals together, from the moon from the sun, etc.

[Exercise]

Prediction for Saint John →

Which type of tide is it?



(Fisheries and Oceans Canada)

which type of tide is that ? Semi durinald.

Lecture 17

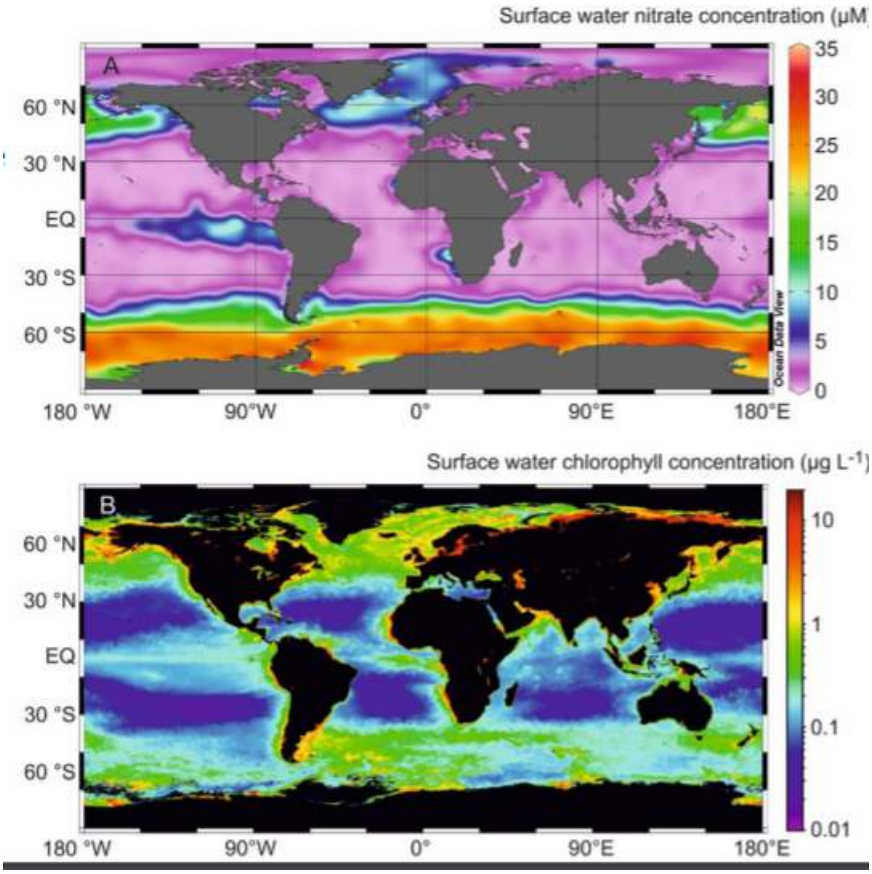
Part 3. Life in the Ocean

[Definiion] (*Marine biogeochemistry*) : The study of the chemical, physical, geological and biological processes and reactions that govern the composition of the ocean.

- We want to understand the composition of water but also the composition.
- Understand the link of the ocean with life.

[Definition] (*Nutrient*) : A substance that provides nourishment essential for growth and maintenance of life.

- help produce the energy (sugar and proteins consumed by the organisms)
- helps form the structural parts of organisms (shell, cells ,etc)



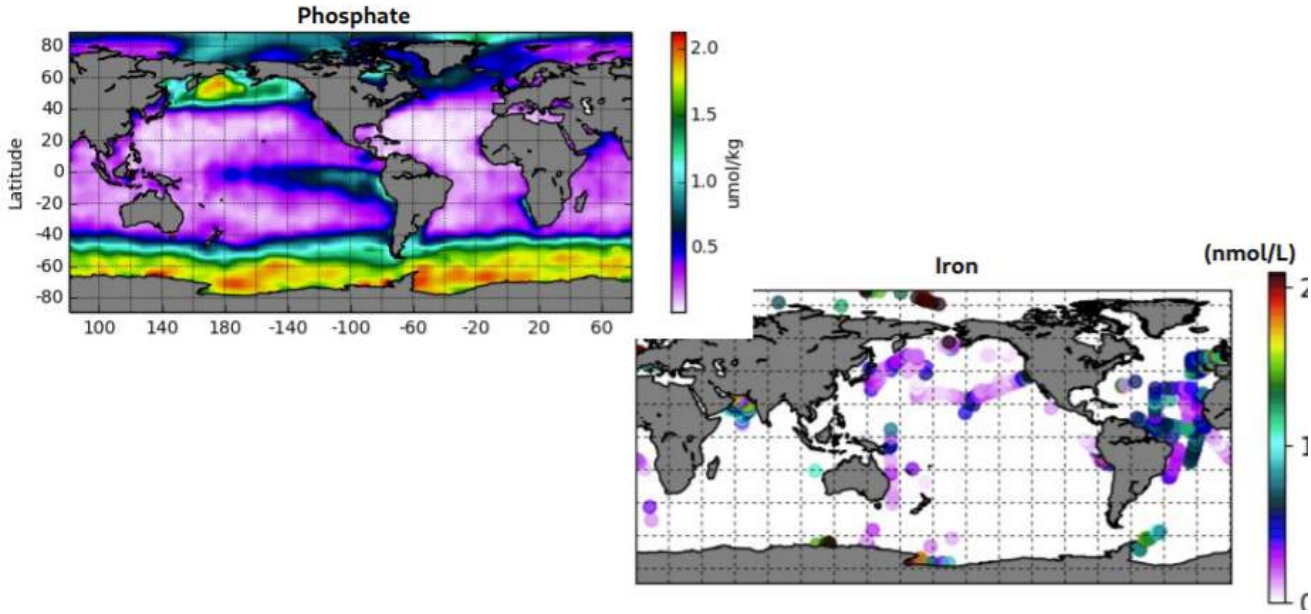
The top images shows nitrate and at the bottom we see the chlorophyll concentration at the surface. Chlorophyll is used as a proxy to measure how lively (how much plant organisms are there) is the ocean.

> the chlorophyll is like a solar panel for the plants.

We a good correlation between life and chlorophyll : see high concentration of chlorophyll in southern ocean, around equatorial region.

Classification of nutrients

- macronutrients : present in large amounts, used primarly to produce energy or for tissue growth and repair.
- micronutrients : Present in smaller amounts, have subtle biochemical and physiological roles in cellular processes.



> ↑ these are macronutrients examples, Lots of white spots because very tiny concentration (we don't have data for that yet).

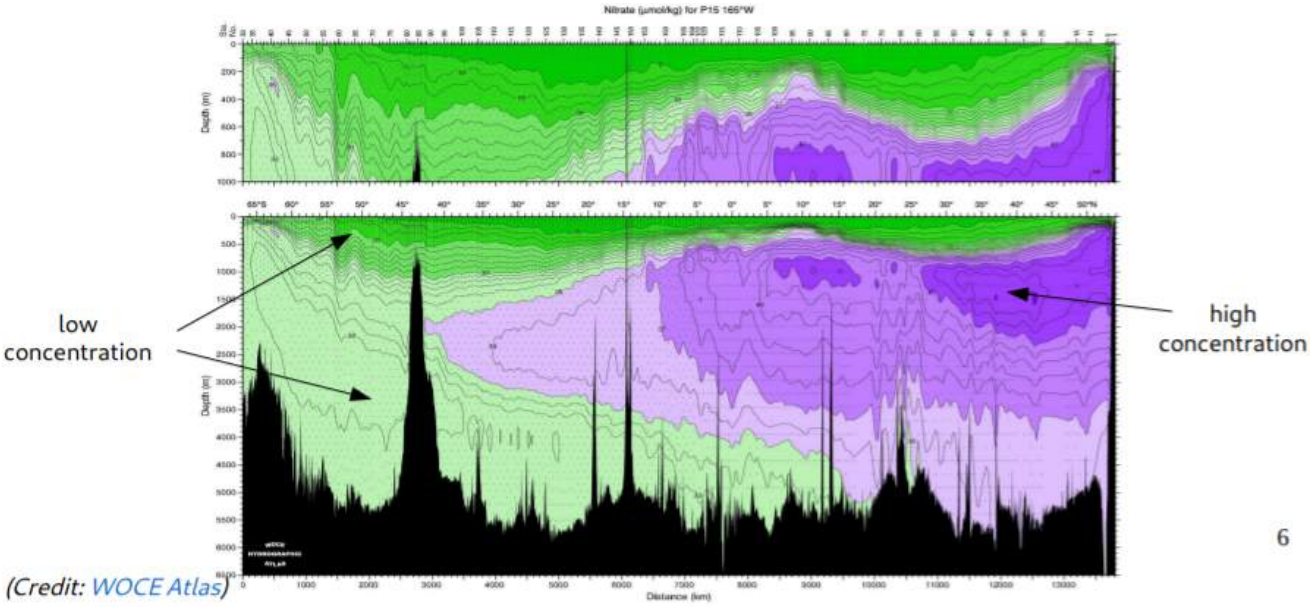
A. Nutrients

Macronutrients

- the main nutrients are Nitrogen (N) found in the water as Nitrate (NO_3-)
- phosphorus (P) found dissolved in seawater as phosphate (PO_4^{3-})

These nutrients mainly arrive through rivers. Once in the ocean they dissolve in their form, and at the surface of the ocean they are consumed by the phytoplankton.

> They consume them through photosynthesis, and thereby grow and repair, etc. When they die (they stay at the surface since they need the sun), they sink in the deeper part of the water column and decay back into phosphate and nitrate nutrients.
>
> > This constitutes a cycle. Consume nutrients at top ⟶ sink and decompose in nutrients



↑ to the right we have N.Pacific and to the left we have Antartica. We see a low concentration at the surface.

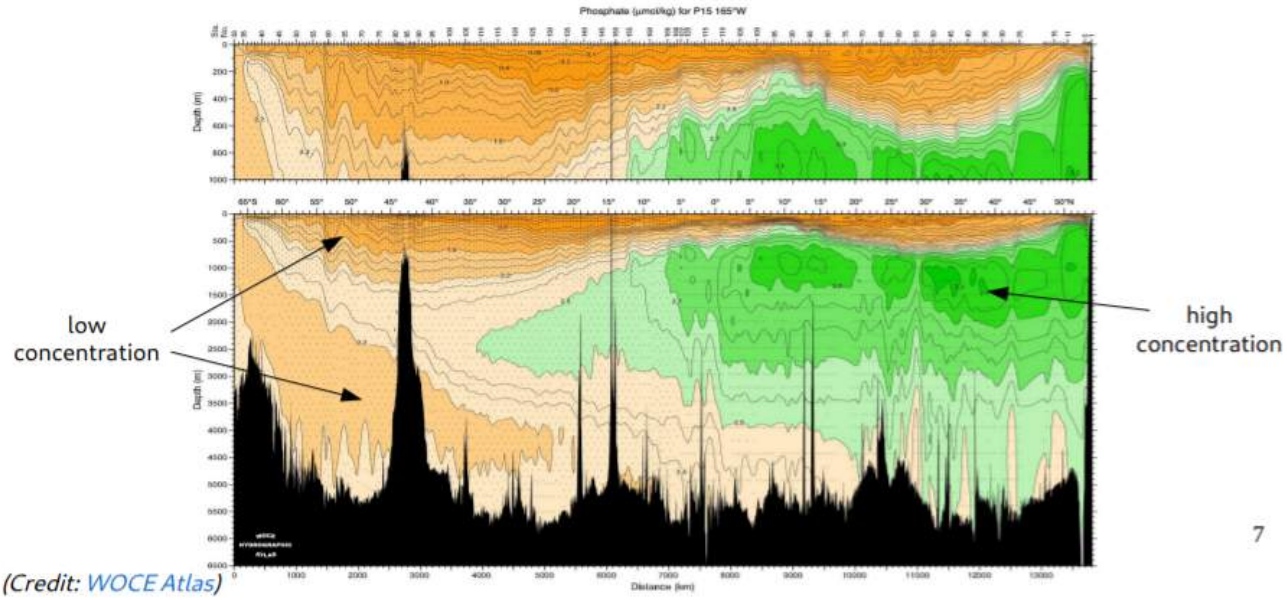
Q why such low concentration at the surface ? Because at the surface we have consumption of nutrients by phytoplankton

Q Why high at depth? Because phytoplankton die and sink down and decompose. This process is called reminerization

Q Why high concentration in the N.Pacific but lower towards Antarctica? Because difference in currents -

Recall how there was no CFC at bottom, because the water in that region hasn't seen the atmosphere in a long time (so it was old). In this example the water is old, so it had a lot of time to accumulate the nutrients, hence the violet color (towards N.Pacific)

> we conclude that nutrients is *also* a good proxy for water age.



↑ we find the phosphate concentration map to be quite similar to the Nitrate concentration map.

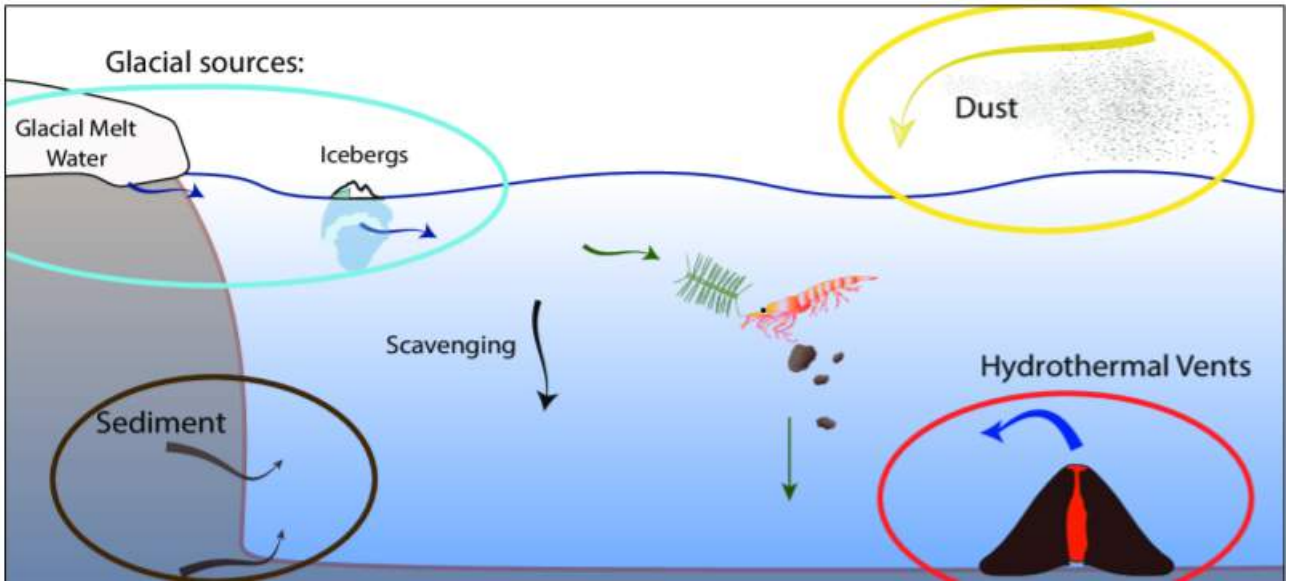
Micronutrients

The main ones are

- Iron (Fe) , Copper (Cu) and Zinc (Zn)

Q From what sources does iron in seawater comes ?

- Dust from the atmosphere ()
- Sediment dissolution along continental margins
- Fluids from hydrothermal vents (*near the mantle magma outburst in the deep ocean)*
- Glacial sources



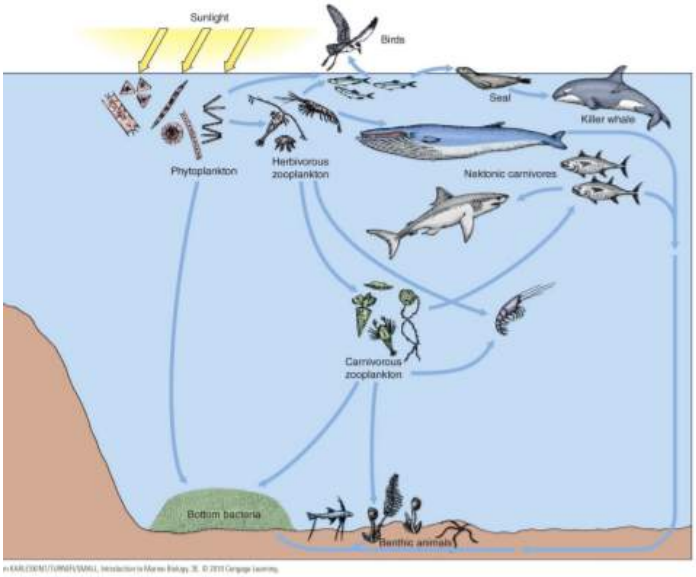
We find dust mainly coming from deserts from Africa and travels all over Atlantic (good source of iron)

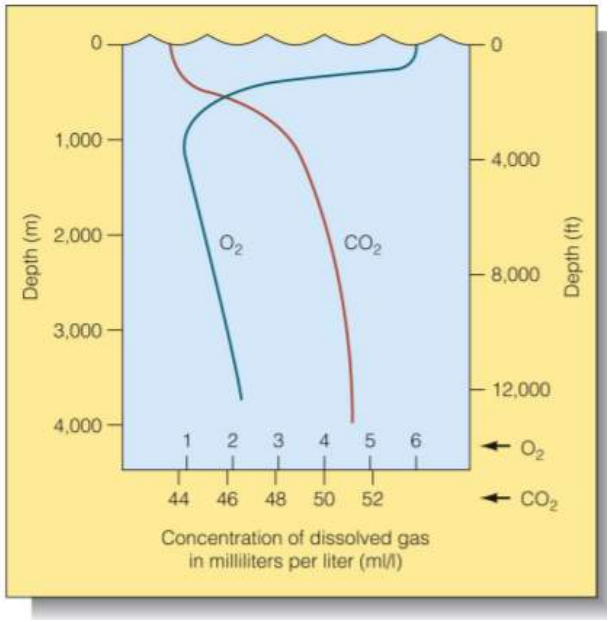
B. Oxygen

Importance

- *oxygen is both the product and elixir of life*
- oxygen is produced by plants when they convert inorganic materials to biomass.

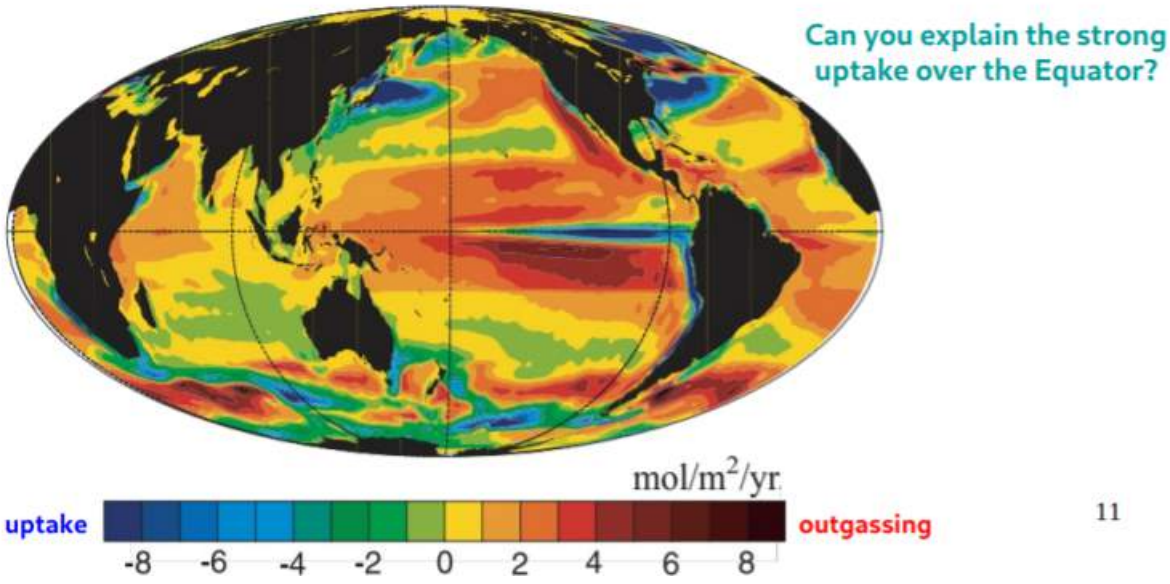
[Definition] (*biomass*) : sum of tissues and cell all together.





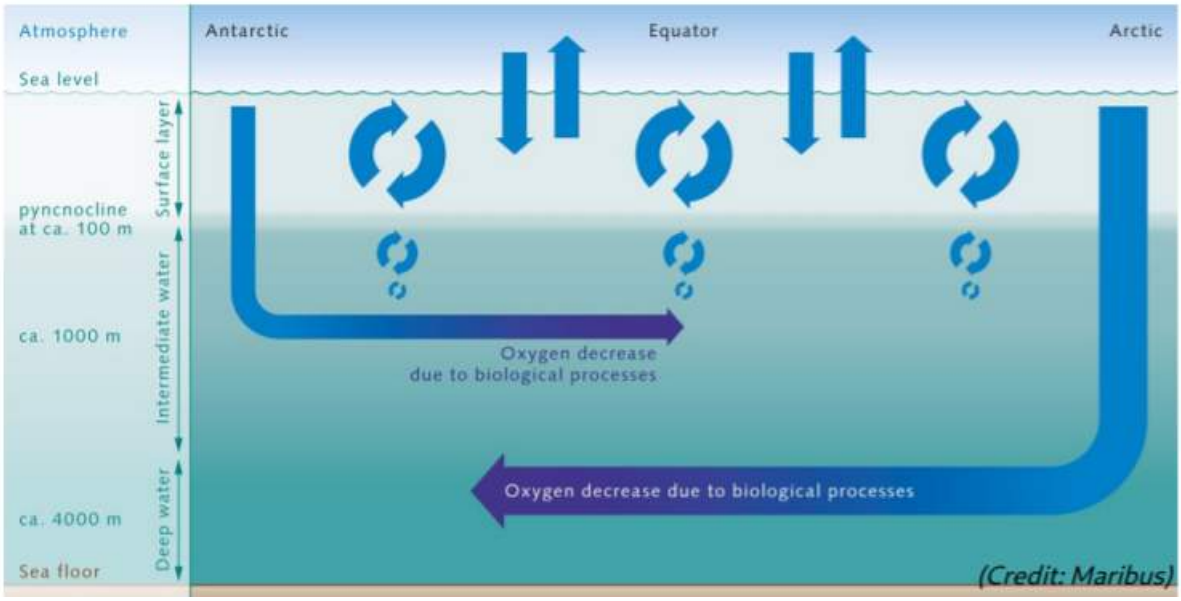
Oxygen is consumed at depth and generated at surface (this explains the shape).

- oxygen is exchanged between the ocean and the atmosphere at the air-sea interface
- Polar oceans tend to take up oxygen while tropical oceans tend to release oxygen

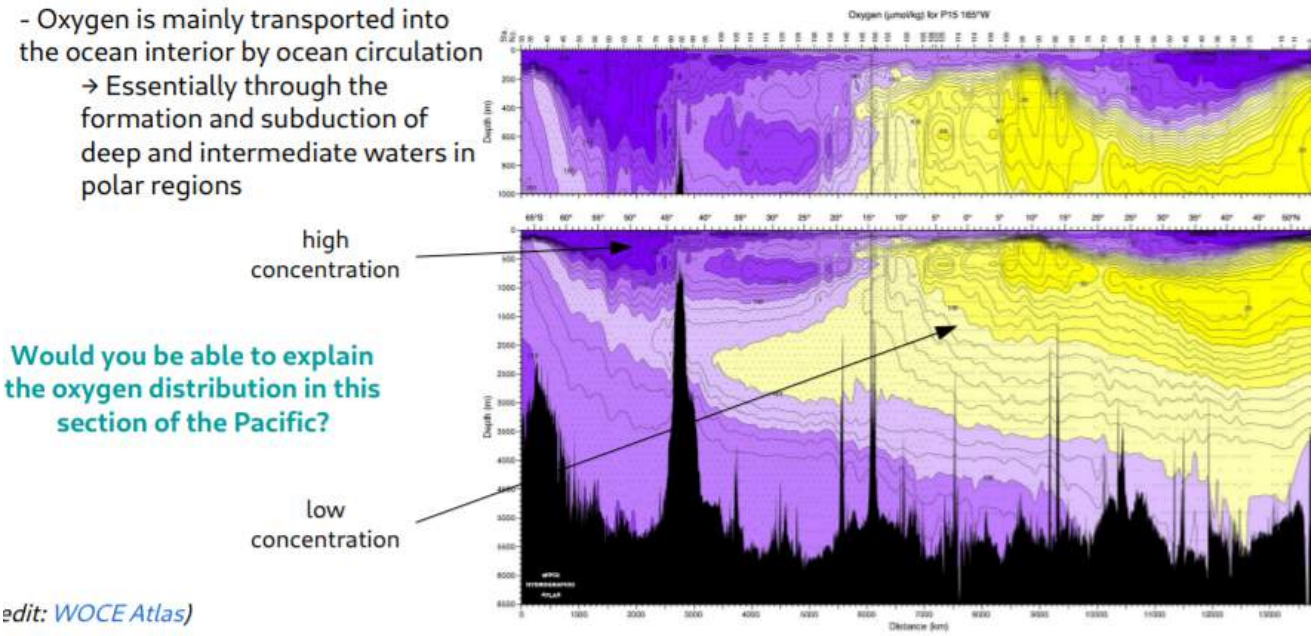


↑ on average, the blue regions are mostly found in high latitudes.

Q but what about the blue stripe on the equator ? because upwelling bringing cold waters, which encourages uptaking of the oxygen.



The oxygen sinks along from the Arctic and Antarctic , and this is how the oxygen is ventilated ,i.e., how the ocean breathes to sustain the cycle of life.

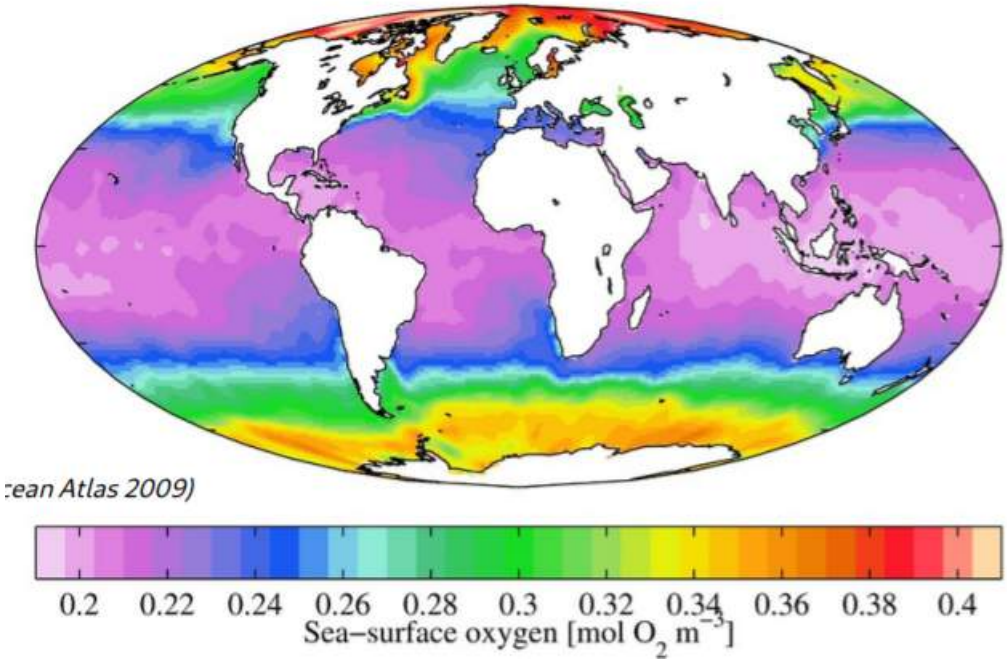


↑ Observe how the oxygen is mostly present at the surface (because produced at surface and consumed at depth). The water is old in N.Pacific while young to the left (subduction) $\Longrightarrow$ well oxygenated.

> - Young (left) $\Longrightarrow$ the biological processes haven't had time to intake all the oxygen
> - Older (right) $\Longrightarrow$ the biological processes have had time to intake most of the oxygen

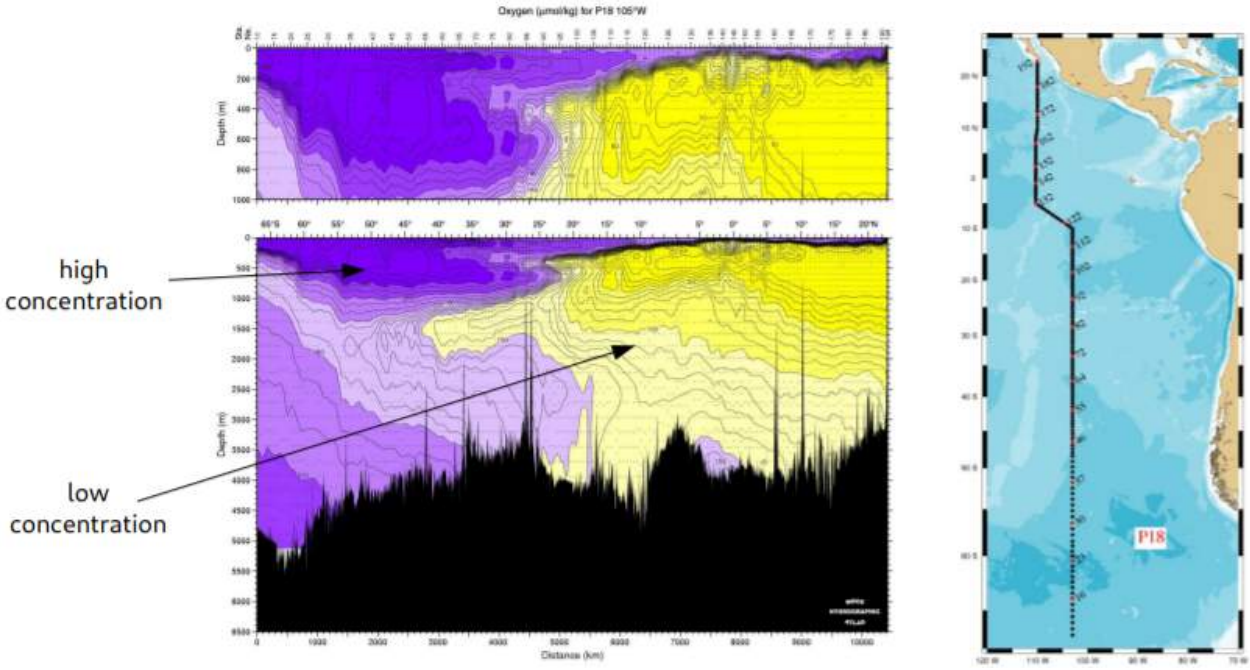
Q Can you link this to CFC ?

> We conclude that we can use oxygen as well as a proxy for water age.



- high latitudes -> high surface oxygen concentration
- low latitudes -> low oxygen concentration because of weak oxygen supply and poor water circulation ?

> the more biological processes at the surface, the more microorganisms sinking, the more food, and the more oxygen consumption by the bacteria at the bottom.



↑ Antarctica to the left. Note the low concentration at the right top (first 100m) because if we produce a lot, many sink and feeds the bacteria.

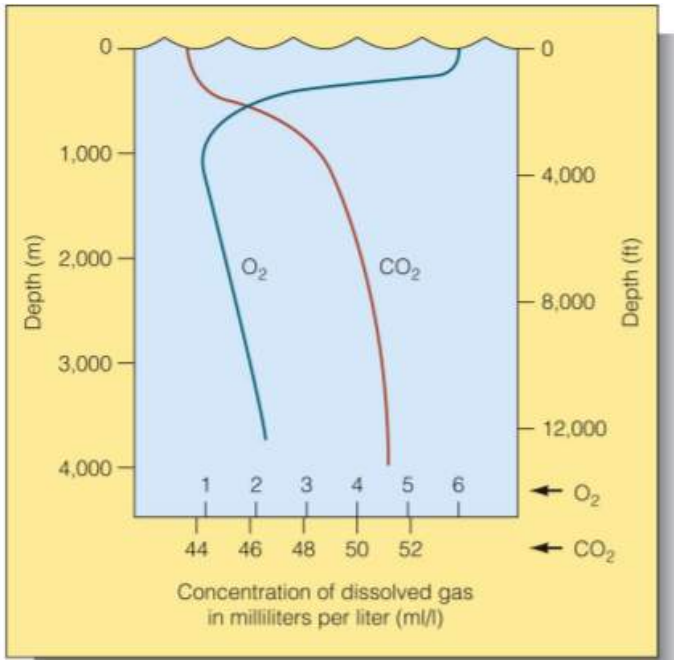
Lecture 18

C. Carbon

Carbon is the element of life

- present in many living and non living things
- Photosynthesis uses carbon
- Plant take a carbon and out of this carbon produce food. $\Longrightarrow$ reduces carbon off the earth

Recall the carbon oxygen evolution inside the ocean's depth:



Typical profile. Life is present in zones with most oxygen . In bottom ocean the bacteria, or animals the consumers than breathe through respiration use oxygen to burn the food and do decomposition and release CO2

> in deep ocean oxygen is depleted and produced at the top (phytoplankton who use CO2 to make Oxygen)

> phytoplankton are the base of the food chain

$$CO_{2(g)} = CO^*_{2(aq)} \quad (1)$$
$$CO^*_{2(aq)} + H_2O_{(l)} = H^+_{(aq)} + HCO^-_{3(aq)} \quad (2)$$
$$HCO^-_{3(aq)} = H^+_{(aq)} + CO^{2-}_{3(aq)} \quad (3)$$

these 3 reactions correspond to carbon oxide dissolving in water. In line (1) the solid carbon is aquefied. In (2) when the aquefied molecule is mixed with water it dissociates in another molecule plus a proton (H^+).

> the concentration of the proton (H^+) defines the pH. The more the protons (H^+) the lower the pH
>
> $$pH \downarrow\uparrow H^+$$

As CO_2 is dissolute in seawater releases free protons, the molecule acts as an acid (proton donor) in seawater.

- Dissolved inorganic carbon (DIC) is defined as:

$$[DIC] = [CO^*_{2(aq)}] + [HCO^-_{3(aq)}] + [CO^{2-}_{3(aq)}]$$

DIC is what is measured in the ocean to see the carbon content?

[Note] need to understand and describe the reaction, no need to memorize by heart

---

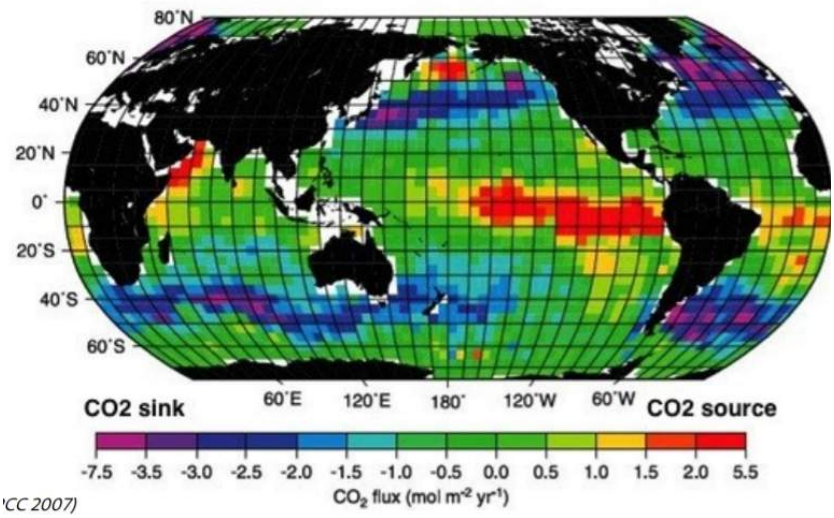
Carbon Pumps

How is carbon exchanged between the surface of the ocean and ocean, and atmosphere and surface of the ocean.

- if high CO2 concentration at the surface of the ocean and relativelty smaller at the atmosphere, then the CO2 is transfered from the ocean to the atmosphere
- Similarly the other way around.

This gas change is occurs because

- differences in temperature (lower and higher altitude)
- wind, the stronger wind the more penetration in the ocean and whatnot



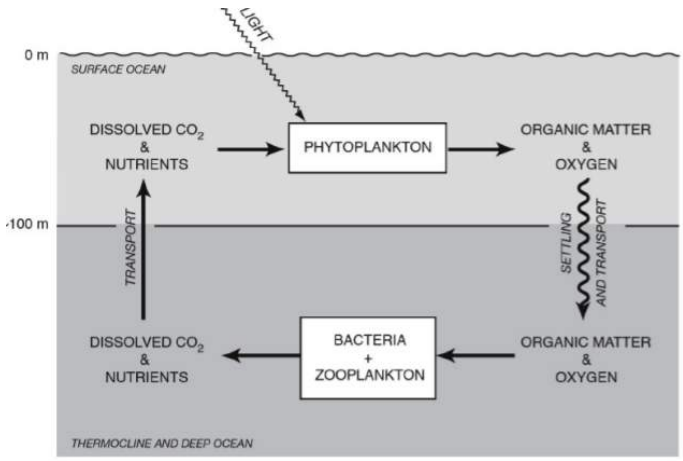
↑ sink means CO_2 penetrates in the ocean.

> we see sinks near mid low and mid high latitude, since it's cold. big source at the equator, because of warm temperature $\implies$ gazing.

No direct contact between CO2 of deep ocean and atmosphere, so if Co2 is at the deep ocean then we say that CO2 is *sequestrated*. Ocean circulation in deep ocean is slow, so the co2 stays there for centuries and millennia !!

> $\implies$ consequence for climate since CO2 goes in the atmosphere then on the deep ocean and remains there.

- There is carbon that can go aback to the surface though, for instance through upwelling.



The biological pump,the phytoplankton use dissolved CO_2. Then the plant like organisms die and sink in the ocean, are decomposed by bacteria (using oxygen for decomposition). Out of that reaction we get dissolved CO_2 and the gas get's back to where it started. But, some of the organic matter actually turn into sediment.

> the sediments have no chance of getting back to atmosphere.

Carbonate counter pump

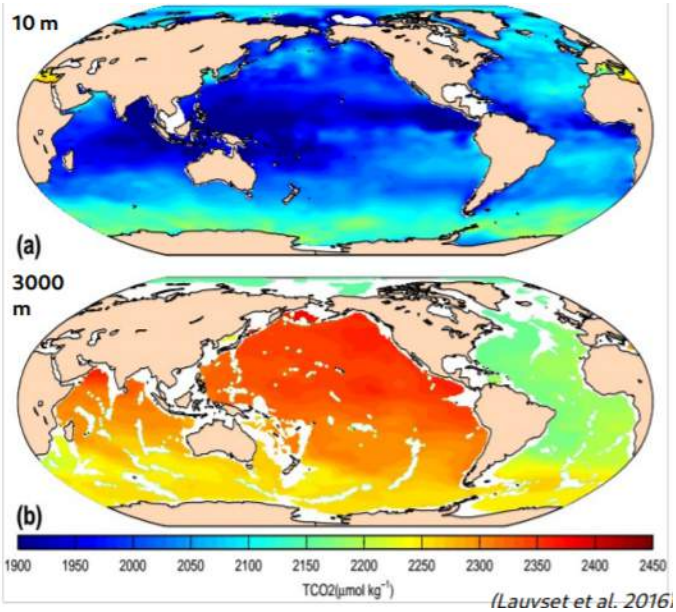
In the upper part of the ocean, marine organisms produce calcium carbonate ($CaCO_3$)

- this molecule is used to create shells for the organisms
- formation of this molecule releases CO_2

$$Ca^{2+} + \underbrace{2HCO_3^-}_{DIC} = \underbrace{CaCO_3}_{\text{shell}} + CO_2 + H_2O$$

the net reaction here is production of CO_2.

Distribution of dissolved inorganig carbon in the ocean



- at surface higher , DIC concentration is higher at high latitudes over low latitudes

  Because the physical pump (high solubility and upwhelling)
- In the deep ocean, DIC concentrations are higher than at the surface and increase with age of waters

  Because the biological pump (remineralization).The DIC accumulates with time, so the more DIC the older the water

Q Why is DIC concentration higher in the deep Pacific than in the deep Atlantic?

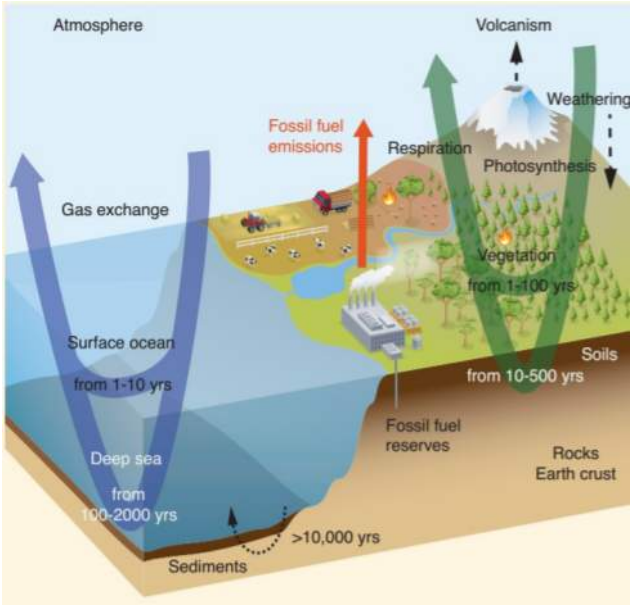
North Pacific doesn't have ventilation. The water that reach the north pacific are old and don't see the surface so they had time to accumulate a lot of Carbon. They are also depleted from CFCs since isolated from atmosphere for a lot of time.

Carbon cycle and reservoirs

($\star$) important to understand the carbon cycle.

[Definition] (*Reservoir*) : Place where carbon is stored. Plants,trees, homeland, sediments, crusts, etc.

> the reservoirs have different
>
> - sizes
> - timescale (how long carbon stays there)



Note that the carbon can stay for milenia in the deep ocean (since no circulation). For sediments it's $> 10\ 000$!!

> the ocean stores $60x$ mores than the atmosphere

This high storage of carbon is because

- it's easily dissolved in seawater (high solubility)
- The removal of carbon from the surface ocean by the action of physical and biological pumps.

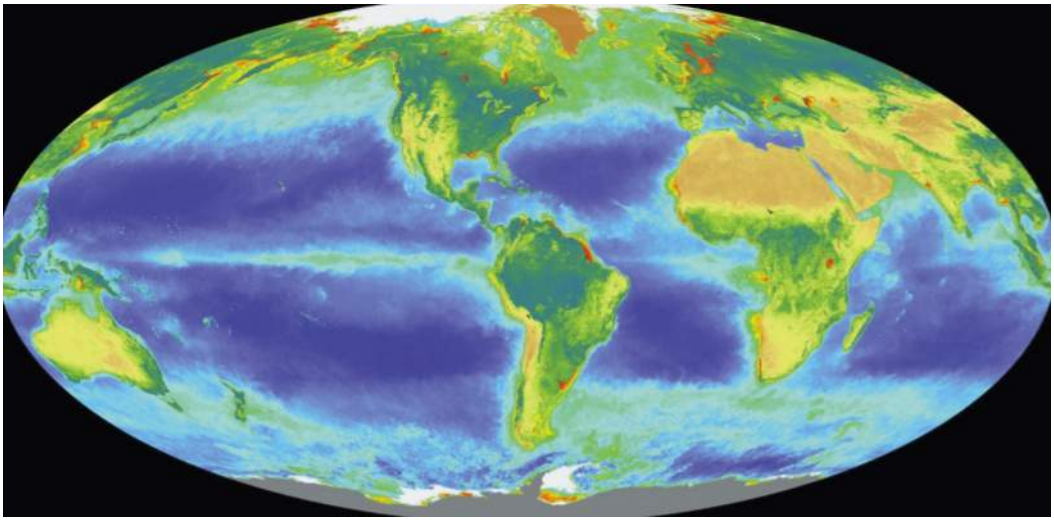
> *The ocean exerts a dominant control over atmospheric CO_2*

Photosynthesis and Productivity

[Definition] (*Primary productivity*) : The production of organic material from inorganic material by marine organisms.

Q why is primary productivity important ?

1. Produces 50% of the O_2 in the Earth's atmosphere (and hence to us...)
2. Consumes large amounts of CO_2 (biological pump)
3. Primary producers at the base of the food chain $(\star)$. Without them there is nothing!!
4. Produces much of the organic matter than was eventually transformed into the oi we consume today.



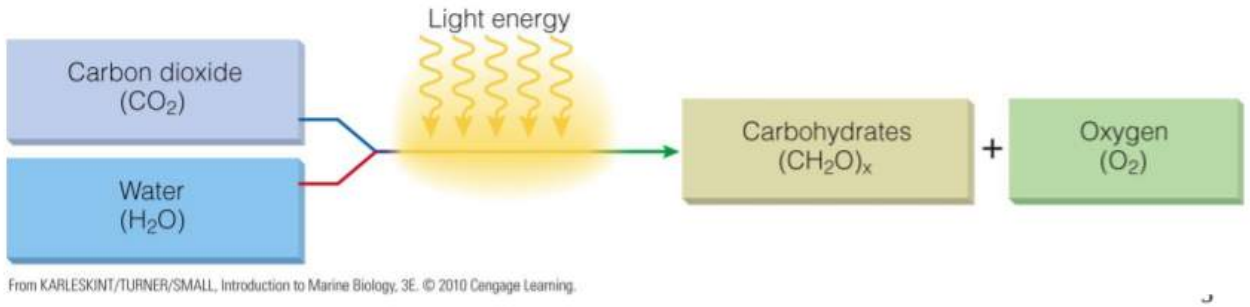
↑ chlorophyll concentration as seen from satellite.

Global net productivity of marine ecosystems is comparable to that of terrestrial ecosystems.

> for a plant to grow they need nutrients, Sun, and to grow roots and leaves
>
> While phytoplankton is more efficient because abundant nutrients and sun at the surface of the ocean and no need to grow anything , just produces photosynthesis efficiently and immediately.

A. Photosynthesis and respiration

Process of photosynthesis



[Definition] (*Primary producer*): An organism capable of using energy from light or energy-rich chemicals in the environment to produce energy-rich organic compounds (Carbohydrates).

- photosynthesis : when energy of light is used
- chemosynthesis: when energy from chemicals is used

[Definition] (*Food*) : Source of energy (other than light or chemical reactions).

In Class Activity

- Anthropogenic carbon whcih results from human activity.
- We can't tell if the carbon exists naturally in the sysstem or if it comes from humans.
- We can do numerical analysis to estimate the part of natural/anthropogenic carbon .
- total carbon : combination of both

  this is what we actually sample in the ocean without knowing the proportions,.

Southern ocean has ability to take in carbon.

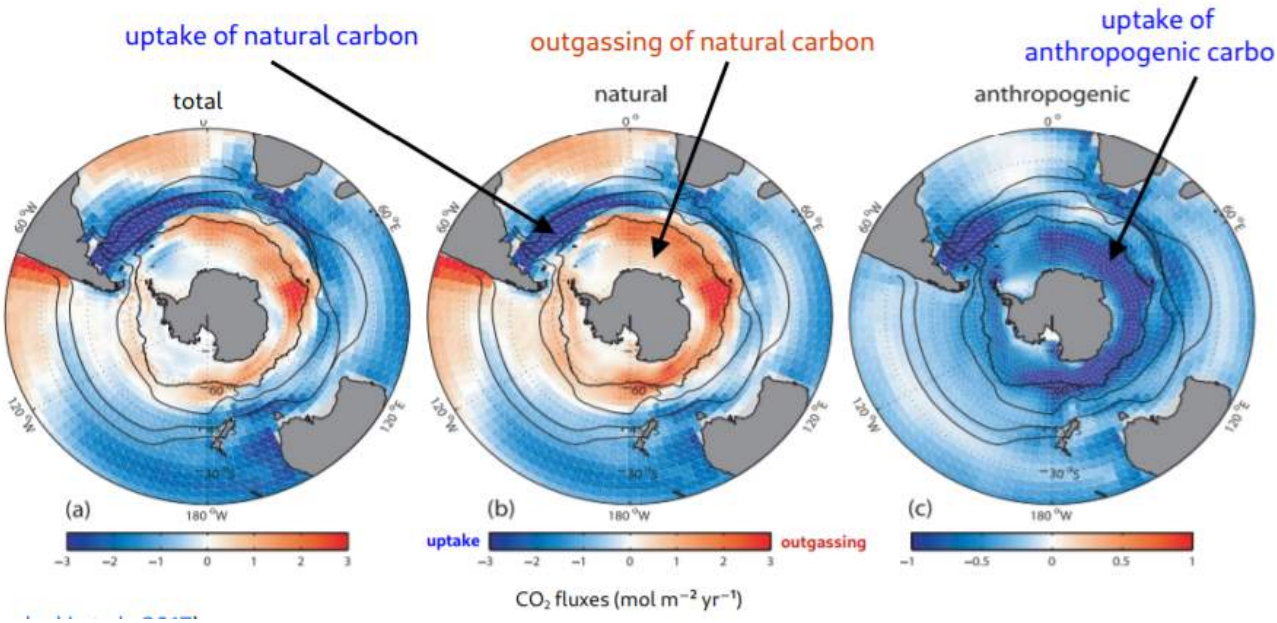
Wind coming with dust Ekman transport is to the left (*southern hemisphere*). Divergence, so leads to upwelling water as seen in the picture. What upwells is the deep water that is rich in carbon (since it's deep and because of respiration , bacteria and all living organisms deplete the water with oxygen and release carbon , so if the waters are deep and isolated from the surface at depths there's only respiration going on and depletion of oxygen, which accumulates carbon).

> when they upwell at the surface they have a lot of CO2 which leads to up gazing in the atmosphere of CO2 (since gaz goes from low concentration to low concentration).

these waters are deep and old so they don't have anthropogenic carbon because. Since atmosphere anth.carbon is larger than surface water anthropogenic carbon (deep water upwhelled), then anthropogenic carbon goes in the water.

At the top surface we have uptake of both carbons, because some factors,

> the southern ocean is a very large sink for anth. carbon. Half the global's anth.carbon total sink.



For anthropogenic carbon e have either uptake (cause of upwhelling) or outgazing (uncertain) so the total is either a big bar or if there's the out part as well , a little less

---

- we need a lot of data in space to estimate the carbon sink in the southern ocean
- the lines are tracks of the ships.
- we don't have many places that ships went through and not data year round either

BGC floats are used to estimate carbon sink

- temp, salinity, pressure
- they sink the parking depth, drift and after 2 days they sink further and begins the data collection when they start to go back up.

> SOCCOM floats are used to calculate the carbon flux across the surface ?

the estimate relies on assumptions and empirical relationships, it is not a direct measurement. i.e., there is uncertainity associated with the variables that are used to calculate the carbon flux F

> ⋆ the adv. to the ship measurement is they are there all seasons and can go in more regions !

Lecture 19

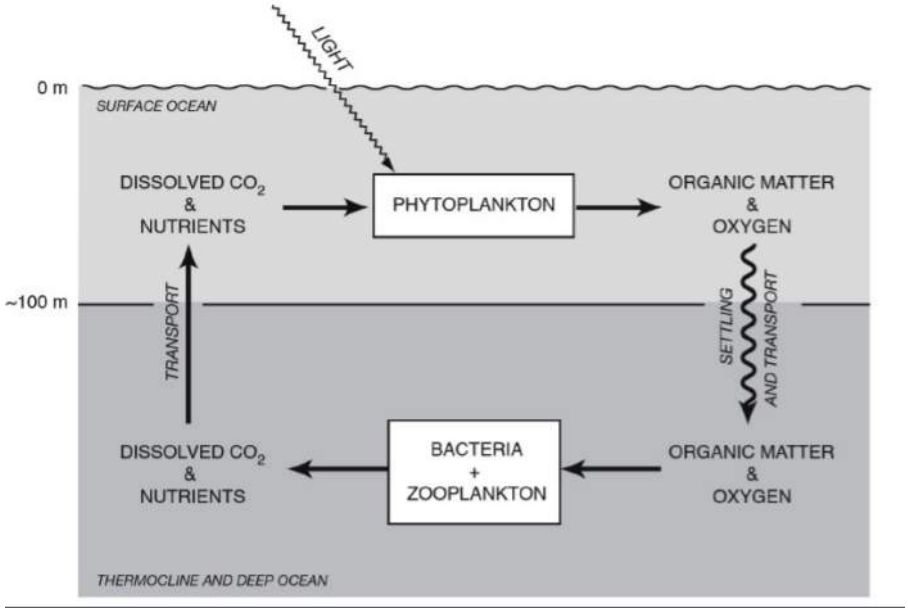
Recap

Primary reproducers use carbon dioxied and water to produce carbohydrates (food for themselves and other animals) along with oxygen.

- they also use nutrients, and combined with the light they build shells and whatnot.

The reverse reaction is (*respiration*) they burn carbohydrates using oxygen and through this reaction heat energy is released along with carbon and oxygen.

> if we combine these two reactions we get what's called the *biological pump*



This biological pump constitutes a cycle.

Q Why does photosynthesis only take place in the upper ocean ?

A Because it's the only place where there's light.

Part B. Environmental factors

Concepts of limiting factors

[Definition

1. Physical factors: from physical environment that affects living organisms

   For instance, us humans can't live at 100° C. salinity, pressure, etc.

2. Biological factors: biologically generated aspect that affects living organisms.

   For instance predation, metabolic waste

3. Limiting factors: physical or biological factor that when in absence or presence in inappropriate amounts limits the normal actions of an organism.

   For instance, to much light, or not enough nutrients.

[Note] There's never not enough carbon dioxide, so it's not a limiting factor (important for synthesis)

[Remark] Not everything is a limiting factor.

> - For the photosynthesis rate : the optimum photosynthesis productivity is at around 10 meters depth, since abundant light. As we go down light goes down until photosynthesis becomes impossible.
> - For the respiration rate : It is constant, it occurs from top to bottom (*common mistake is to think it occurs at depth* [like in the biological pump schematic for instance])

[Definition] (*Net productivity*) : Net productivity = photosynthesis - respiration differential.

Light

[Recall] sunlight is reflected, scattered and absorbed. Light only penetrates down a couple hundreds meters from the surface.

Light inside the water is separated in 3 zones

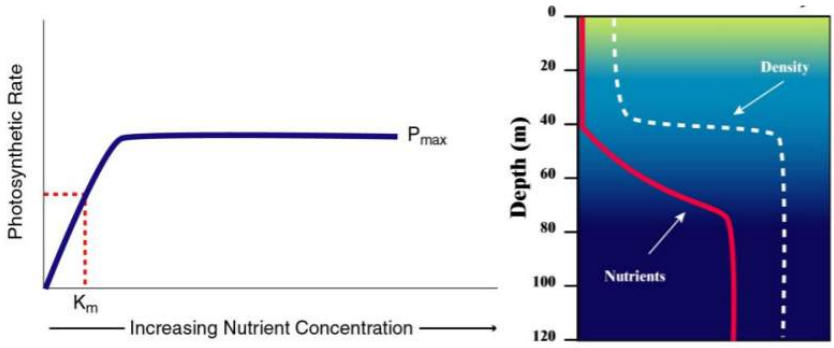
1. Euphotic zone: ~ 70 meters, primary producers can capture enough light energy for photosynthesis. (represents only 1 % of the world ocean volume).
2. disphotic zone: ~ 600m , light is present here but not enough to allow photosynthesis to dominate over respiration.
3. apthotic zone below 600m .Permanently dark layer of seawater. Overwhelming majority of the world ocean volume

---

Nutrients

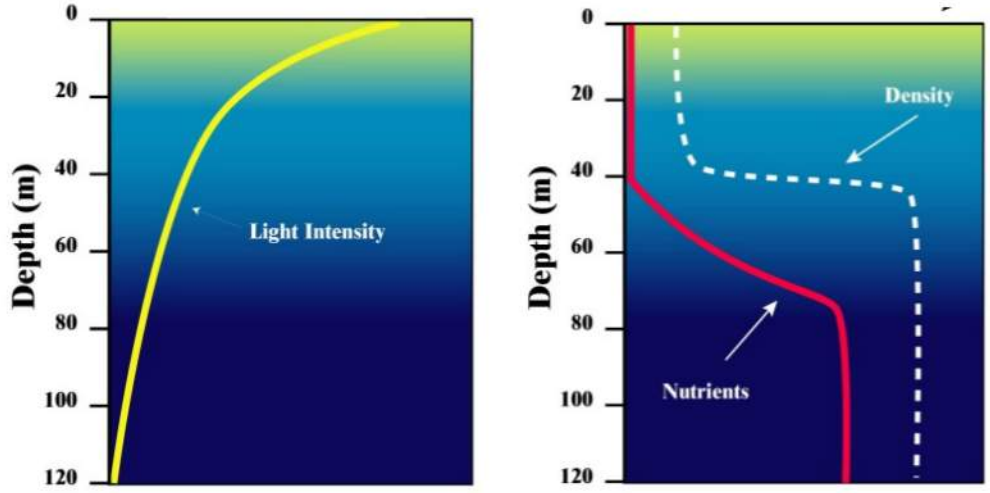
[Definition] (*Nutrients*) A substance that provides nourishment essential for growth and maintenance of life.

- Macronutrients, Micronutrients, other produces (things used to build shells) .

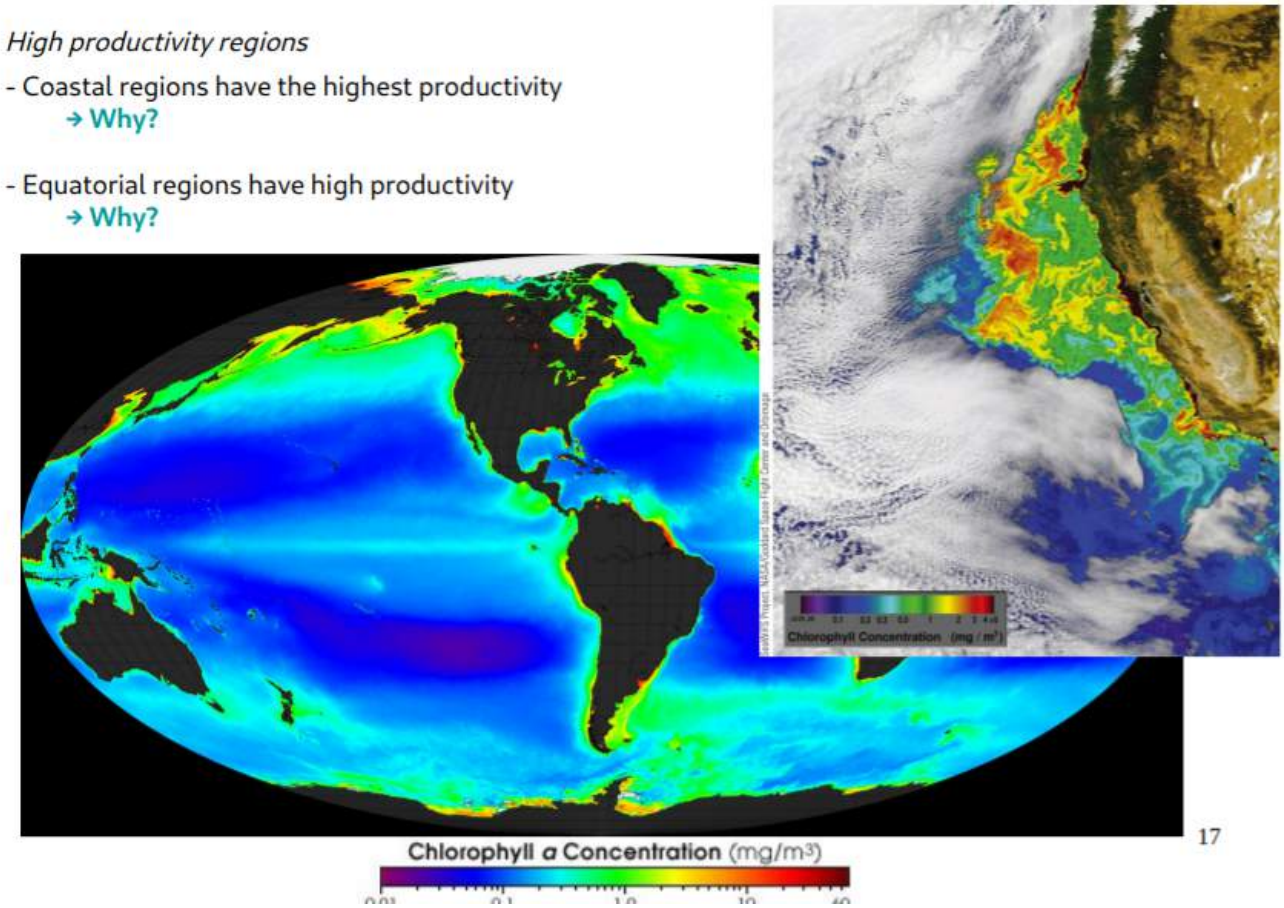


↑ the more nutrients the more photosynthesis rate, until we reach the plateau where even if we increase the nutrients concentration . the organisms have reached their limit (Biological limitation maybe ?).

> Q Can you see the problem for primary reproducers ? No nutrients at surface but no light at depth. we can solve this by upwelling since we can't penetrate light deeper into the ocean.



Distribution of chlorophyll with satellite actually show that zones where productivity is high is linked to high availability of nutrients and vice-versa.



1. Q why do costal regions have the highest productivity ?

   A Because nutrients levels are highest near the continents and because the river runoffs and coastal upwelling

2. Q Why do equatorial regions have high productivity ?

   A Due to wind-driven upwelling a=of nutrient rich waters

> the open tropical oceans are also known as *oceanic deserts*.
>
> Q What is the limiting factor and why ?
>
> A Nutrients are limited due to downwelling. Light and CO_2 are abundant. Also due to stratification

For the low productivity regions (polar regions) Q what is the limiting factor ? light of course, there is enough nutrients there but not enough sunlight.

> In summer though we have spectacular blooms. So year round it kind of evens out and this is why on the chlorophyll map we see a greenish color.

Some regions like the Southern ocean has high nutrients but low chlorophyll. Recall there is massing wind-driven upwelling in that region.

Q What is the limiting factor?

Lecture 20

Recap

> We looked at the chlorophyll concentration map and we saw high concentration at higher latitudes since

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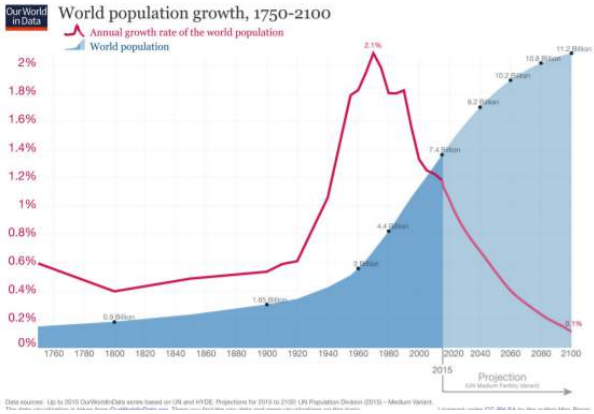
Part 4. Human Impacts on The Ocean

1. Pollution and exploitation of natural resources

A. Some introductory comments

Humans have a huge impact on climate

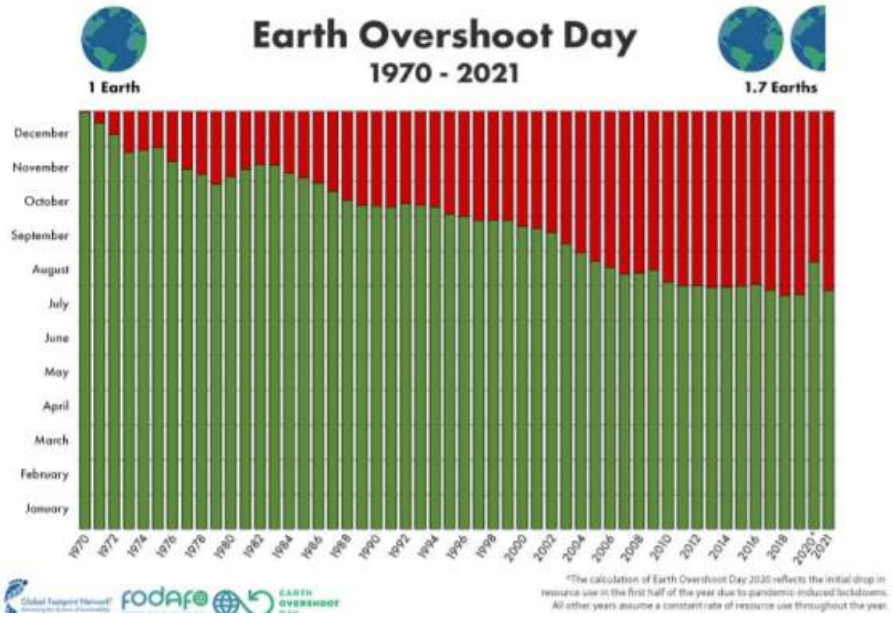


The red corresponds to the speed of growth of population. Blue is the total amount of people.

Note that almost half of the people leave close to the ocean (within 150 km). This implies an increase in exploitation of natural resources.

> before, we were getting resources from the coastal ocean, now it's from all ocean as technology improves.

[Definition] (*Earth Overshoot Day*) : Metric to measure the day where the consumption will exceed the capacity of nature to regenerate.



In 1970 we needed one earth to meet everyone's needs. But as we get closer to today, around in August, we will have consumed all we have for that year. But we keep consuming , so we enter the red regime where we are in "*debt*".

Today, we need 1.7 earths for a year round proper consumption according to this metric.

> Note The 2020 bleep is because of the pandemic where consumption decreased substantially.

There are three main types of services that the ocean provides to humans :

1. Regulation of the climate system

   Heat and carbon uptake.

2. Provisioning services

   Oxygen (50 % of the ocean we breathe comes from the phytoplankton at the surface of the ocean), rain, food (50% comes from the ocean), minerals (sand gas oil), reusable energy (infrastructure installed in the ocean)

3. Cultural services (*non extractive resources*)

   tourism , surfing

Pollution and Climate Change

There are two related concepts

[Definition] (*Marine pollution*) : Introduction by **man**, directly or indirectly of substance energy into marine environment resulting in deleterious effects such as harm to human health, living resources, etc

[Definition] (*Climate change*) : More focused on the climate system (killing fishes is not climate change), winds ,temperature. Formally, a change in climate that is attributed directly or indirectly to human activity altering the composition of the atmosphere

> note that in both cases the source contribution is the man.

($\star$) A volcanic eruption is not pollution it's natural process.

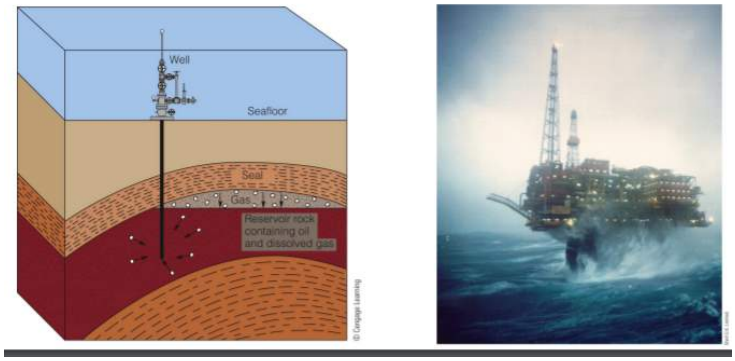
B. Natural resources and their exploitation

Physical resources

[Definition] (*Physical resources*) : Results from deposition, precipitation or accumulation of useful substances in the ocean or seabed.

For instance hydrocarbon, minerals deposits, freshwater

> 2 very important physical resources are oil and natural gas.



Oil and natural gas are often found in marine sediments

($\sim 1/3$ lie in the continental margins because this is where you have the most intense blooms).

Both originate from sinking organic matter (plankton and bacteria)

- dead organisms accumulate on the seafloor
- under high temperature and pressure, this organic compounds are transformed into hydrocarbons
- very very slow process (3 My to make 1 year worth of oil) .

> because this process is extremely long (geological scale) they are regarded as "non-renewable" energy.

> 2 other very important physical resources are salts and freshwater

Salt evaporation ponds

Desalination plant

The salt is extracted from evaporation ponds. We let the seawater evaporate until we have the salt. The we move the saline residue water in another pond, and so on and so on until we have these different salts with differnt chemical composition.

Freshwater is a very important resource (need to extract the salt from it)

[Note] Only 0.017 % of earth's surface water is in liquid form and fresh !!

For the rest water we need some form of extraction.

1. Boiling 50% of production (requires energy)

2. Freezing $\Longrightarrow$ brine rejection $\Longrightarrow$ fresh water (requires energy)

Biological Resources

[Definition] (*Biological resources*) : Living animals and plants collected for human and animal feed.

> fishing used to be traditional, but now it has turned predominately industrial with mass fishing with the rely on use of technology.
>
> 1. troli fishing (they focus on 10 species only)
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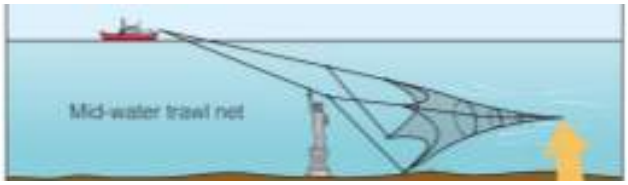
> 
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>
> 2.

[Remark] Between 1950 and 1997 , commercial marine fish catch increased more than fivefold.

But the productivity has decreased (i.e. cost to obtain each unit of seafood has increased), that is because fuel and personnel and what not is now more expensive ?

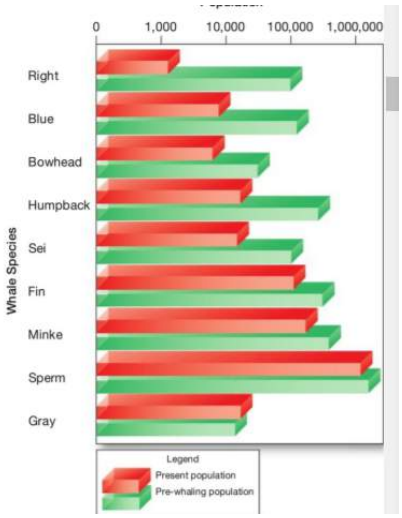
[Definition] (*Overfishing*) : Harvesting so many fish that here is not enough breeding stock left to replenish the species.

[Definition] (*Bycatch*) : Animals sometimes get unintentionally killed while collecting desirable organisms.

For example 4 pounds of bycatch is discarded for every pound of shrimp caught in Gulf coast.

[Definition] (*Maximum sustainable yield*) : The maximum amount of fishes that can be caught without impairing future populations.

[Concept] (*Whaling*) Since the eighties whales have been hunted down to provide meat for human and animal consumption ,oil for lubrication ,cosmetic ,etc



↑ LOGARITHMIC SCALE !!!!

Non-extractive resources

[Definition] (*Nonextractive resources*) : Use of the ocean in plane (includes waste disposal, transportation and recreation)

Marine energy Resources

[Definition] (*Marine energy resources*) : From the extraction of energy directly from the heat or mostion of ocean water.

Renewable energy It's a growing industry. Wind power is the fastest growing energy source as an alternative to oil.

> Waves, currents and tides can be used to produce electricity.

On the left we see wind powers on the ocean and more curiously on the right, it's an apparatus with pistons that extract the energy from the waves at the surface of the ocean (*wind waves*).

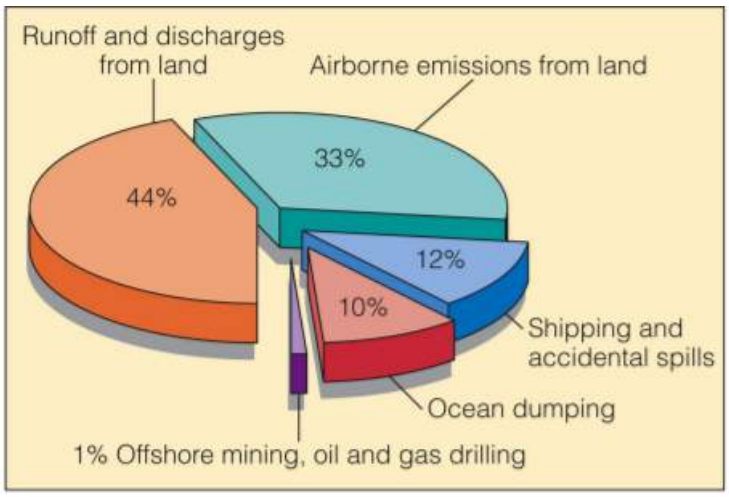
C. Pollution and interference with the environment

Identification of polutants is not easy, because most of it are found in the nature as natural chemicals.

For example a volcanic eruption (releases sulfur compounds, large amounts of carbon dioxide, etc).

> carbon dioxide is considered pollutant only if released in the nature by humans.

[Definition] (*Pollutant*) : A substance that causes damage by interfering directly or indirectly with an organism's biochemical processes.



> (⋆) what we throw on the ground on the road ends up in the ocean !!

Impact of a pollutant also depends on its presence.

- many pollutants are <u>biodegradable</u>

[Definition] (*Biodegradable*) : Ability to be broken down by natural processes into simpler compounds.

Oil, chemicals, heavy metals

The amount of oil entering the ocean has been increasing in recent years (because of marine transportation of petroleum, offshore drilling, nearshore refining, etc).

> the runoff is very dangerous because it's not crude oil, but mostly refined oil
>
> - crude oil is biodegradable and natural from nature
> - refined oil more harmful to the environement.

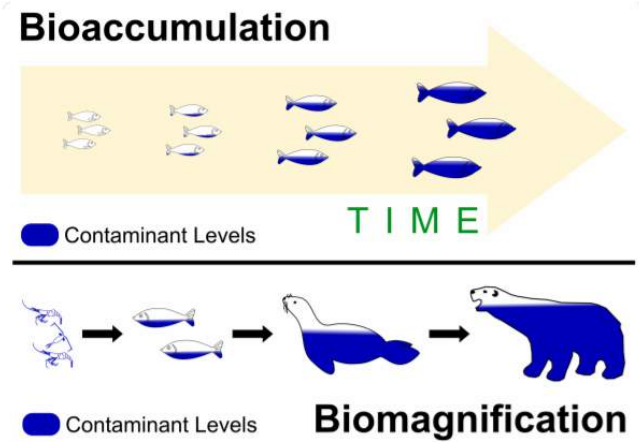
fish injest the pollutant and develop diseases and population decreases over time.

- some *synthetic organic chemicals* end up in the ocean through runoff (things like chlorine, bromine, iodie, etc)

  case in Japan Minamata disease was prevalent because fishes were filled up with high concentration of mercury
- some *heavy metals* end up in the ocean as well

[Definition] (*Bioaccumulation*) Processes by which certain marine organisms concentrate within their tissues many substances found in minute concentrations in seawater.

[Definition (*Biomagnification*) : Process by which animals eat other animals (*food chain*) some of these substances (including toxic chemicals) move up food chains and become concentrated in tissues of larger animals.



> so again, it's really good to eat low on the food chain !

Q : *Explain how greenhouse gas emissions impact pH in the ocean.*

- covid resdulted in a 9 % drop in greenhouse emissions
- but that emission had no impact on slowing the ocean's acidification due to covid 19 emission reduction

So of course we don't see a change in pH since it's logarithmic !

- we conclude that it has not solved ocean acidification

Q : *by 2021, the oceans were already absorbing slightly less carbon from the atmosphere due to COVID-19 emissions reductions.*

Lecture 21

Recap

- we saw that we can extract salt from the oceans
- consequences on fishing
- non-extractive resources (*tourism, etc*)
- Marine energy (renewable energy that the ocean can offer)
- Oil (*marine pollutants*)
- Toxic synthetic chemicals and heavy metals. (*mercury for instance is high presence in species*)
- Bioaccumulation (accumulation of toxins in species [because they can't eliminate/degrade these toxins]) (*across same species*)
- Biomagnification (accumulation of toxins spreading through animals eating other lower food chains animals, and so on) (*across food chain*)

> - *because of biomagnification ,it is good to eat at low food chain*
> - but also because it is more sustainable

C. Pollution and interference with the environment

Plastic and Other solid wastes

About 80% of marine debris comes from land-based sources, and the majority of that is plastic.

> We find plastic in the Antarctic (because carried by currents) , depth of ocean, surface, pretty much everywhere.

It is problematic because plastic is non-biodegrable. (*even if broken down in smaller pieces*) .

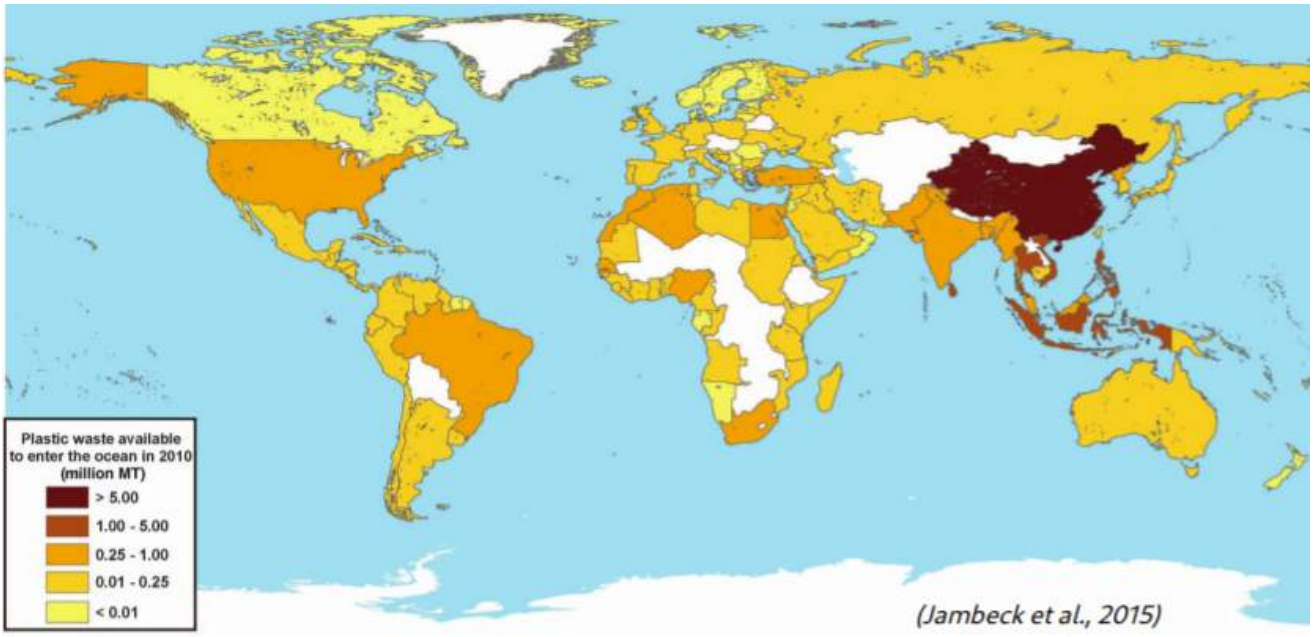
It takes centuries to millennia's to degrade plastic.

[Definition] (*Photodegradation*) : decomposition of plastic in smaller pieces due to the sun at the surface of the ocean.

After photodegradation, it still is plastic, we don't see it, but then it enters in very small organisms like phytoplankton and zooplankton so it climbs up the food chain this way, up to us!

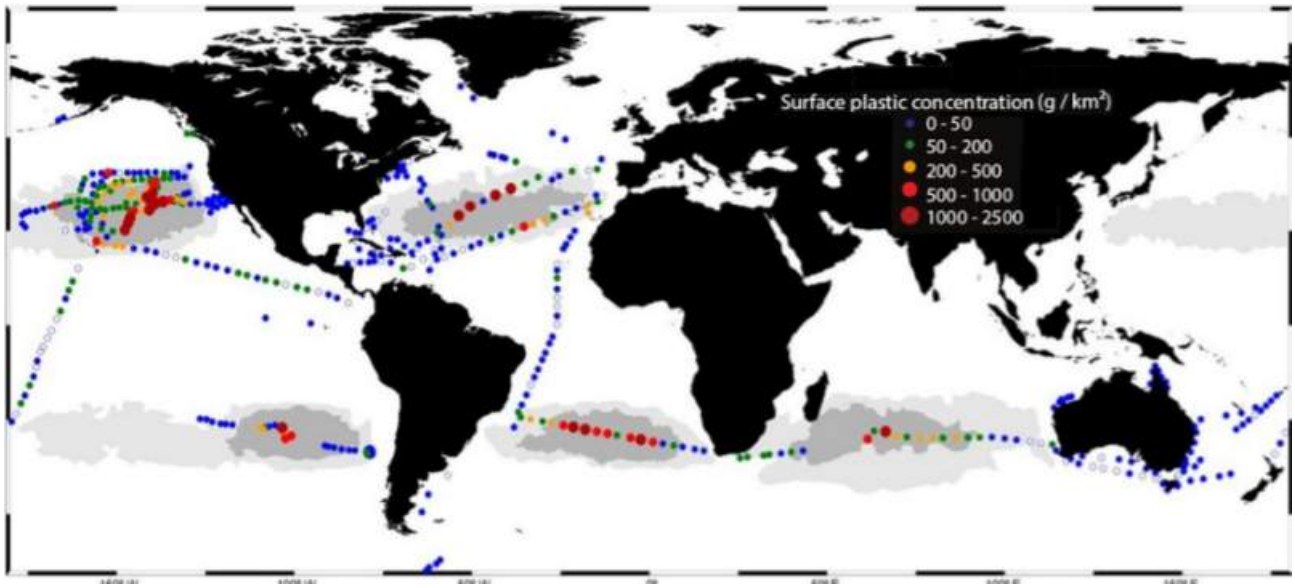
> other issue with plastic, high affinity with toxins. So animals eat plastic PLUS poison ! they pretty much go hand-in-hand.

Plastics debris accumulates very fast. Tenfold every 10 years.



[Remark] ↑ hard to estimate. Some countries transfer the plastic to other countries.

Oceanographers have tracked the plastic on the ocean and found that it accumulates in some specific locations.



Q do you recognize this regions?

A These are the subtropical gyres. For instance for the blob on the left of the map. On top of the blob there is to the right westerly winds, and at it's bottom (equator) leftward winds , creating a convergence in the middle due to Ekman transport $\implies$ downwelling. This creates a *doming* with pressure gradient forces of opposite directions which creates a circular current across the blob ,thereby *trapping* the plastic.

[Definition] (*Eastern garbage continent*) (millions of metric tons of garbage with size twice that of Texas).

Plastic recycling

the vast majority of plastic is not recyclable lol. We remove the plastic from the ocean

---

Part 4. Human impacts on the ocean : Physical changes

[Definition] (*Anthropocene*) : A human-dominated geological epoch

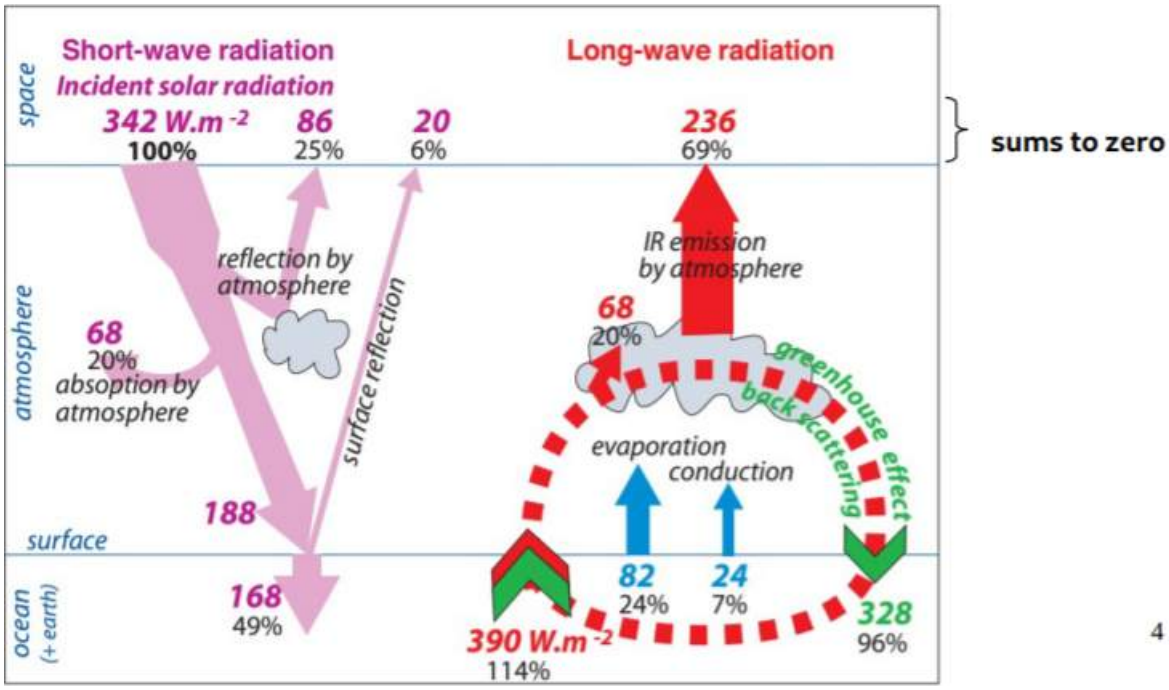
For instance glaciers period, etc.. (industrial era in 1850 , they saw a lot of coal).

Geologists claim we are entering a new geological era.

> they inspect the sediments and ice

Part A. Greenhouse effect

Averaged over a year the energy balance at the top of the atmosphere is zero.



- Left part Short wave radiations enter the atmosphere, some are reflected (25 %), and some are absorbed as *aerosols* (68 %), the rest is absorbed by the surface of the earth.

  Recall (*Albedo*)

  earth reflects or absorbs varying from one region to the other given the albedo differential.

- Right part The heat at the surface of the earth is reemitted. A body that you heat radiates long waves (*infra red*) towards space.

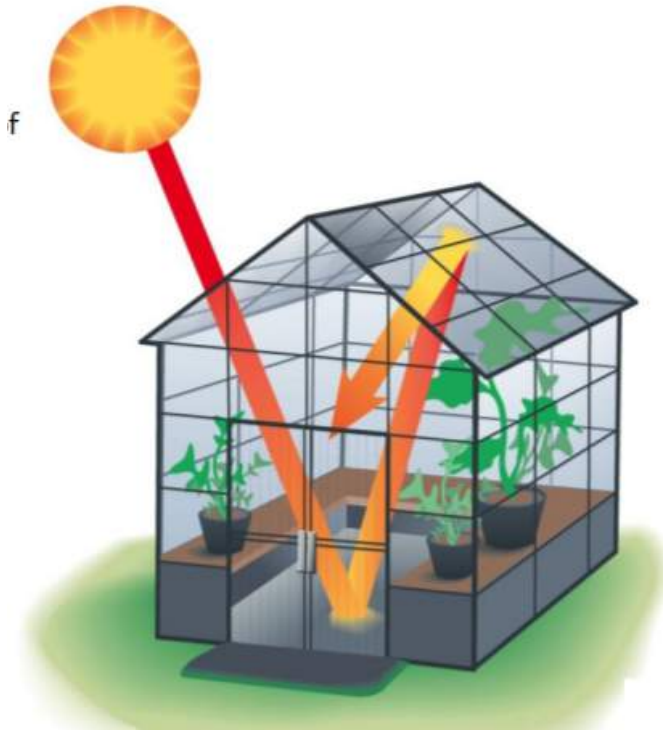
> (Steady state) If we add all the percentages up, we have 100% in and 100% out. In other words, there is no accumulation or loss of energy in this system.

[Definition] (*Greenhouse gases*)

```
_____________________________________ Atmosphere
    \     /        /           /
     \   /       /           /
      \ /       /          x x x x   /*aerosols*/
       \       /           x x x x   /*and clouds*/
        \     /            /  \
_______  \ / _____________/_____\_(warming)__
```

[Note] Greenhouse effect is a natural process ?

[Note] without the atmosphere the earth would be -80°C. Because there is the atmosphere then there is a greenhouse effect in the atmosphere thereby trapping heat in the atmosphere.



Enhanced greenhouse effect

Q What happens if we increase the concentration of greenhouse gasses in the atmosphere ?

A due to human activity, we'll have more aerosols , creates more trapping, so more reemissions to the earth $\Longrightarrow$ warming.

Note this is the ultimate cause of global warming !!

[Recall] we call anthropogenic the gasses that origin from humans, for instance CO_2, methane, ozone.

B. Investigation of climate change

Introductory comments

Climate is different from weather

[Definition] (*Climate*) : Long-term statistical sum of weather in an area

[Definition] (*Weather*) : State of the atmosphere at a specific time and place.

> weather is predicatable over a couple of days. While the climate can be predicted for long time-scales

[Definition] (*Climate system*) : refers to the many elements that contributes to creating a climate in a region (*atmosphere, oceans,land ,biosphere, etc*.)

> climate system is a very complex framework ,so it's also very hard to simulate.

[Definition] (*variability*)

1. natural : the variability driven by natural processes (e.g. seasons)
2. forced : the variability originating from anthropogenic sources (e.g. increase in CO_2 emissions)

[Remark] it is not easy to differentiate between forced and natural variability (*need long term observations for that. We can do that with models*).

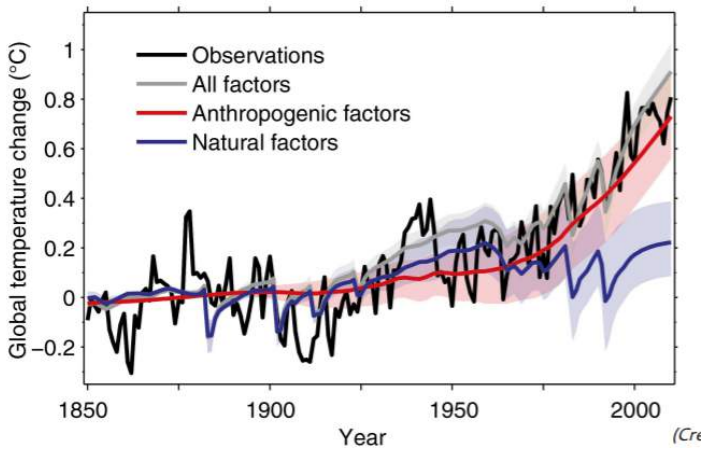
Lecture 22

Recap

- We saw the physical aspects of climate change
- greenhouse effect (*energy balance*). Half of the incoming solar radiation is absorbed by land and ocean (earth). No gain/loss of energy in the system (*steady state*).
- this trapping and reemission is made by the greenhouse gases, dioxide, vapor, methane, etc.

> note that these are NATURAL processes

If we inject gases in the atmosphere, then there are more molecules in the atmosphere that trap the heat, so the balance of steady state is broken ! and there is a net gain of energy $\implies$ warming.



We look at *trends* to assess the to maybe spot an indication of a variable climate system, to avoid the short term fluctuations.

> We want to separate natural variability, anthropogenic induced variability, this is hard to do in practice because we lack data points.

Some academics simulate the previous CO2 levels (blue line) and calculate the anthropogenic factors which is all factors - natural factors.

Note that the residual (red shadow) grows with time, because we start burning more fossil fuel , etc. So scientists infer that the right most trend is due to the anthropogenic factors.

Observations available

- in-situ observations : research vessels, moorings, etc.
- remote sensing : satellite, aircraft, etc.

> Argo floats has helped immensely in sampling data on as much surface of the ocean as possible.

Climate Models

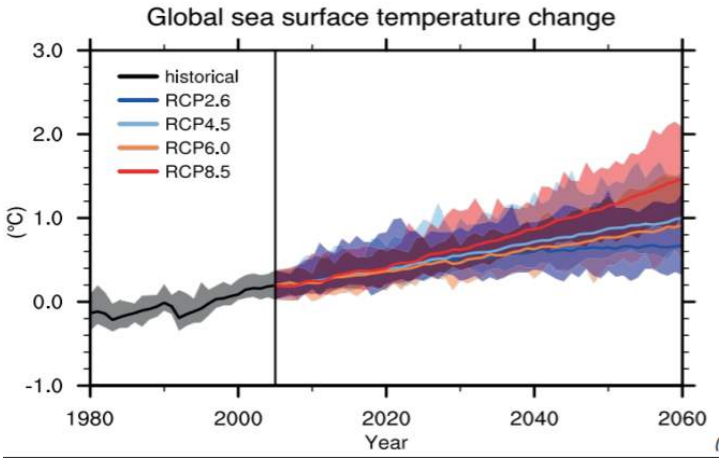
[Definition] (*Climate mode*) : a mathematical representation of the climate system based on physical, biological and chemical principles that include atmosphere, ocean, land , and sea ice components.

Incorporates physics for fluid mechanics with data sent to computers to solve the equations.

IPCC and Climate Scenarios

scientific and intergovernmental body under the auspices of the United Nations created in 1988.

- Depending on the climate projections, climate models can be ran with different scenarios (concentration of greenhouse in the atmosphere) , and see after solving the equations what it projects.
- we can investigate the past, and prescribe that in the model , to project what the climate looked like 40 000 years ago and what not,



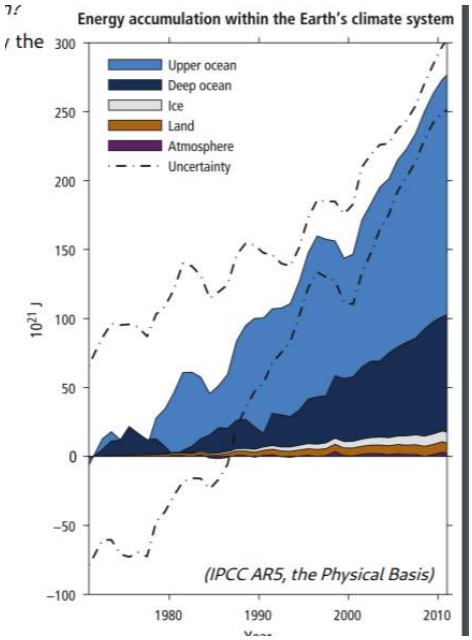
The grey is the historical data. The curves are modeling of the *hypothetical future*

- business as usual is the RCP8.5 (if we continue as is)
- some mitigations (emissions)
- big collapse in the economy and what not

C. The major physical changes

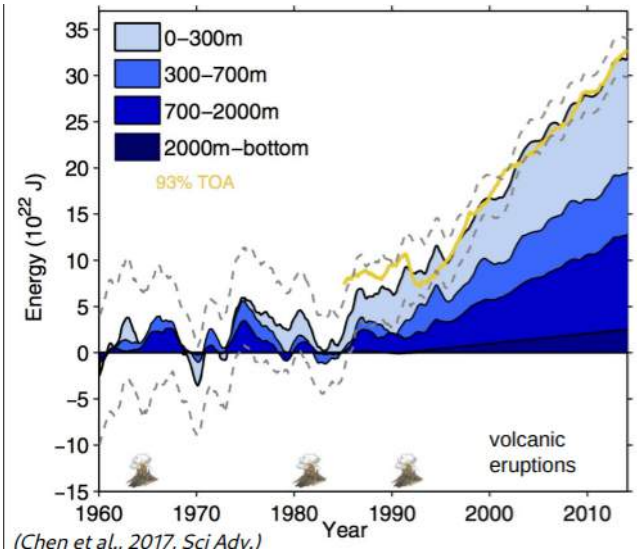
Ocean warming

What is the impact of the energy balance on the ocean (energy imbalance from the excess greenhouse effect).



We see a net increase in the energy. That can stay in the atmosphere the cryosphere, land, etc.

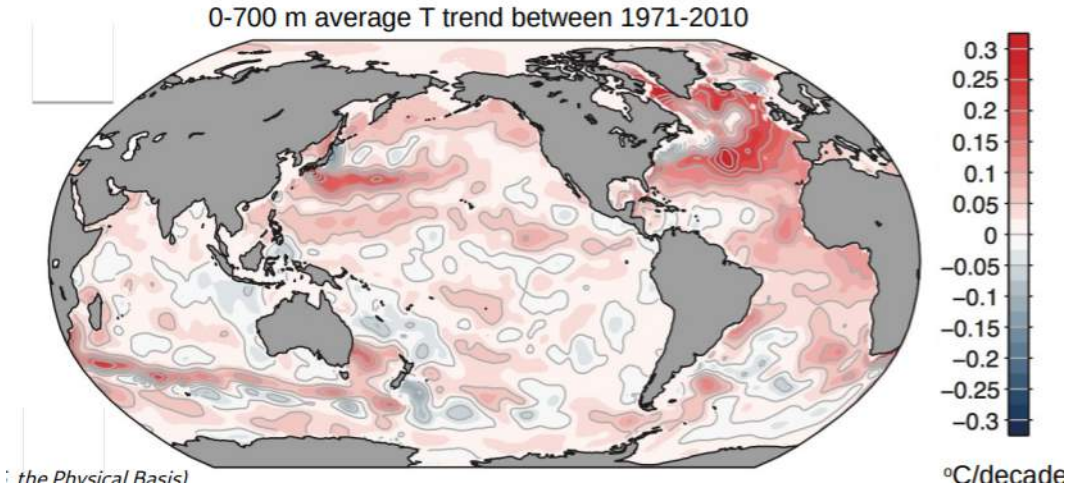
Where does this additional heat go in the ocean ?



The top 700 meters is where most of the heat go. Which makes sense.

- Note that it's not a smooth continuous increase
- volcanic erruption cause aerosols in the space, which reflect sunlight back into space, causing temporal cooling.

Warming occurs on almost the entire ocean



But there are zone that warm up faster (North Atlantic), and some regions that warm up slower (Southern Ocean)

> Ocean warming is spreading from the surface to the ocean interior,
>
> - warming occurs faster at the surface because of uptake of heat at the air-sea interface and propagation of the excess heat into the ocean interior follows subduction of water mases

Circulation Slowdown

Lecture 23

Recall

We looked at how to investigate climate change based on observations.

- climate models
- IPCC (major knowledge and progress that we have been doing in understanding climate and climate change through reports.)

  Climate scenarios $\longrightarrow$ past present future.
- Ocean warms as a result of greenhouse effect excess heat ?
- Some regions warm up faster than others; *surface warms faster than the deep ocean*
- We saw how warming affects circulation (*warming*)
- We saw that we have data of sea level since ninetieth century.

  We see a continuous rise in sea level.

  1. Ocean warming (resulting from thermal expansion)
  2. Freshening from glaciers and ice caps

  [Note] Icebergs don't affect directly the level of sea level. Ccan affect the properties of freshwater which could affect the sea-level , but don't affect it *directly*.
- We saw the glaciers are the main contributors, melting from Greenland ice caps and Antarctic ice caps.
- [Note] Ice cap of Greenland is heavily melting.

Sea level Rise

Q If 10% of the Antarctic ide sheet melts by 2100, how much would global average sea level rise ? Density of meltwater is 1000 kg m^3, mass of Antarctic ice sheet is 2.1×10^19 kg, surface are of world's ocean is 3.6×10^14 m^2.

$$\begin{aligned} e = \frac{m}{V} \implies v &= \frac{m}{\rho} \\ &= \frac{2.1 \times 10^{13}}{1 \times 10^2} \\ &= 2.1 \times 10^16 \text{ m}^3 \end{aligned}$$

So we conclude that

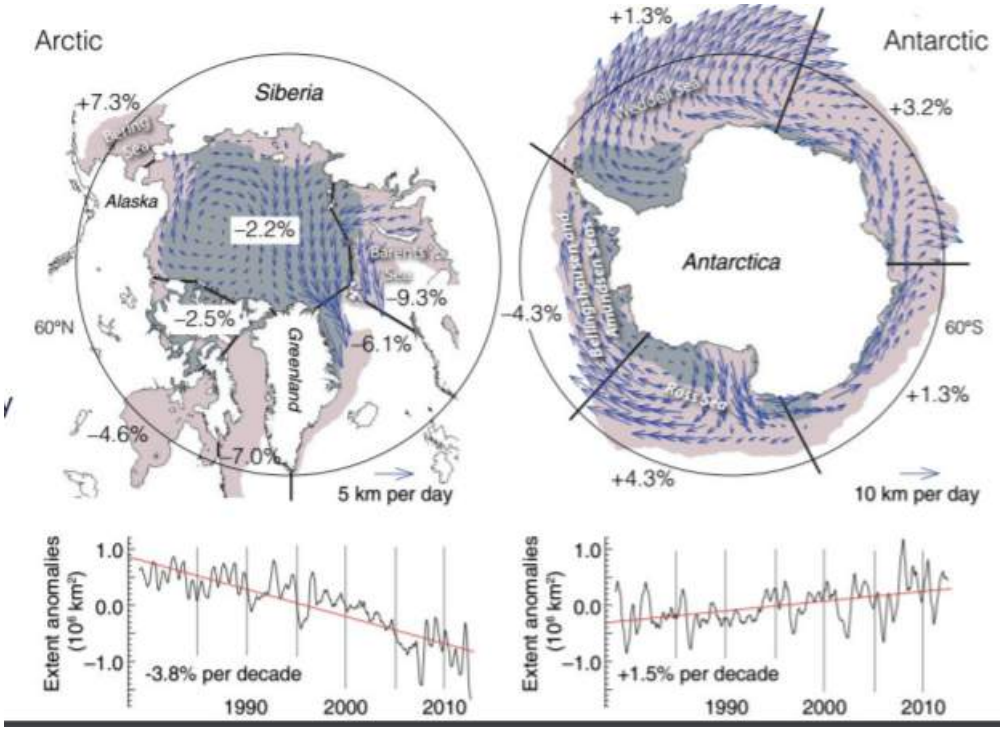
$$V_{10} = 10\% \, V = 0.1 \times 2.1 \times 10^{16} = 2.1 \times 10^{15} \text{ m}^3$$

Since $V_{10} = H \times S$, then it follows that

$$H = \frac{V_{10}}{S} = \frac{2.10 \times 10^{15}}{3.6 \times 10^{14}} = 0.5810 = 5.8 \text{ m}$$

This result makes sense since we said that if we melt all the Antarctic ice cap we would get 56 meter rise, here we get about 5 for 10%.

Sea Ice Melting



[Recall] The Arctic and Antarctica are different in many aspects, as it was seen in the Sea Ice lectures.

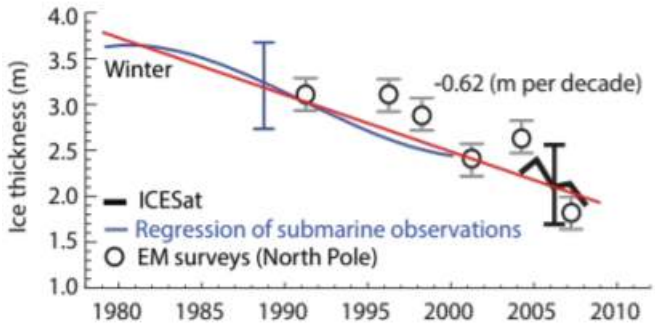
> Sea ice is climatically important for the climate due to albedo, ocean circulation, gas exchange, etc.

[Remark] The Antarctic sea ice extent has been increasing at a rate of 1.5% per decade, and it is not clearly understood why

($\star$)Arctic sea ice cover has consistently decreased over the last 40 years.

> Lots of climate models predict ice free Arctic in summer by 2050
>
> Factors explaining this dramatic shrinking
>
> - Changes in weather and atmospheric patters (storms breaking the ice and what not)
> - Some of the heated waters in the ocean reaches the surface and contributes to melting the ice (since ocean transports heat from low to high latitudes)
> - *ice-albedo-feedback loop* : ocean absorbs lots of heat since low albedo $\implies$ temeprature rise $\implies$ more melting $\implies$ more surface ocean to be warmed up
> - Natural variability. But it is hard to point out if it's natural variability of *anthropogenic*.

[Important] The decrease in ice thickness decreases a lot.



This data is collected by submarines and satellites.

[Remark] The Antarctic sea ice cover has been increasing unexpectedely (on average : east shrinking ,west growing).

Causes :

- intensification of winds and shift in wind patterns sea ice drift. Recall that winds are what pushes sea ice to drift more, then the sea ice expands this way.
- Ocean surface cooling
- Increase in land ice melting

Q If we add fresh water at the surface of the ocean does it increase or decrease stratification ? Increases

So there's heat isolated from the surface by this cold fresh layer. So if we add warmth, we inhibit mixing so the heat below the surface has a hard time to get to the surface ,this makes it easier to form sea ice. Also freezing point decreases.

- Natural variability

Part 4. Human Impacts on The Ocean

3. Climate Change : Biogeochemical changes

A. Anthropogenic Carbon Uptake

The ocean anthropogenic carbon sink

CO_2 emitted by human activities is distributed in 3 main reservoirs

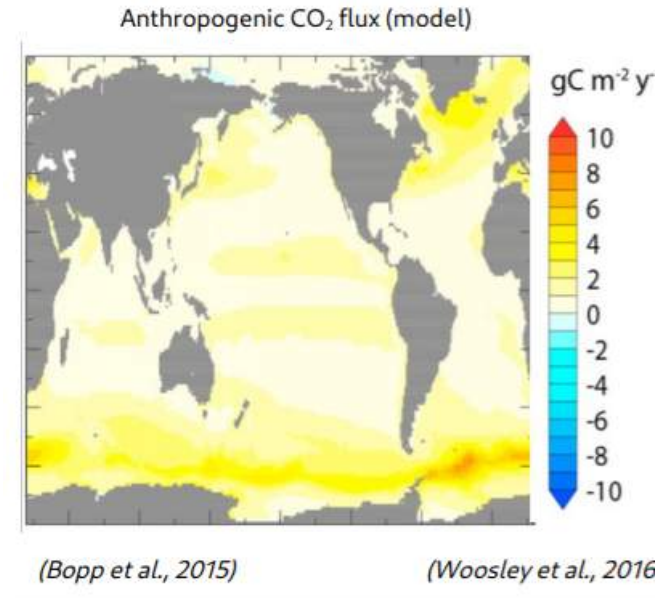
- 50% of it stays in the atmosphere.
- Main contributor is the burning of fossil fuel and cement.

Q How does this anthropogenic carbon get into the ocean ?

Atmospheric an anthropogenic carbon act in a similar way.

Some factors that contribute to enchanting this absorption

- temperature (the colder the water the more gas we can dissolve in the water)
- winds (stronger)
- rate of removal of anthropogenic carbon at the surface. This impacts the flux (the difference between atmosphere and surface)



↑ red carbon goes from atmosphere to ocean, and blue vice versa.

B. Ocean Acidification

the protons that form from carbon dissolving in the water

> climate models predict further decrease of ocean pH in the future

We saw that adding carbon in the ocean leads to consuming the carbonate ions. Carbonate ion disolves into proton and

Anthropogenic co2 int the ocean combines with carbonate ion to produce bicarbonate ion.

Organisms consume calcium carbonate to make squelet,bones, shells all structural parts of their bodies.

This molecule is found through the reaction of

Lecture 24

Recap

- Some ocean regions are more efficient than others at taking and storing carbon
- in regions of formation of deep waters, transport is more efficient ?
- Addition of carbon dioxide in the ocean is related to ocean acidification. When ocean absorbs carbon dioxide, pH decreases.
- The bicarbonate is the dominant form of
- ocean acidification has been ongoing for several decades (more CO2 in the atmosphere the lower pH we have (*climate projections approve of this*))
- Carbonate ion drops. But organisms use carbonate ion with calcium to produce calcium carbonate to make shells and what not.

> lots of organisms are affected by the drop in carbon ion and the decrease in pH
>
> - tropical coral reefs (as said in the media)
> - some organisms at the bottom of the food chain $\implies$ huge impact on the whole food web !

An experiment was conducted

$\star$ $\implies$ this is what happens for the climate projected model of 2100 .

C. Ocean Deoxygenation

Causes of decrease in oxygen in the ocean

Global warming affects oxygen concentration through 3 major ways :

1. Solubility : if we warm the ocean then we can dissolve less gases, so it can absorb less oxygen.
2. Stratification : Connection between ocean interior and oxygen is reduced.

3. Biological productivity Nutrients come from the deep oceans through upwelling and macronutrients come from dust. Along with light we have biological production. When they sink , they do respiration which consummes oxygen.

   If we have stratification, then we have the same amount of incoming light, but less nutrients because lower flux of nutrients from deep waters. So we have less biological production. Thus, the organic matter flux towards the depths decreases and the respiration is decreased as well which implies less oxygen is consumed.

   So les oxygen can be produced at the surface (since we bring less nutrients with oxygen produced through photosynthesis)

Q how does adding nutrients to the surface impact oxygen at depth ?

Nutrients and light come to surface. Sink then respiration and consume oxygen. If we add even more nutrients, we will have more productivity , so increased flux implying decreased oxygen until we don't have oxygen no more ! (there exists a limit).

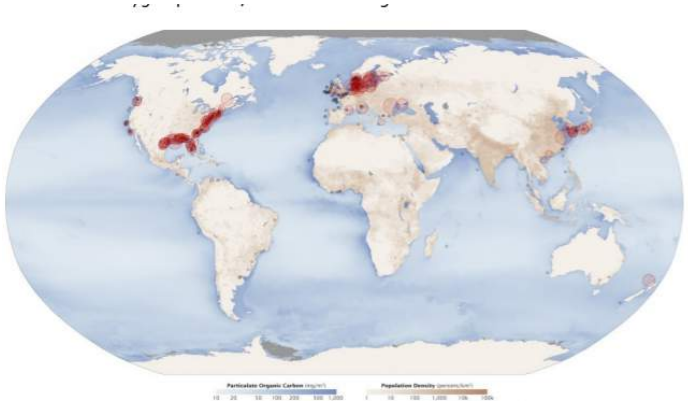
> oxygen concentrations have been decreasing in the past decades (effect of climate change)

Impact on ecosystems

some species are affected more than others

- some species range shifts occur due to deoxygenation (migration to shallower depths ; they go upper in the water column (*since more oxygen there*))
- the habitat is reduced (habitat squeezing)
- But other mobile species like whales for instance can move to other oxygen rich regions.

[Definiton] (*Dead zones*) :



The red dots are zones in the ocean with little ocean so not many fishes live there. They are along the long coasts because fertilizers used in agriculture which is dumped into the ocean

[Definition] (*Eutrophication*) : the process described above. (problem for ecosystems)

D. Geoengineering

[definition](*Geoengineering*) : The deliberate and large scale intervention in the Earth's climate system with the aim of affecting adverse global warming.

- greenhouse gas removal (not reducing emissions but taking it out immediately)
- solar radiation management: