OCEANS

So far in this course, we've concentrated on the structure and dynamics of the atmosphere.

This lecture we'll briefly look at the oceans and the interaction between oceans and atmosphere.

The oceans and atmosphere are a coupled system, and exchange energy, momentum and mass

Energy

* Heat is exchanged between ocean and atmosphere
  → acts as a reservoir
* transports heat between tropics & poles

Momentum

* wind drives ocean currents

Mass

* Evaporation & precipitation of water
* Gasses e.g. CO_2, SO_2 dissolve

Acts as a reservoir, etc.

Ocean heat capacity and transport

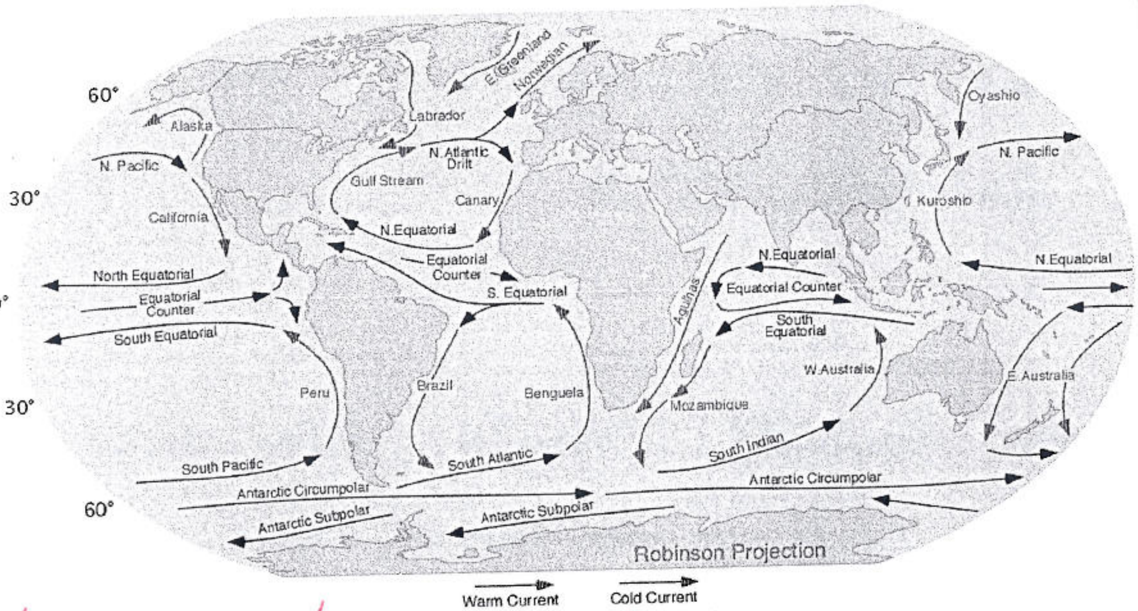
Much more energy is required to change the temperature of the oceans than the atmosphere, so the oceans take longer to warm up or cool down. When surface water is cooled, it becomes denser and sinks, to be replaced by warmer water from below. The result is that for the 2/3rds of the Earth covered by ice-free ocean, the temperature only varies between -2°C (freezing point of salt water) and +30°C. At any given place the variation is hardly more than 1°C in a day and 10°C over the whole year.

The ocean not only stores heat, but transports it, driven by currents due to the wind, temperature and density gradients. Oceans are responsible for a part of the heat transported between the tropics and poles.

The UK climate is particularly affected by ocean currents, the Gulf Stream and North Atlantic Drift transport large amounts of energy from the south to northern Europe.

Ocean circulation 1 : Wind stress

Wind blowing over the ocean experiences friction which transfers momentum to the ocean. The prevailing winds (trade winds, westerlies) are a major cause of ocean surface currents. An important restriction on ocean circulation is the presence of land masses, but the overall pattern follows the observed wind direction.



- Indian ocean has seasonal wind reversal (Monsoon) so ocean currents reverse too
- Equatorial Counter-flows due to pile-up of water on western edge.

Typical current velocities

Open ocean: 0.2–0.5 m/s (~1 km/h)

Western coasts of ocean basins

~ 2 m/s (7 km/h)

The upper 150m or so of the ocean which is directly affected by friction with the atmosphere is known as the EKMAN LAYER.

In this layer, the velocity is determined by a balance between the pressure gradients, Coriolis forces, and friction.

Below the Ekman layer, in the open ocean friction can be neglected and the ocean is in geostrophic balance

In the tropical Atlantic, solar heating warms the surface layers of the ocean, and is driven north-west up the American seaboard. As it goes, it gives up heat to the atmosphere, particularly in winter. The westerly winds drive this heat towards Europe, leading to the relatively temperate climate compared with similar latitudes elsewhere.

So much heat is taken out of the ocean that it reaches near freezing in the Greenland sea.

Evaporating and freezing water increases the salt concentration (salinity). The combination of low temperature and high salinity makes the water denser than water below, so it sinks to the bottom, spreads out, and flows southwards again.

This is the <u>THERMOHALINE Circulation</u> (thermo = temperature, haline = salt). Warm water travels on the surface north, cools and sinks then travels south. This mechanism alone provides an enormous heat flux of around 1 PW.

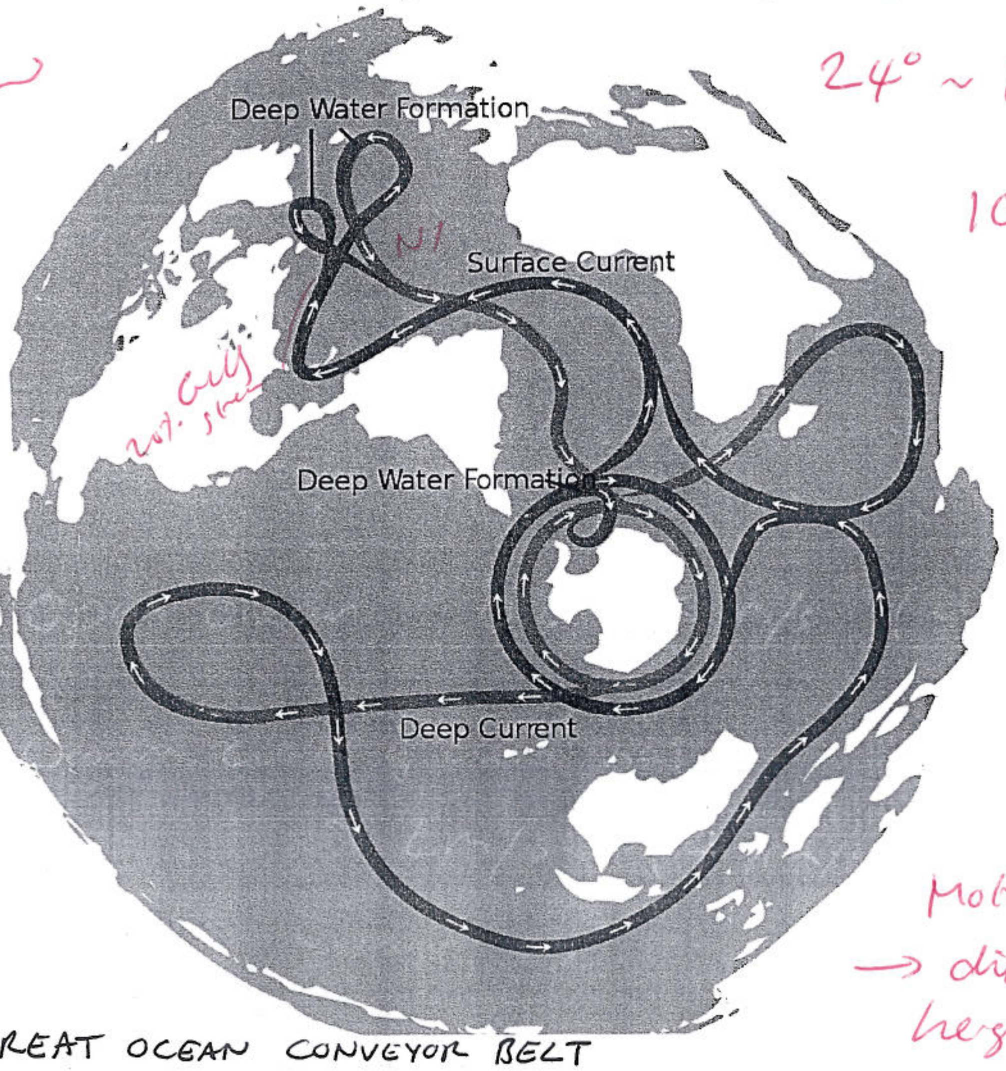
20% of Gulf stream

NADW

$24° \sim 17 \times 10^6\ m^3/s$

$10^6 m^3/s = 1\ Sv$

SVERDRUP

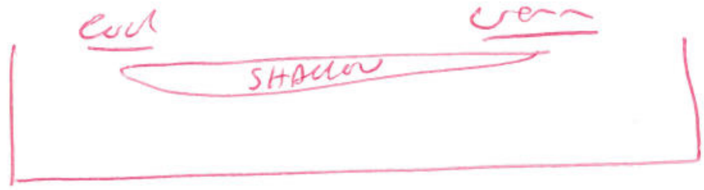


Motion of ocean → difference in heights

GREAT OCEAN CONVEYOR BELT

The real system is quite a bit more complex than this simple picture

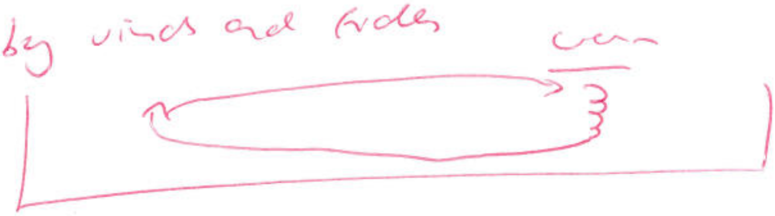
- Can't drive a deep circulation current by driving at the surface



- Heating at depth required (Sandström's theorem)

→ need mixing of deep ocean with surface to transfer heat downwards.

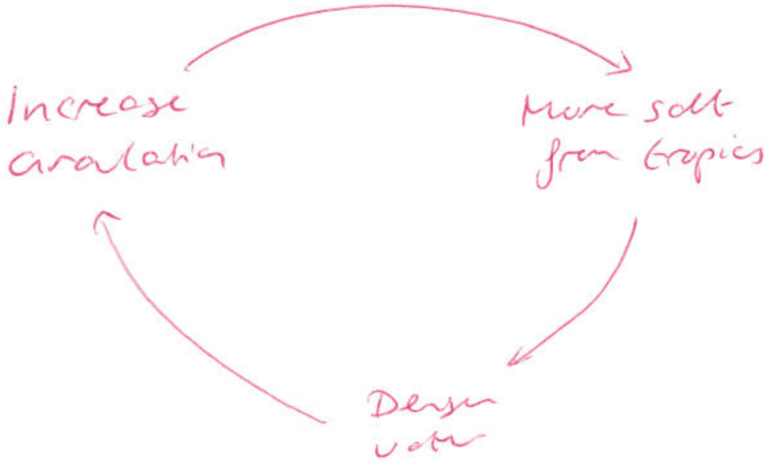
Driven by winds and tides



Salinity feedback

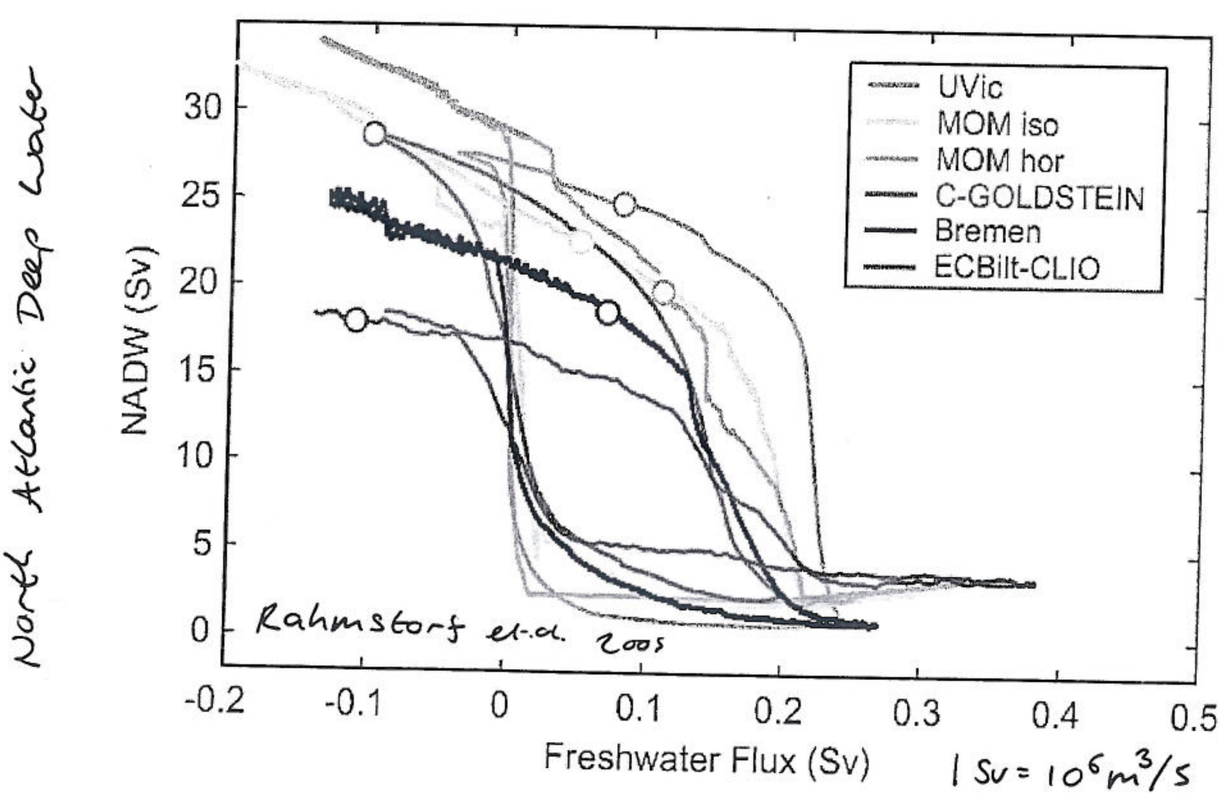
Because there is more evaporation than precipitation (on average) in the tropics, and more precipitation than evaporation in mid-latitudes, water tends to be saltier in the tropics than near the poles. The thermohaline circulation is therefore not directly driven by salt (in fact it's inhibited). Increasing salt concentrations near the poles therefore increases the circulation

This leads to a nonlinear feedback mechanism



This feedback results in two solutions, robustly predicted by models. ~~[illegible]~~

Not known where on this graph the real ocean lies.



Present-day state for each model —o—

Effects of switching off NADW

- In models, switching off North Atlantic thermohaline circulation by switching off NADW leads to
  - ~10°C cooling of Nordic Seas
  - Most models cool Northwest Europe (inc. UK) by a few degrees
- Northern hemisphere cools, South warms
  → moves ITCZ and tropical rains south
- North Atlantic rises by ~1m even if overall average sea level stays constant
  → N.A ~1m lower than pacific due to geostrophic balance of currents
  (motion → ∇p → height)

Paleoclimate events: Has this happened before?

Three major circulation regimes have been identified

- Warm mode, similar to present
- Cold mode, with the NADW forming south of Iceland
- Switched off mode, with little circulation.

Switch-off seems to have happened after large influx of fresh water to north Atlantic

- Glacial Ice sheets (Heinrich events)
  During last ice age (~ 110,000 → 10,000 years ago) large numbers of icebergs would occasionally break away from the ice sheets and deposit large amounts of fresh water into the North Atlantic.
- The Younger Dryas event (~ 12,800 to 11,500 years ago)
  a period of around 1,300 years during which ~~the~~ Greenland and Western Europe dropped considerably (~ 10°C). Mean annual temperatures in the UK dropped to around 5°C, similar to our current winters. Icefields and glaciers formed in upland areas.
  Thought to have been triggered by the collapse of the north American ice sheets.

Timescales: How quickly can this happen?

- Heinrich events

  ~100 years change, lasted ~750 years

- Younger Dryas

  Change over a decade or so

  onset maybe quicker

- Localised changes can be quicker

  e.g. Dansgaard-Oeschger (D-O) events

  rapid warming of Greenland

  ~8°C in a decade or so

  change in circulation pattern (NADW shift north)

Need to alter path of billions of tonnes of ocean;

Cannot happen the day after tomorrow!

IMPACT OF GLOBAL WARMING

Global warming reduces cooling rate at high latitudes, and results in more rainfall, freshening surface waters. Therefore, most models predict weakening of NADW formation (and so thermohaline circulation) of 20-50% in the 21st century.

This was reported in the 2001 IPCC, but the models did not include fresh water from the Greenland ice sheet, as this is very hard to predict.

A melting of the Greenland ice sheet over 1000 years would produce an influx of fresh water to the north Atlantic of around 0.1 Sv ($0.1 \times 10^6 \, m^3/s$), similar to estimates for the Heinrich events.

The possible shut-down of the North Atlantic Circulation would take decades to centuries, and is an unlikely but high impact consequence of global warming.

<u>SUMMARY</u>

- Oceans and atmosphere are coupled together, exchanging energy, momentum and mass.

- The large heat capacity and convection of the oceans reduces temperature fluctuations.

- Surface currents are driven by friction with the prevailing wind, forming gyres.

- Temperature differences and salt drive the THERMOHALINE circulation, known as the Great Ocean Conveyor belt. ~~This~~ transports heat from the tropics to the northern hemisphere.
  An important part of this is the <u>N</u>orth <u>A</u>tlantic <u>D</u>eep <u>W</u>ater.

- Due to geostrophic balance, large ocean circulations imply pressure gradients, and so differences in heights → the ocean "sea level" is not the same everywhere.

- Salt plays an important role in the thermohaline circulation, and leads to nonlinear dynamics where the circulation can have (at least) two possible solutions.

- Large influxes of fresh water into the north Atlantic can have dramatic effects on the climate of Europe.