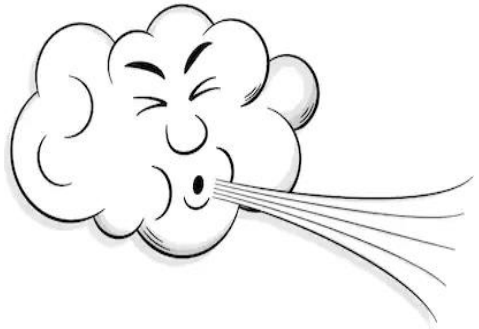
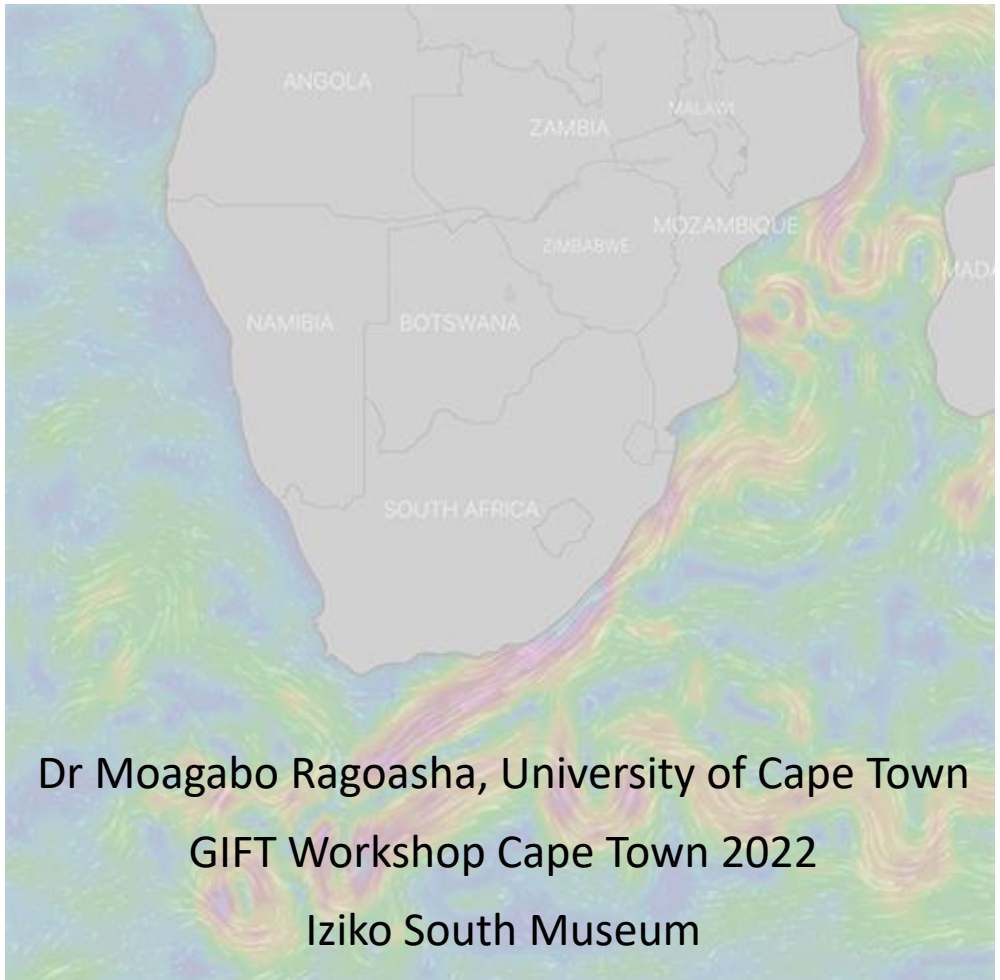


The great thermohaline circulation and introduction to South Africa's oceanographic setting



Dr Moagabo Ragoasha, University of Cape Town

GIFT Workshop Cape Town 2022

Iziko South Museum

Introduction

The ocean is dynamic place. Ocean currents transport important quantities such as nutrients, heat and pollutants around the world, sometimes with direct impact on humans.

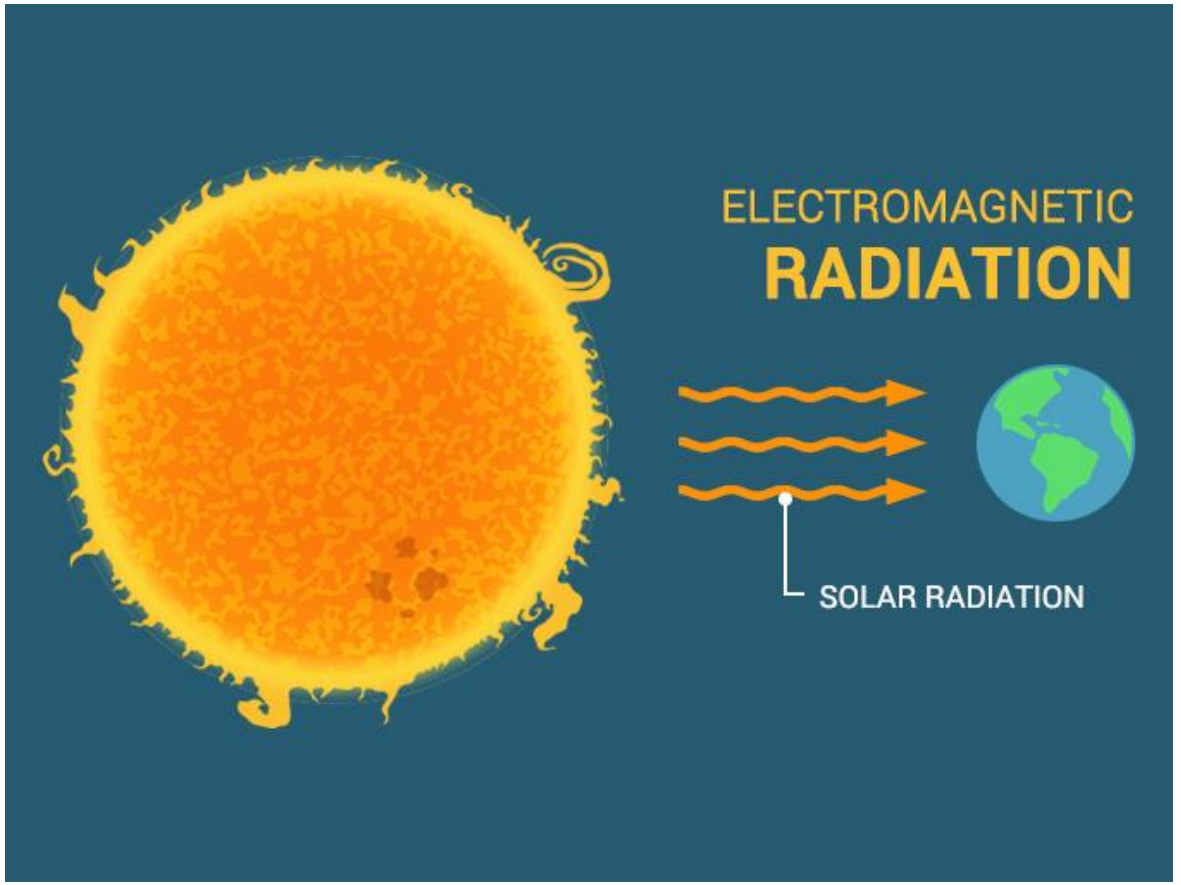
Topics covered

- The heat budget
- Coriolis Effect
- The ocean circulation
  - Surface wind-driven ocean circulation
  - Deep density driven circulation

Overview

- The Earth's climate is solar powered.
- To maintain an average temperature, the incoming solar radiation has to be equal to the outgoing solar radiation.
- Since earth is not flat, the sun doesn't not heat it evenly.
- The atmosphere and the oceans work non-stop to balance the solar heating imbalances.
- Without the re-distribution of heat by the oceans and atmosphere, Earth would endlessly heat up.

Solar radiation



Solar radiation also called sunlight or solar energy is electromagnetic radiation emitted by the sun.

- It provides light, heat and energy to Earth.

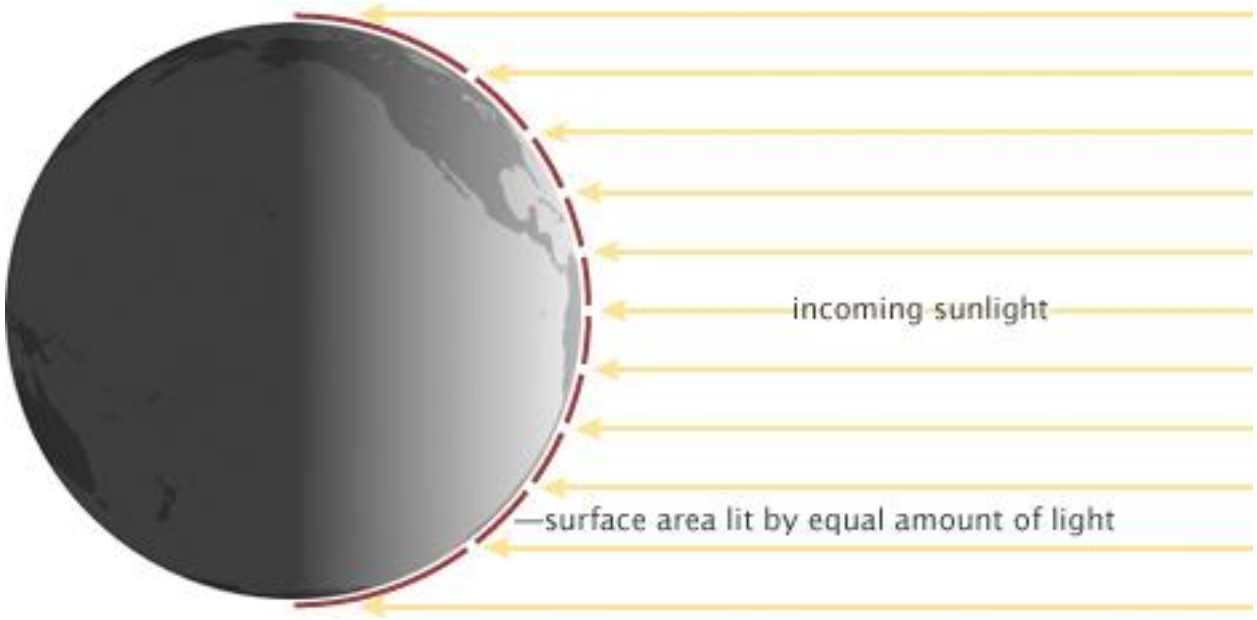
Solar energy from the sun to the Earth's surface

- Sun produces approximately 64 million Wm^{-2} (~6000˚C) in all directions.
- It travels travels 150 million km to be intercepted by earth's top atmosphere at constant value of 1368 Wm^{-2}.
- It takes a little more than 8 minutes to reach earth.

So how much reaches the earth's surface?

To determine the average amount of solar radiance that reaches earth, we must consider what the earth "looks like" to the sun.

- Earth is not flat, it is a rotating globe, therefore the sun sees one half of earth at a time.



What influences solar irradiance?

Solar irradiance is influenced by:

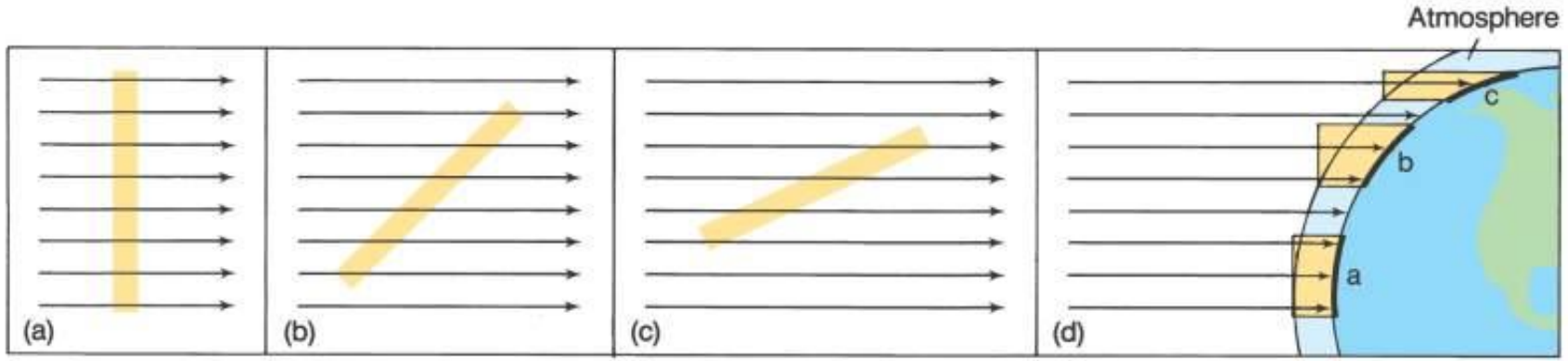
- The angle of sun due to latitude, season, and time of the day.
- Elevation above sea-level
- Atmospheric effects: cloud coverage and air pollution

Less incoming radiation = Less heating

Latitudinal differences

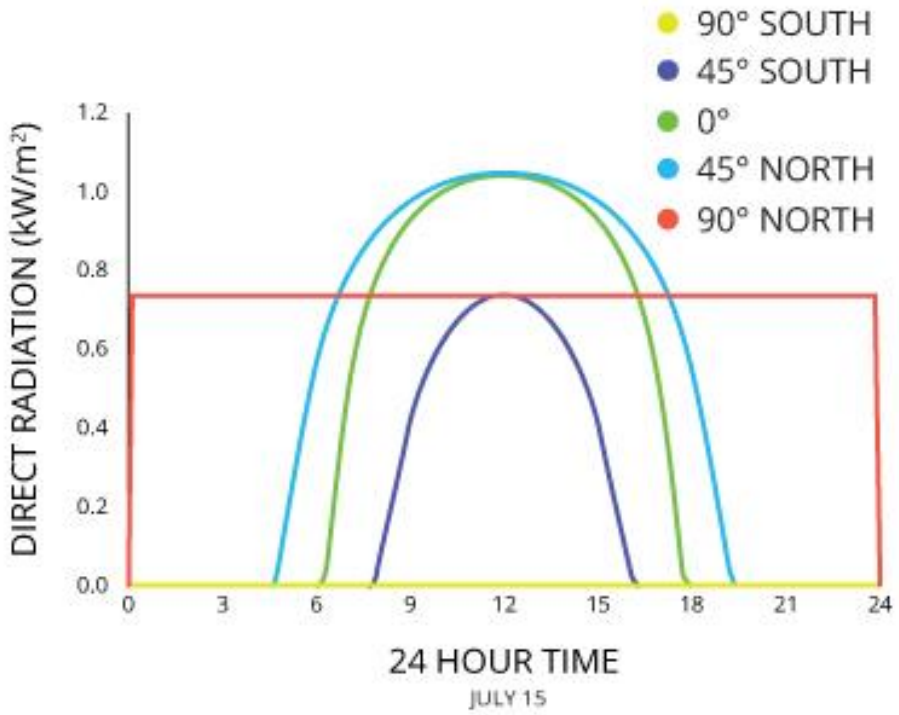
- Distance travelled by radiation is lower when the sun is overhead, hence it is greatest at the equator.

- It decreases with latitude from the equator as the hemispheres are tilted away from the sun, hence the radiation travels greater distances through the atmosphere.



Diurnal and seasonal cycle

- At a given point, the sun's angle will decrease from sunrise until noon, and then increases until sunset.
- The angle is greatest in the morning and evening.



This an example of the northern hemisphere summer. Zero radiation at the south pole in winter (dark).

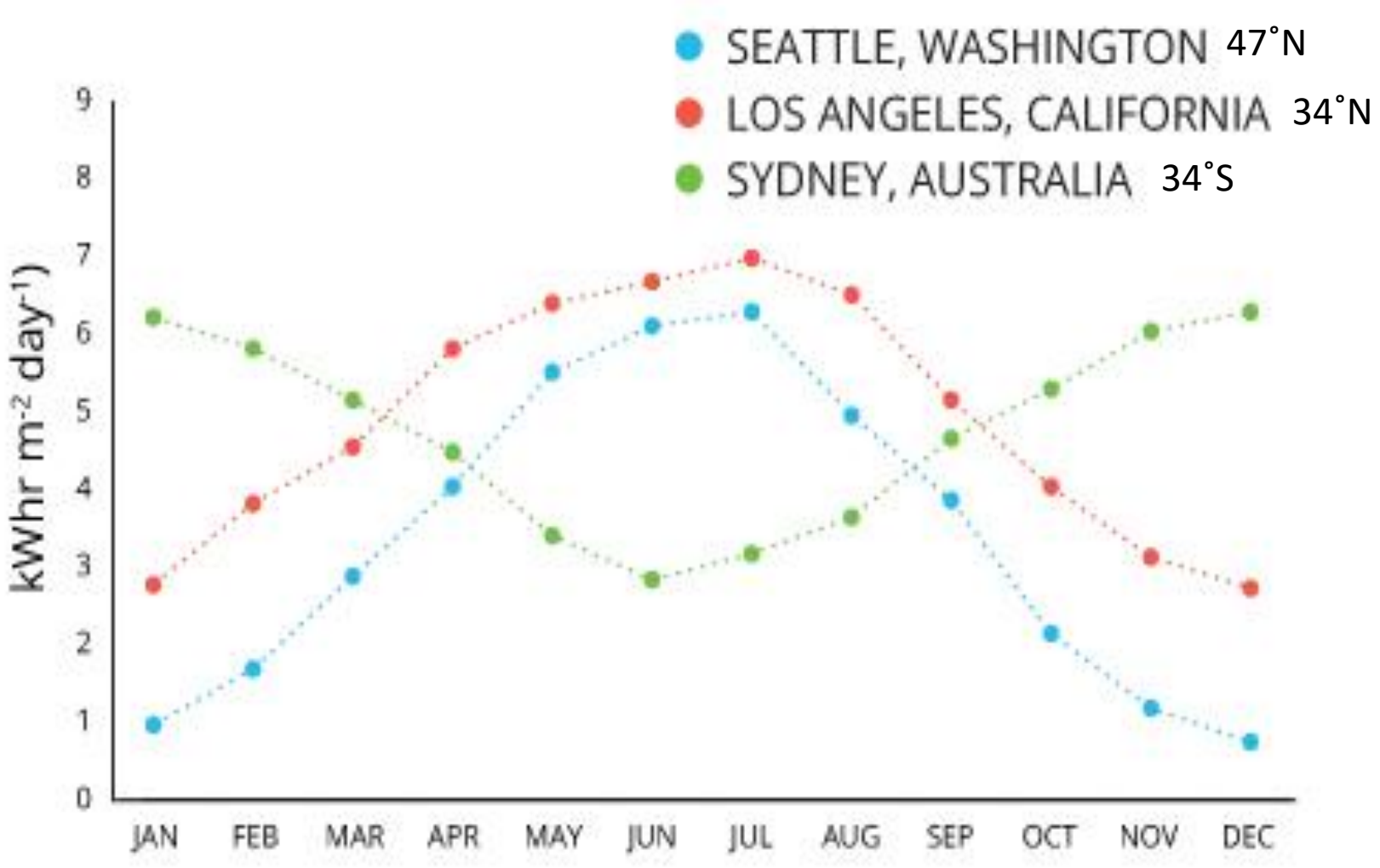
A hemisphere tilted towards the sun (in summer) will have the greatest irradiance.

At the equator, it is greatest all year round.

Diurnal and seasonal cycle

- Solar radiation levels also fluctuates with seasons.
- It is constant at the equator throughout the year.
- It peaks in the northern hemisphere around June or July (summer).
- It peaks in the southern hemisphere around December or January (summer).

Diurnal and seasonal cycle



The further a city is from the equator, the more the solar radiation received will fluctuate with seasons.

Sydney is in the southern hemisphere = low irradiance in winter (June-July).

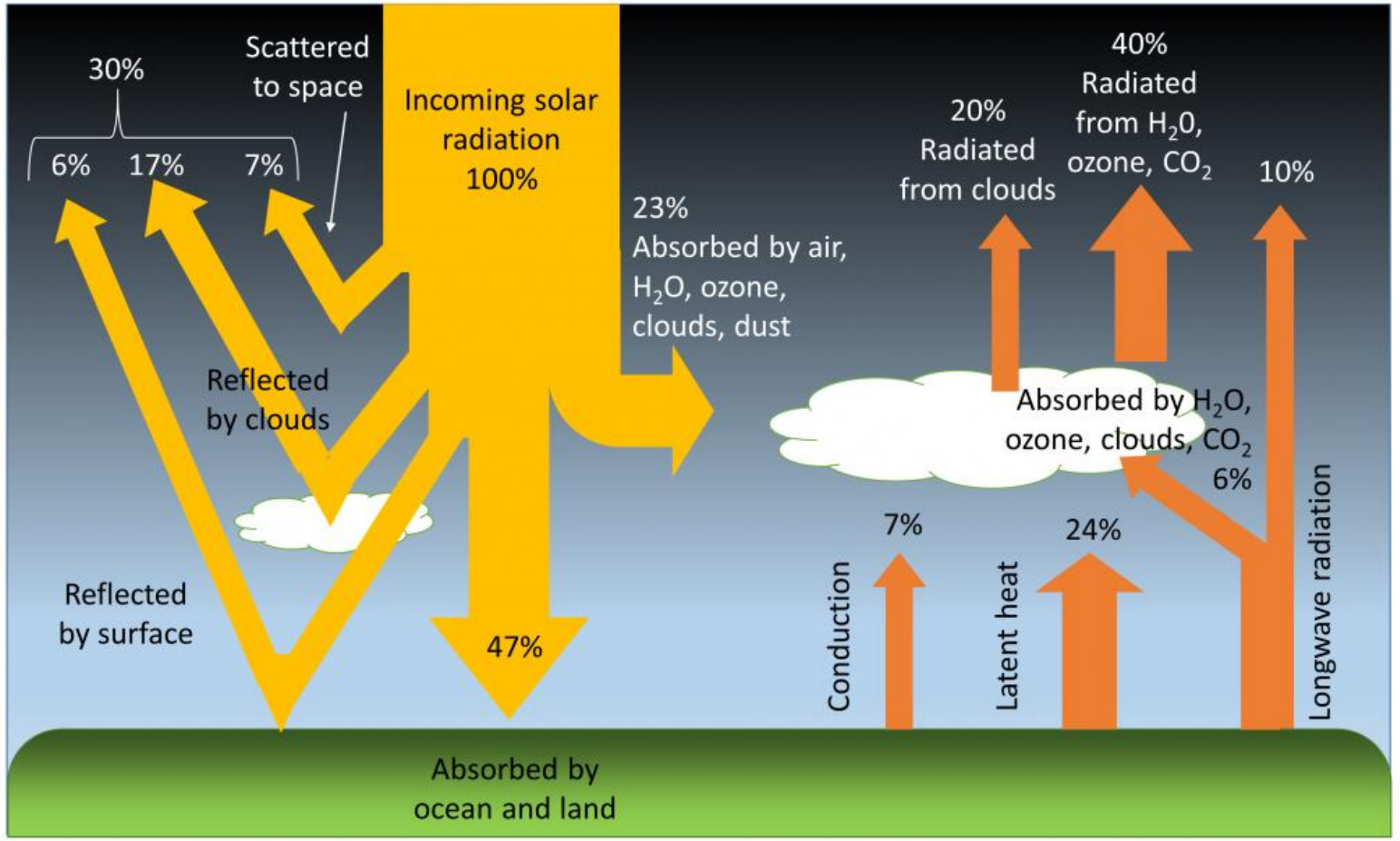
The Heat Budget

- To maintain its long-term mean temp of 16ºC Earth re-radiates as much heat back to space as it receives from the Sun. The gains and losses in heat are represented in the heat budget.

- The Earth's atmosphere greatly influences the heat budget.

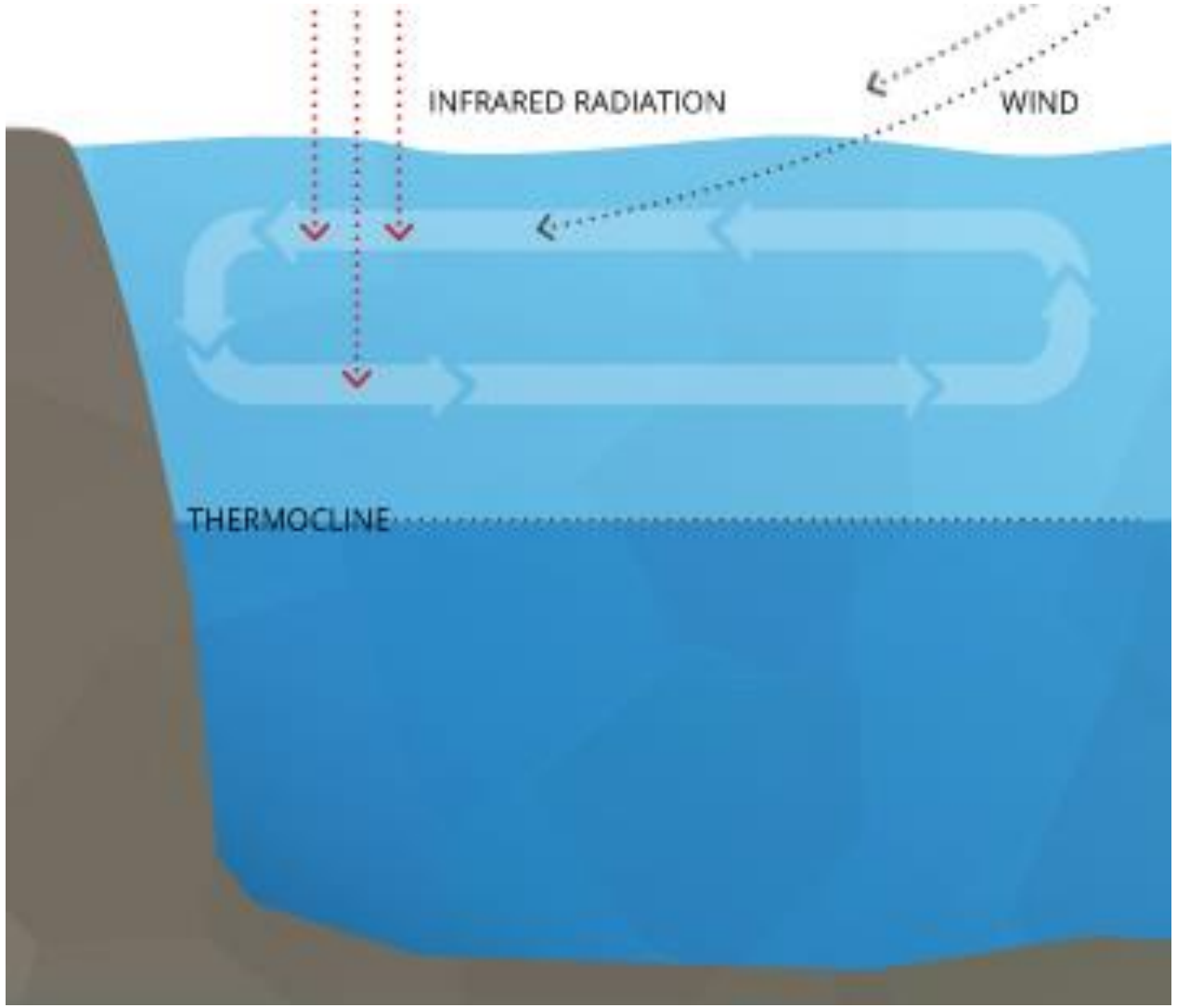
- Clouds and aerosols reduces the amount of radiation reaching the earth's surfaces. They cause scattering, however, the amount of solar radiance is the same but lower irradiance (less intense).
- Hence, humans gets sunburned without realising.

Global Heat Budget:
incoming solar radiation = outgoing solar radiation



Out of the total incoming solar radiation reaching Earth**, 30%** is reflected to space by albedo ("reflectivity of a surface") and **70%** is absorbed by the Earth's surface. In turn, the heat absorbed by the land and oceans is exchanged with the atmosphere through conduction, radiation and latent heat (evaporatiom<->precipitation). The heat (PW) absorbed by the atmosphere is eventually radiated back into space.

Heat, Temperature and solar radiation

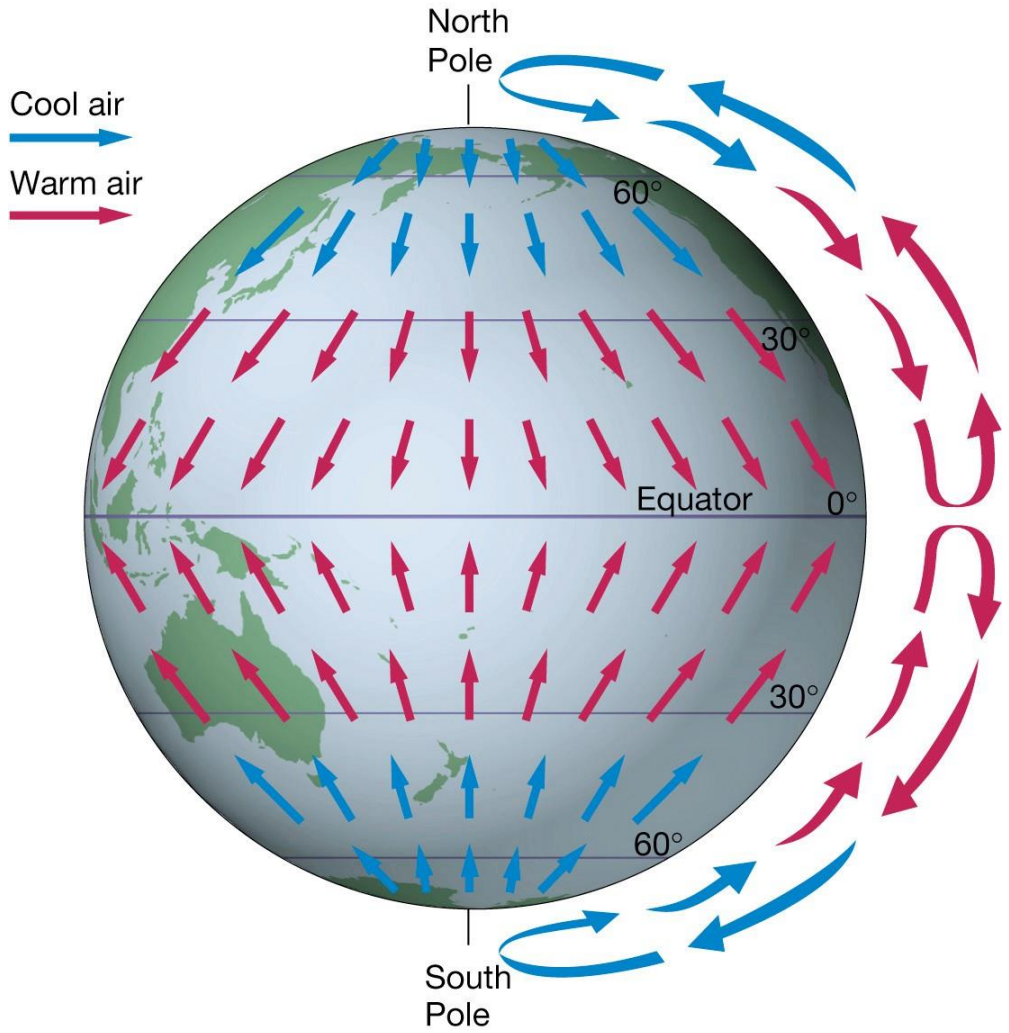


- In the ocean, water absorbs infrared radiation and warms up.
- 90 % is absorbed in the first meter.
- Heat is then transferred to greater depths via convection and mixing by the wind.

Variations in the Heat Budget Across the Globe

- There is an excess of incoming shortwave radiation between 35 °S and 40 °N and a deficit at higher latitudes compared with the outgoing longwave radiation budget.
- If equilibrium were to be maintained at every latitude the short and longwave radiation should balance locally.
- The fact that they are not, and as local mean temperatures close to the equator are not increasing with time and those close to the poles are not decreasing, heat energy must be transported from low latitudes poleward.
- This is achieved by circulation within both the ocean and the atmosphere, transporting heat away from the equator towards the pole and maintaining a higher temperature at latitudes greater than 50° than would be possible.

Atmospheric Circulation in the absence of rotation

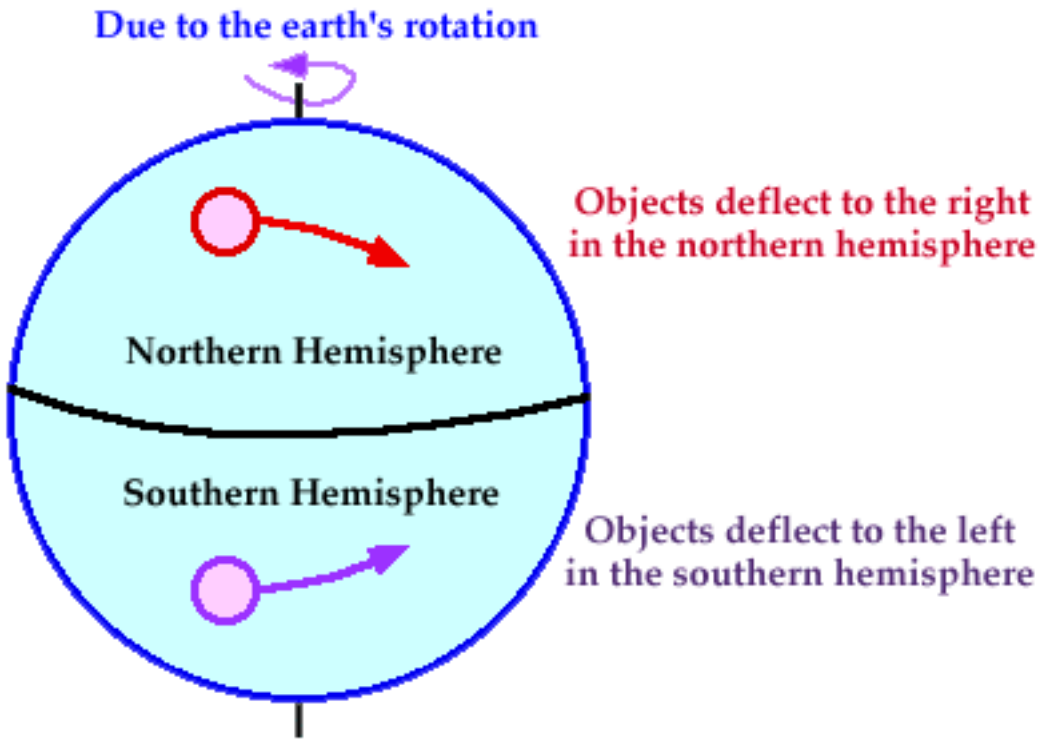


…but the earth rotates

Coriolis Effect

- Coriolis is a pseudo-force due to the rotation of the earth.
- It causes moving objects to deflect to the left in southern hemisphere and the right in the northern hemisphere.
- The object has to be travelling long distance and not firmly connected to the ground (i.e. air and currents).

What is Coriolis Effect?



- It is an artifact of the earth's rotation.
- It causes air and currents in motion to deflect from their path, as seen by an observe on the earth.

- Coriolis does not force anything to happen. It is an effect.

Coriolis Force

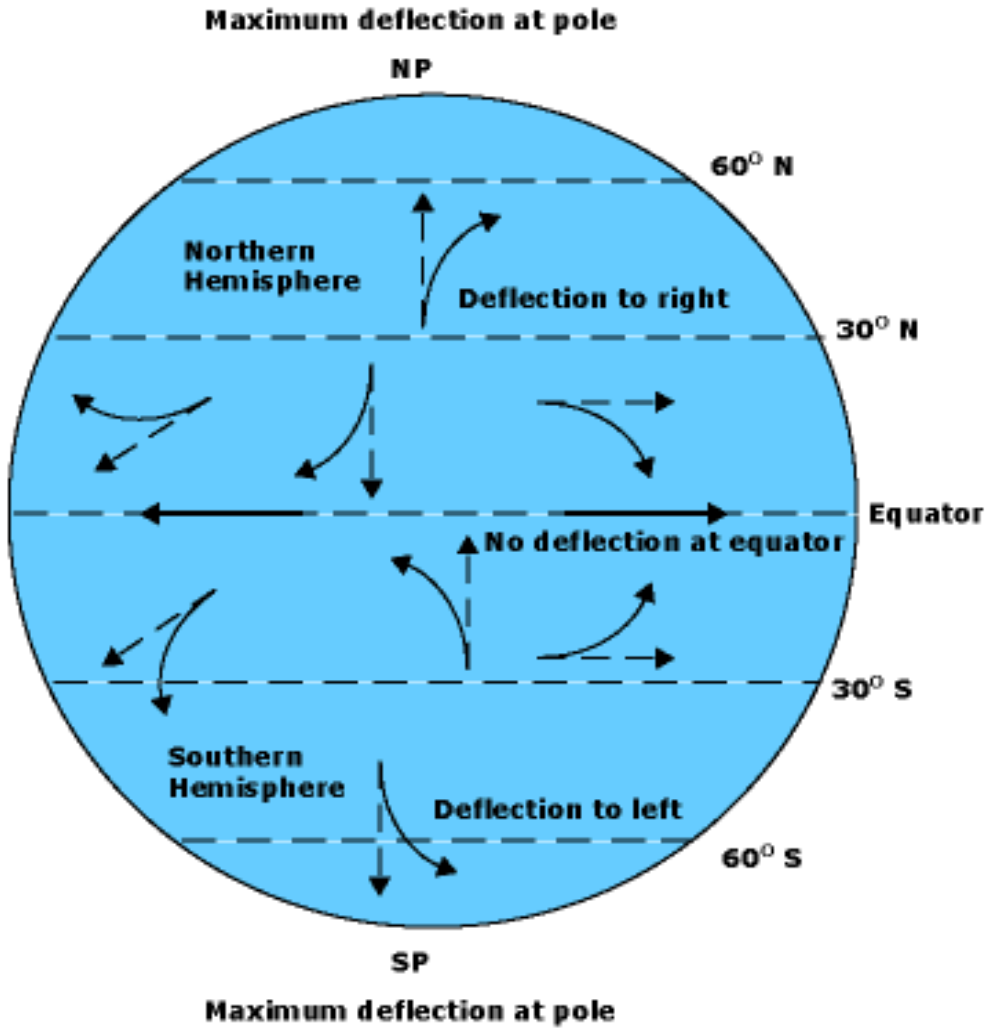
There are two reasons for this phenomenon:

1. The earth rotated eastwards

2. The velocity of a pint on the earth is a function of latitude

Therefore, Coriolis is a function of object's speed, its latitude and earth's rotation. Fast moving object = more deflection.

Coriolis Force



Coriolis is zero at the equator and increases to the poles.

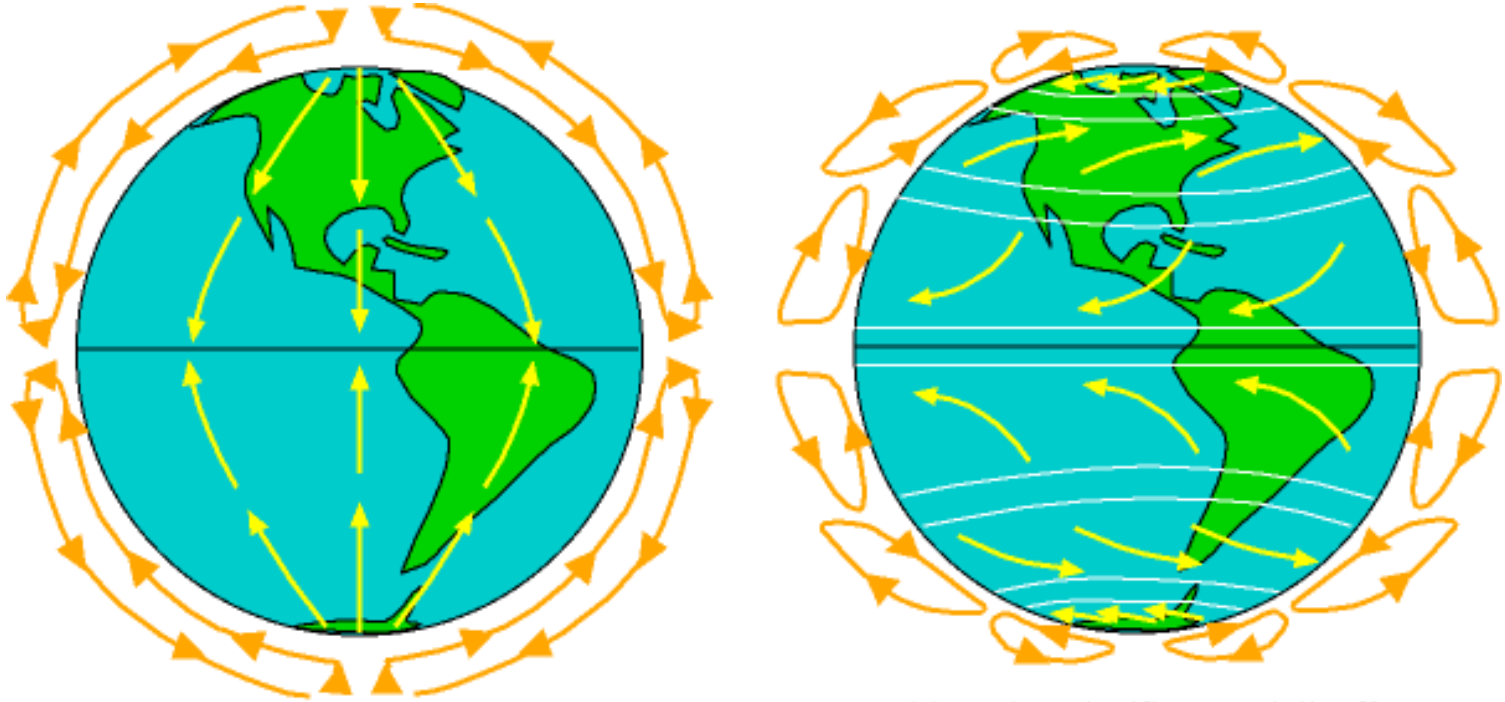
Coriolis effect in real-life: Northern Hemisphere Example

- A plane takes off from **City A** in the northern hemisphere
- The pilot wants to land in **City B** which is 1000 km due north of **City A** during take-off.
- **City B** would have moved east during the time it takes the plane to fly 1000 km.
- Therefore, if the plane flies due north it would arrive west of **City B**.
- To reach **City B**, the pilot has to curve right while flying north.
- The opposite occurs in the Southern Hemisphere.

Coriolis effect in real-life

- Coriolis effect is the reason that airplane's flight paths appear curved tracing the earth's shape (3-D).
- The path appears as a straight line on a 2D map.

The equator-pole temperature gradient drives our atmospheric circulation patterns



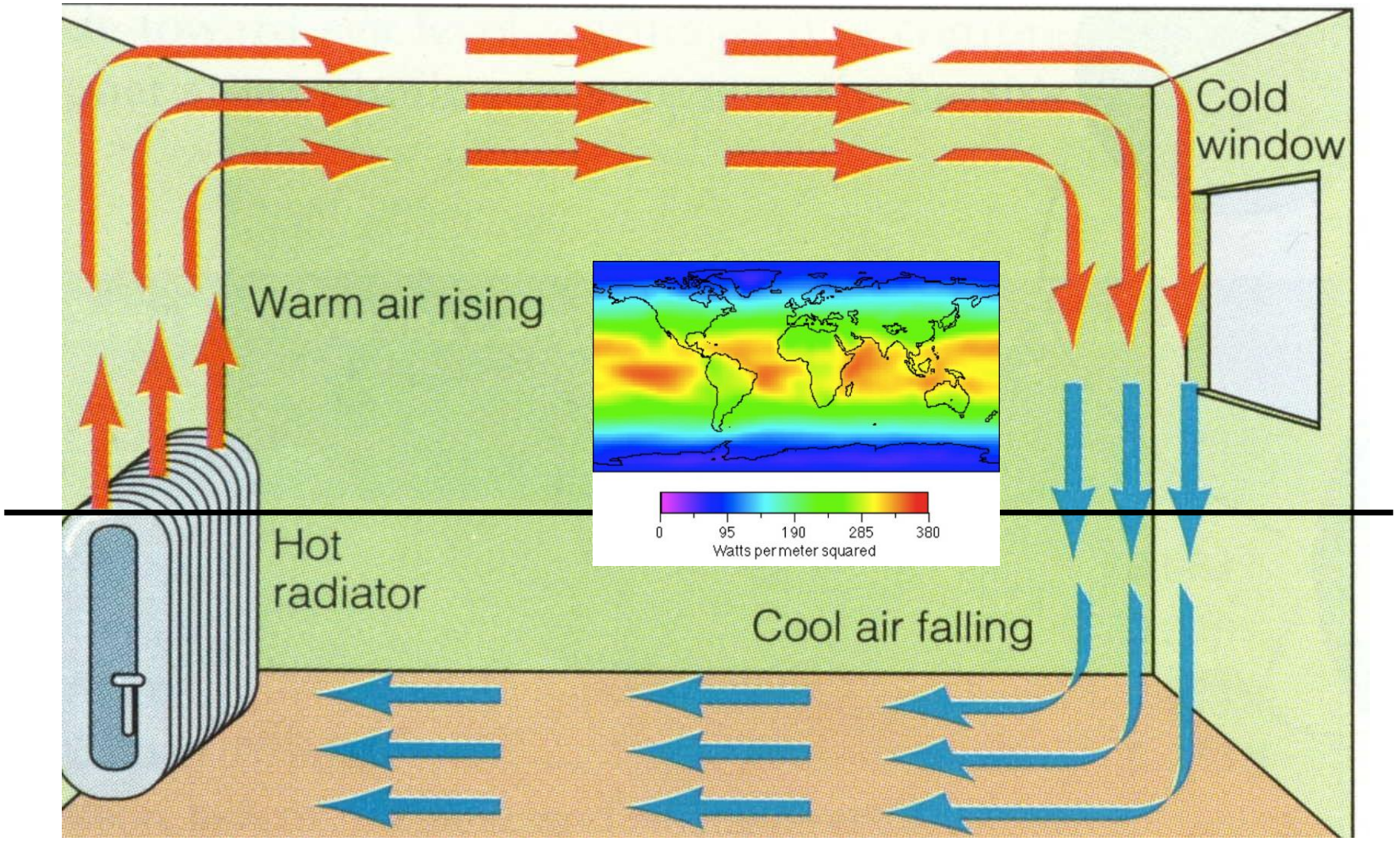
no rotation: no coriolis effect

rapid rotation: significant coriolis effect

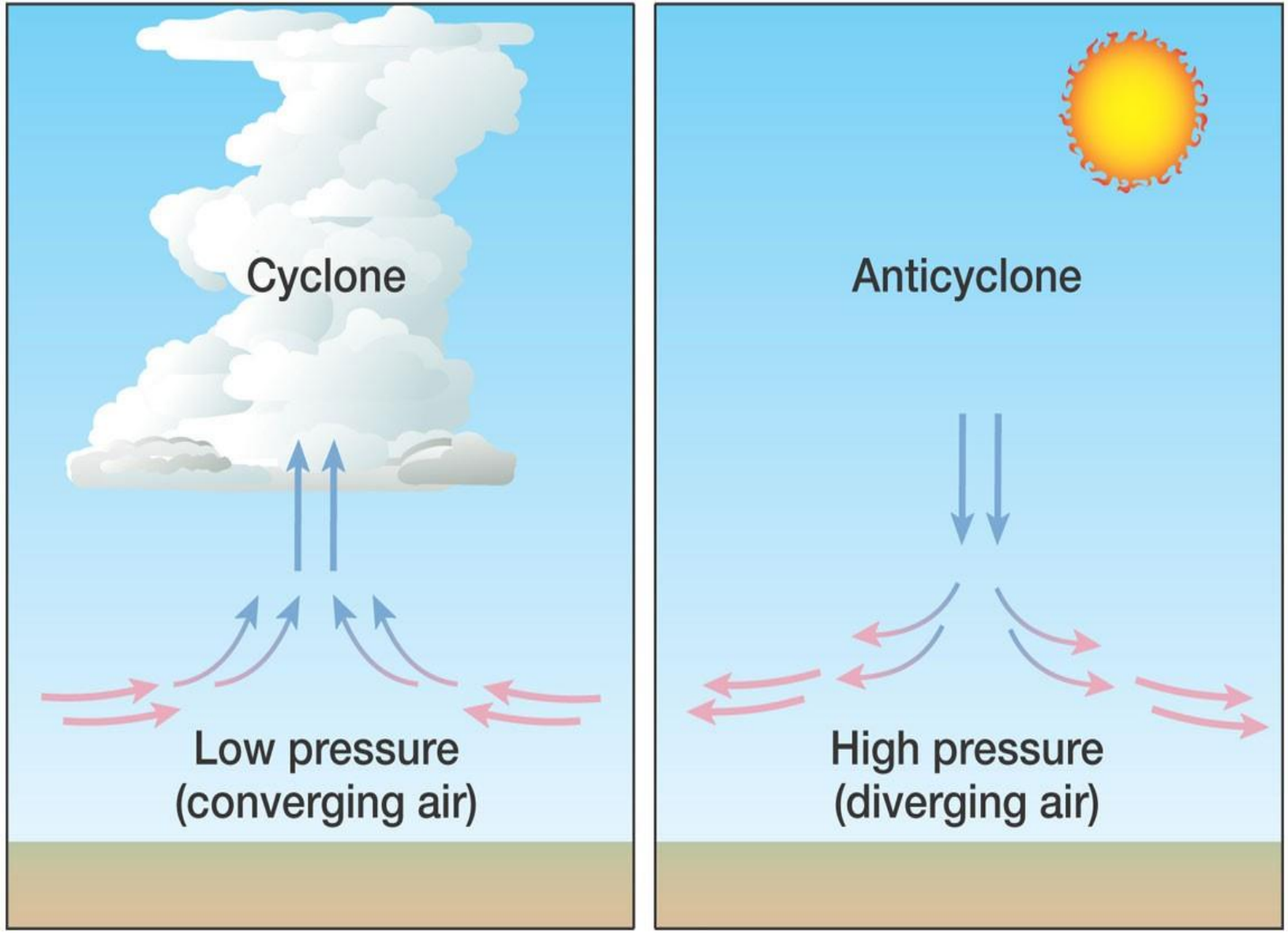
On a planet with little or no rotation, the global air circulation pattern is very simple. On a planet with rapid rotation, the coriolis effect creates large-scale eddies with belts of wind and belts of calm.

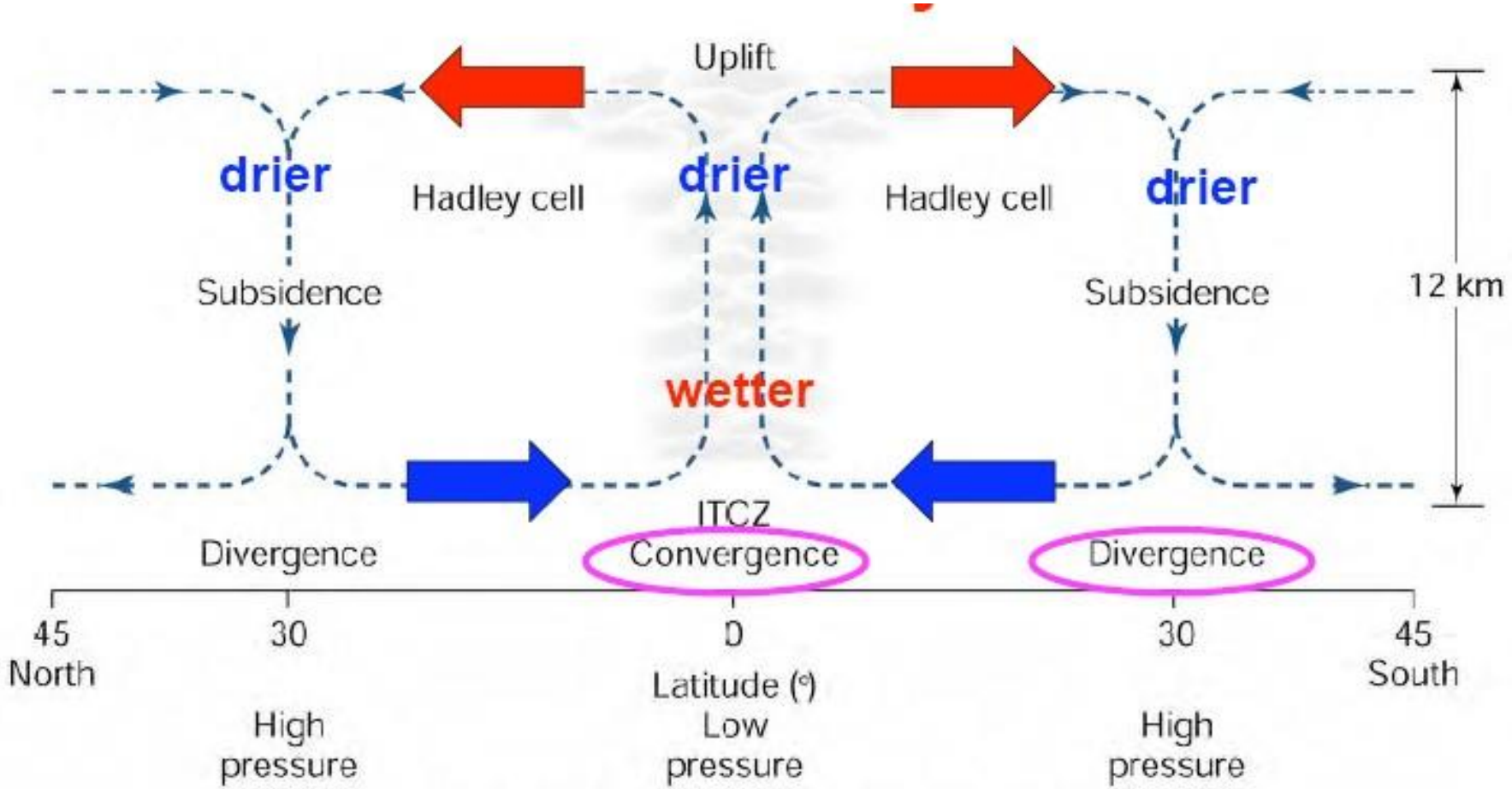
The direction of winds and currents is dictated by the Earth's rotation(**clockwise** in the Northern Hemisphere **(NH)** and **anti-clockwise** in the Southern Hemisphere **(SH)**).

What drives the atmosphere?



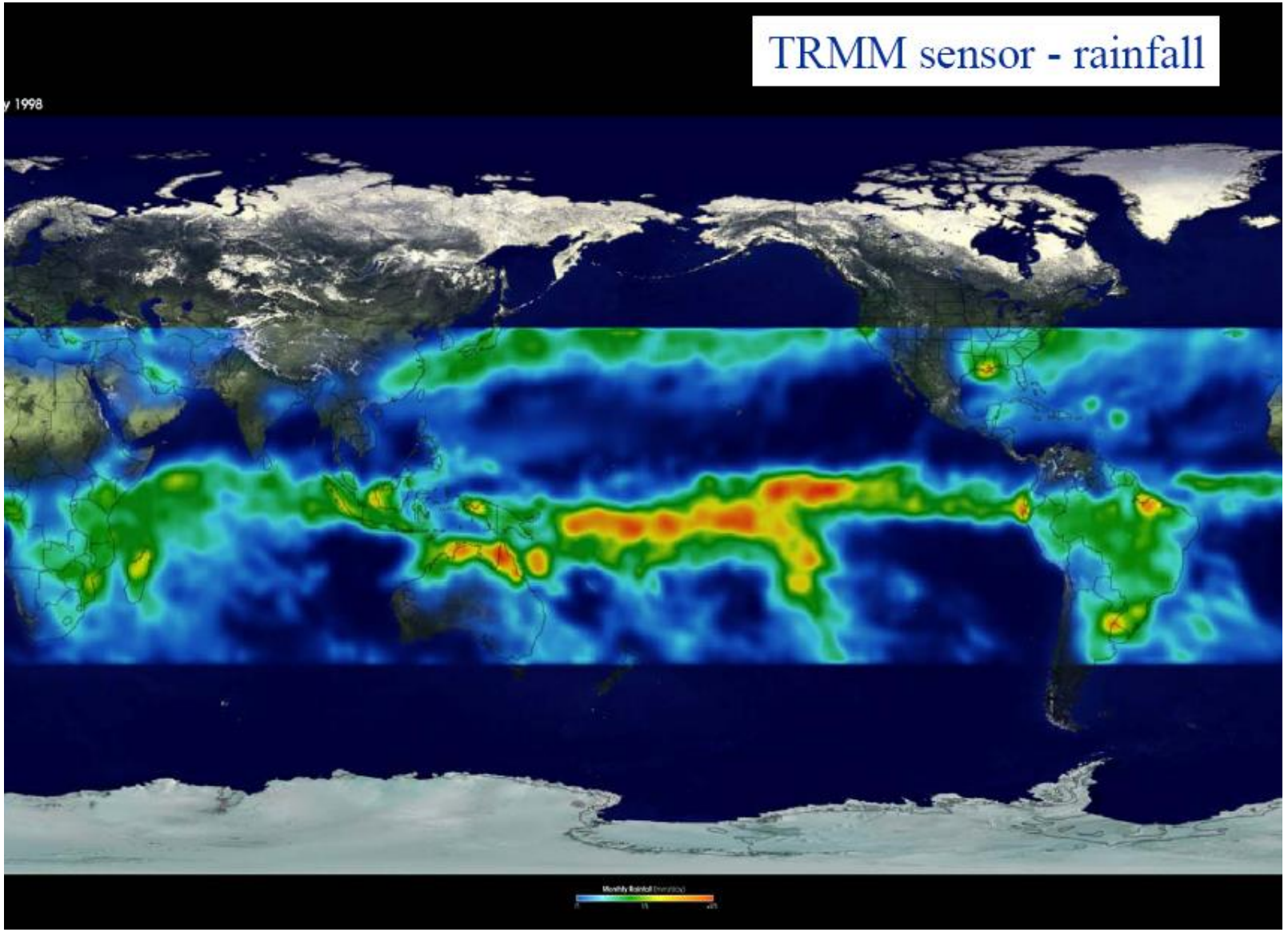
Simplified!! Warm air rises and cool air sinks; a convection current forms in a room resulting from uneven heating and cooling.


Cyclone
Low pressure
(converging air)
Anticyclone
High pressure
(diverging air)



there is a convergence of mass and moisture between cells,
uplift leads to drying (because cold air holds less moisture),
air in the area of subsidence is thus dry

Global rainfall distribution



Highest rainfall is found in the equatorial zone

What do we know so far?.....

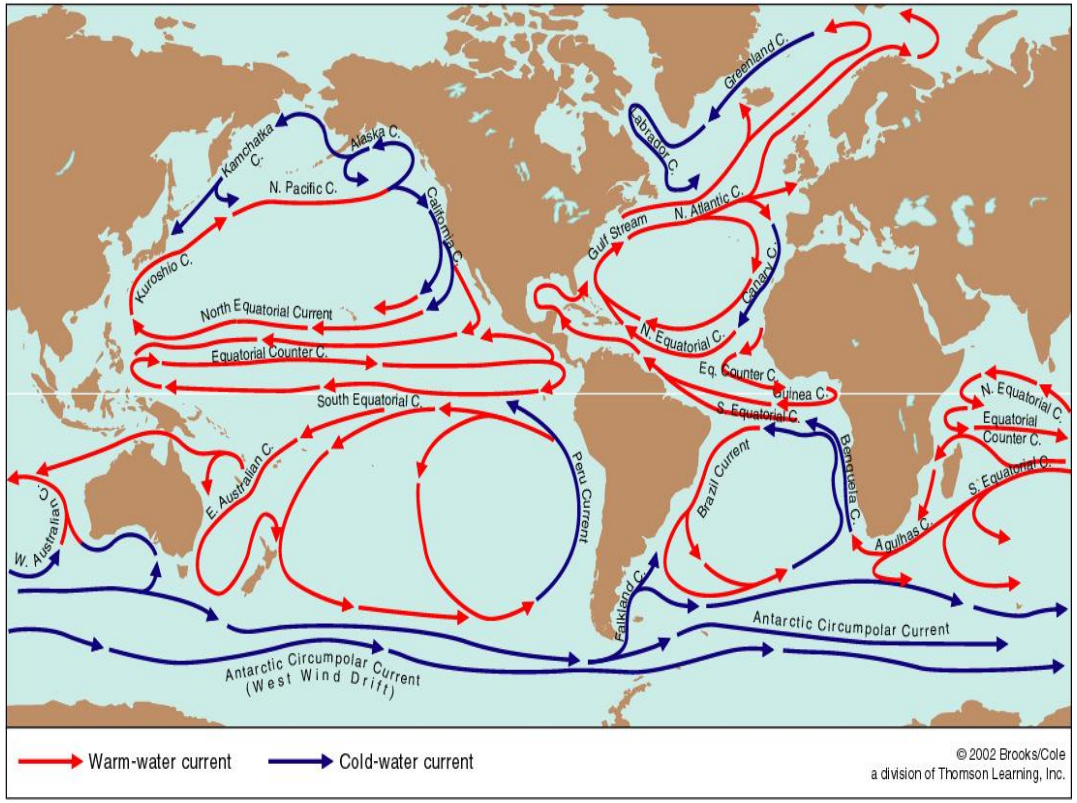
- We learnt that ocean currents also play a role in the global heat budget.

What are those ocean currents?

- There are two type of ocean circulation:
  - Surface wind-driven circulation limited in the upper 1000 m (1 km), it is more vigorous.
  - Deep density-driven circulation, it is full depth and slow.

- Ocean circulation is influenced by the atmosphere.

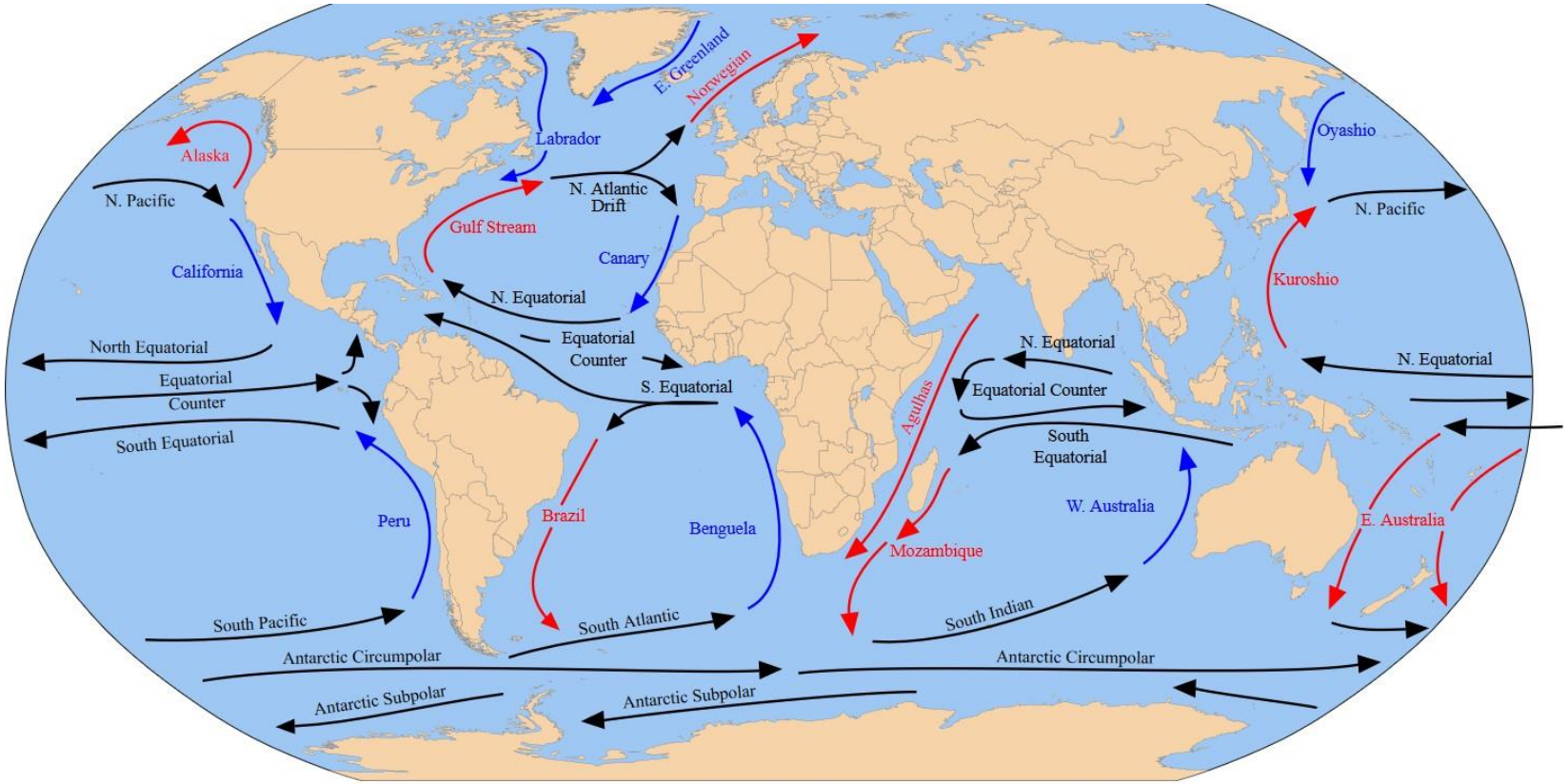
Surface circulation



A map of the ocean showing surface currents driven by winds

- The warm currents found on the western side of the ocean basins transport warm water from the equator to the poles.
- Cold currents on the eastern side transport cold waters from the poles to the equator.

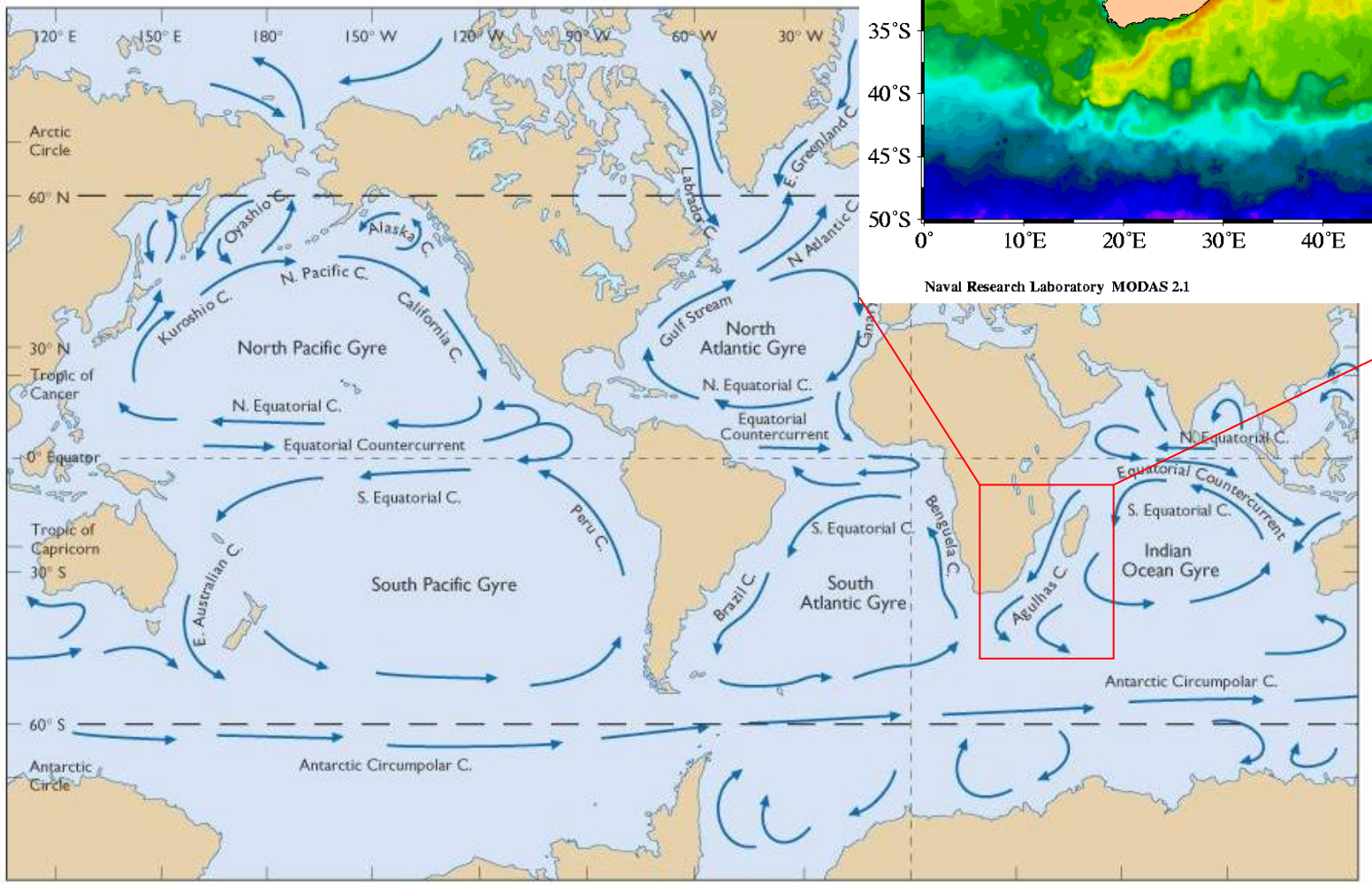
Surface circulation



The warm western boundary currents such as the Agulhus Current, Gulf Stream, Kuroshio, E. Australia and Brazil transport warm waters polewards.

The cold eastern boundary currents such as the Benguela, Peru, California and the Canary transport cold waters equatorwards

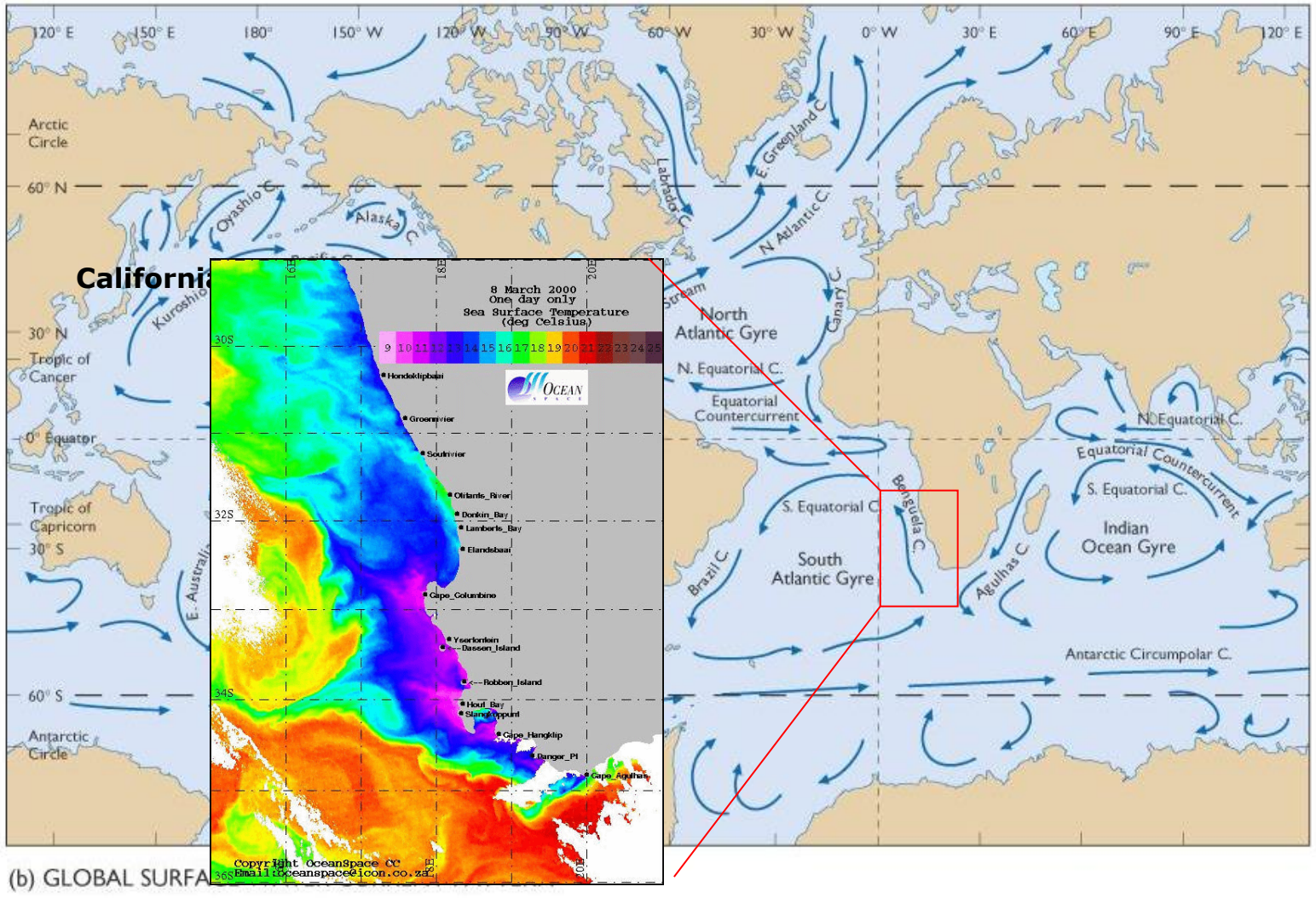
The role of the currents on the coastal climate



(b) GLOBAL SURFACE-WATER CURRENT PATTERN

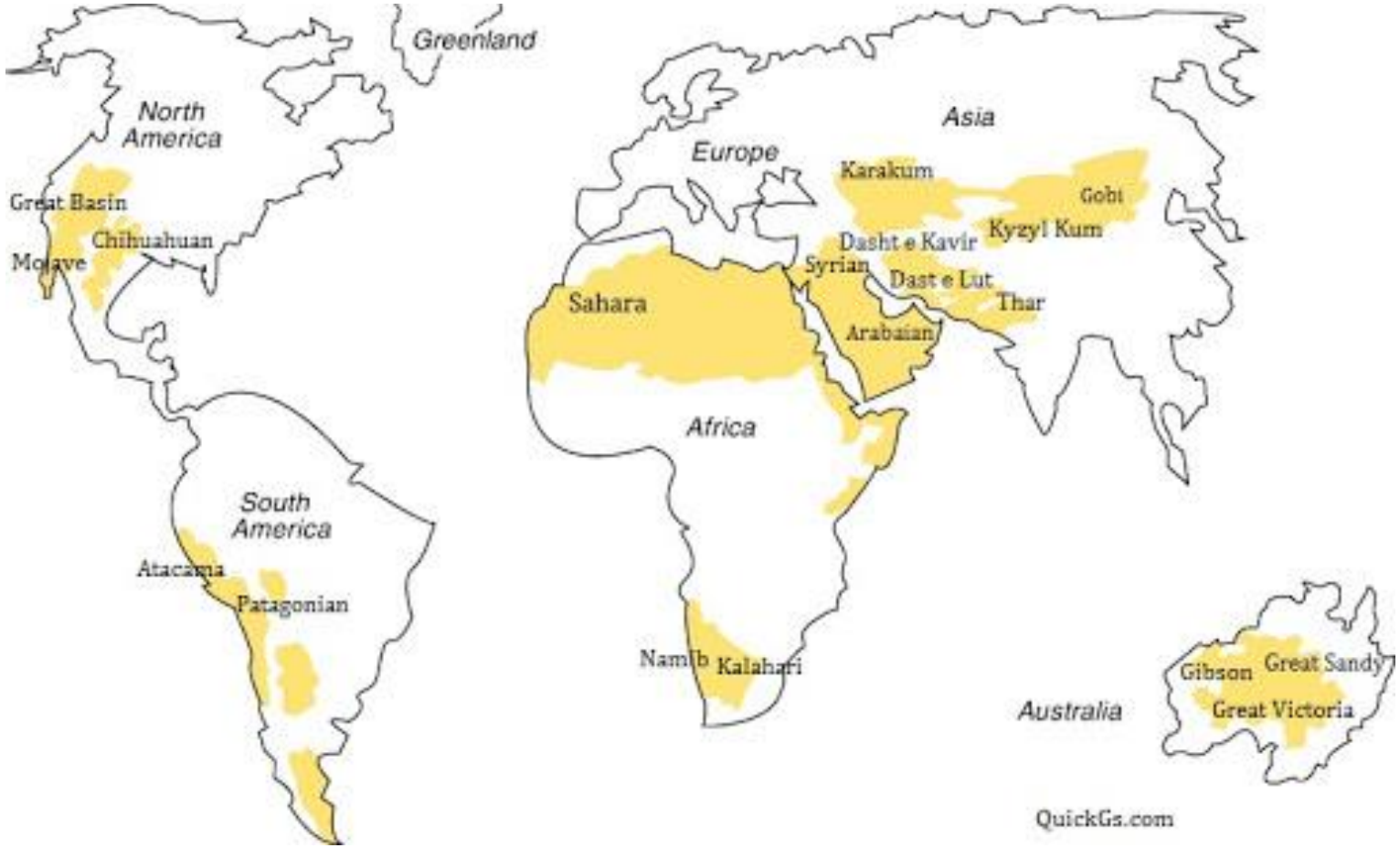
The east coast of south Africa is warm and tropical due to the warm Agulhas Current

The role of the currents on the coastal climate



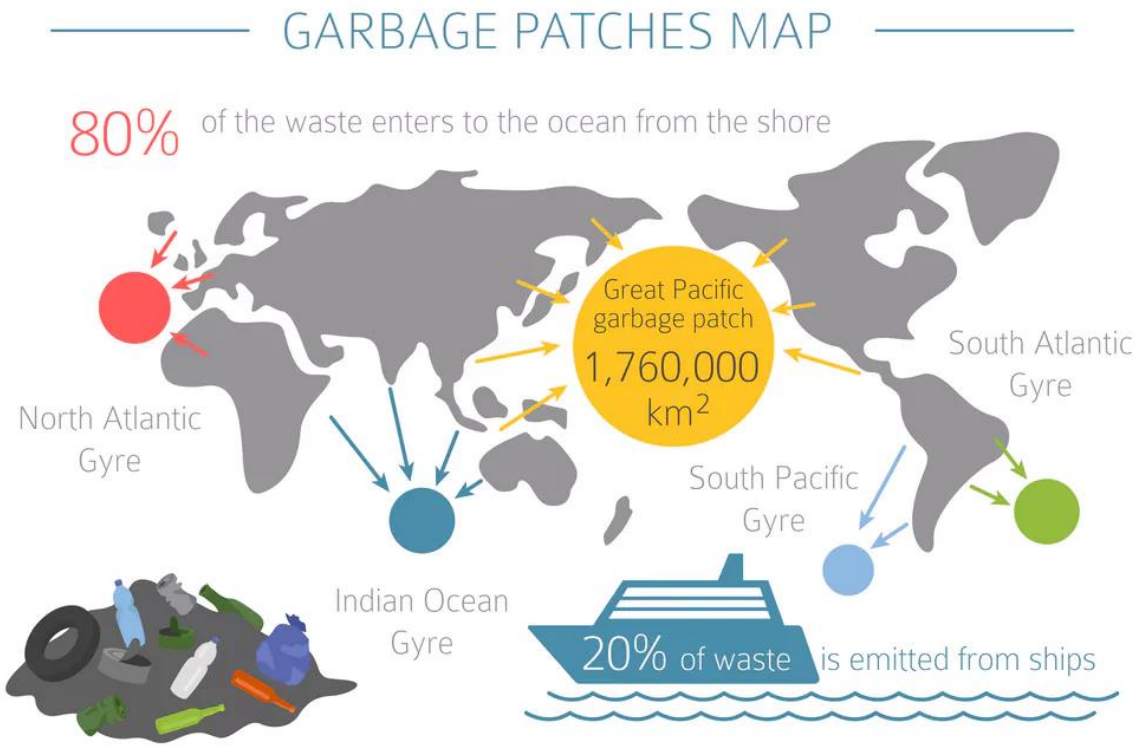
The west coast of South Africa is cold and dry due to the cold Benguela Current

The location of most major world's deserts are found on the western side of the ocean basins due to the cold currents.



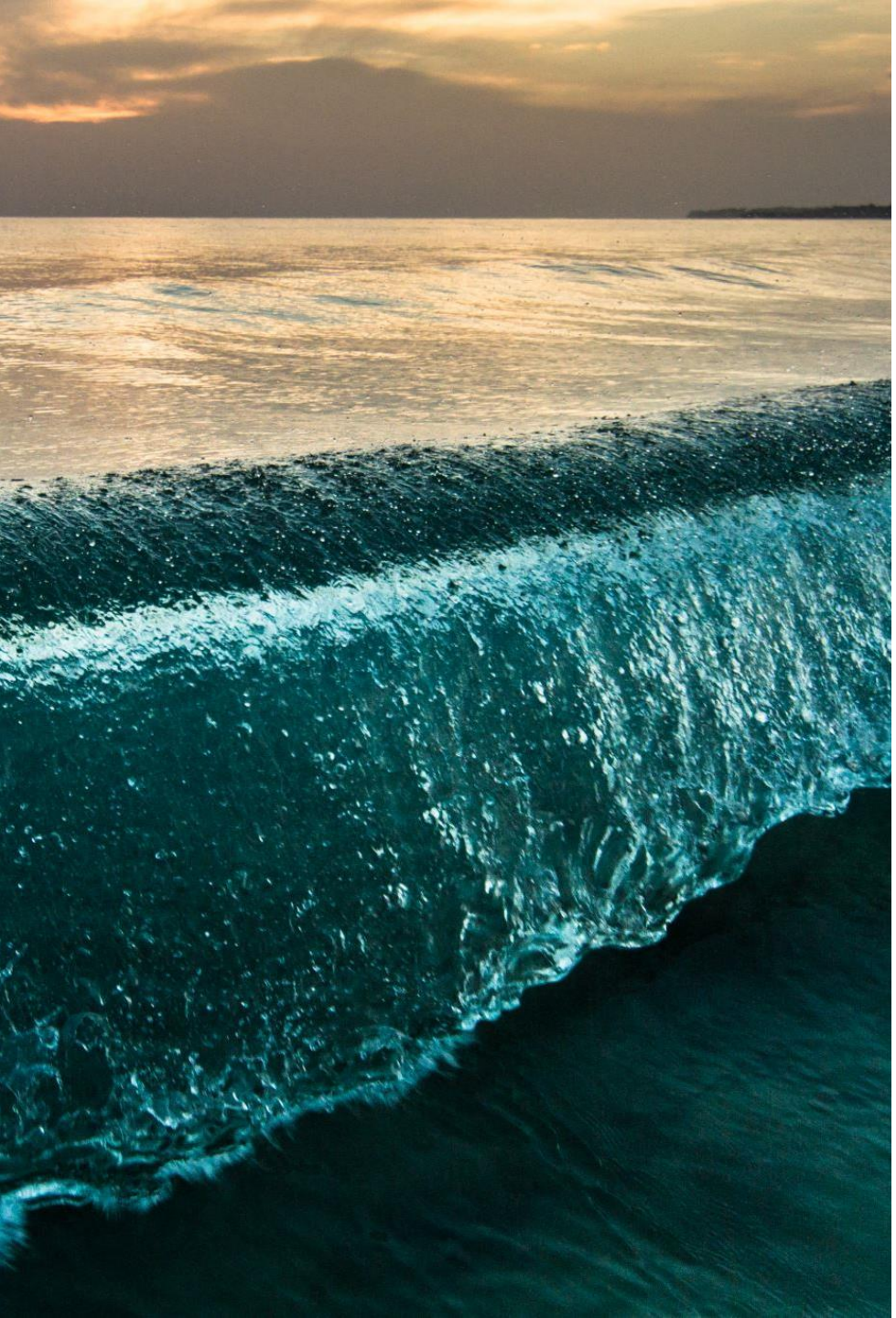
Cold waters => cold air => suppressed convection => less rainfall => arid conditions

Where does all the garbage in the ocean end up?



Source: www.shutterstock.com

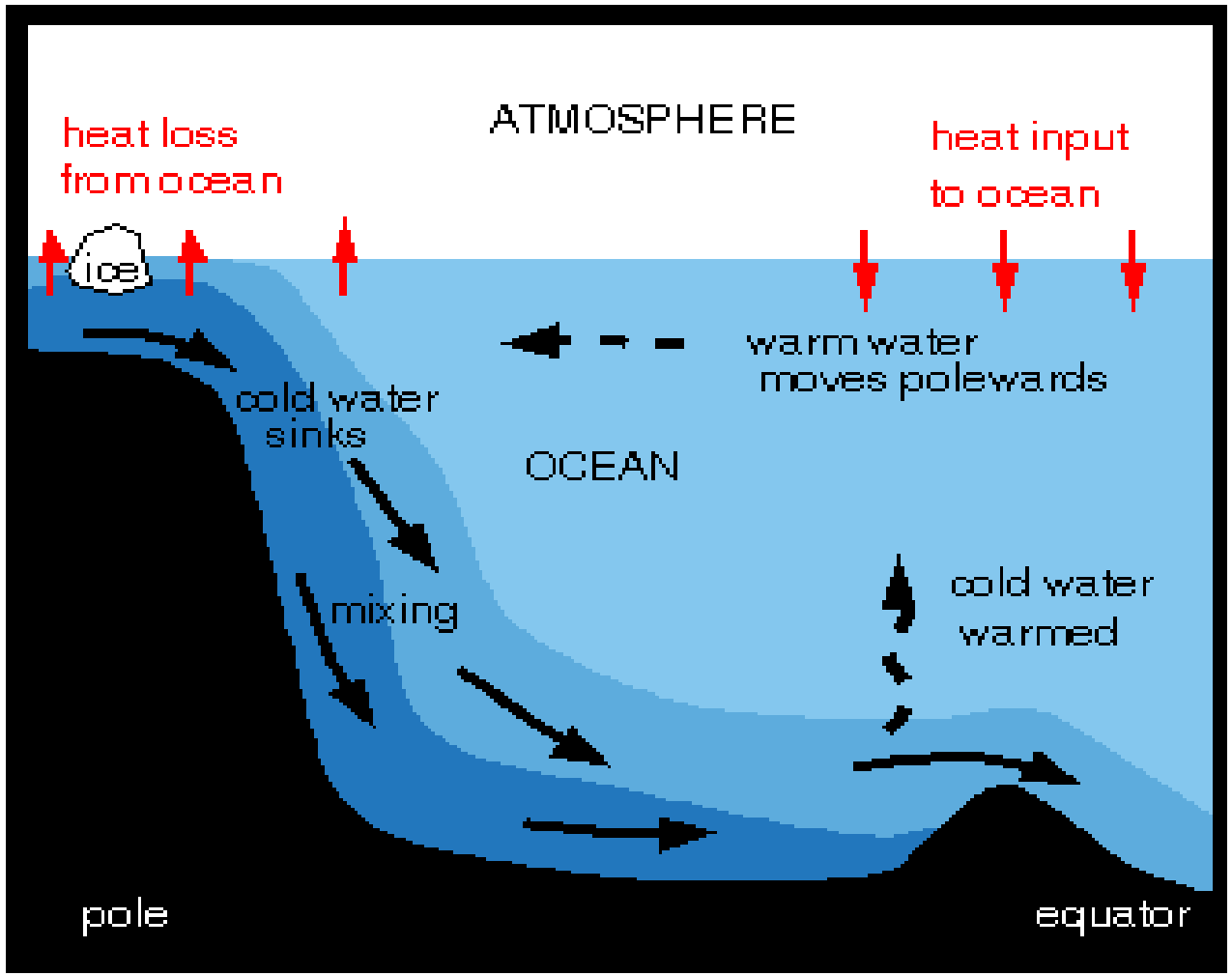
Most plastic enters the ocean from the shore and accumulates in ocean ‘gyres’, where different currents meet.



Thermohaline circulation

- The deep circulation is called the Thermohaline circulation
- Weak and slow ocean currents that flow thousands of meters below the surface
- It is driven by differences in the water's density
- "Thermo- *temperature*" & "haline- *salinity*"
- Has an influence on the Earth's climate

While the surface circulation is driven by wind, the deep circulation is driven by density differences and is often referred to as thermohaline circulation.



The term thermohaline circulation has been dropped in favor of meridional overturning circulation.

Ocean density layers

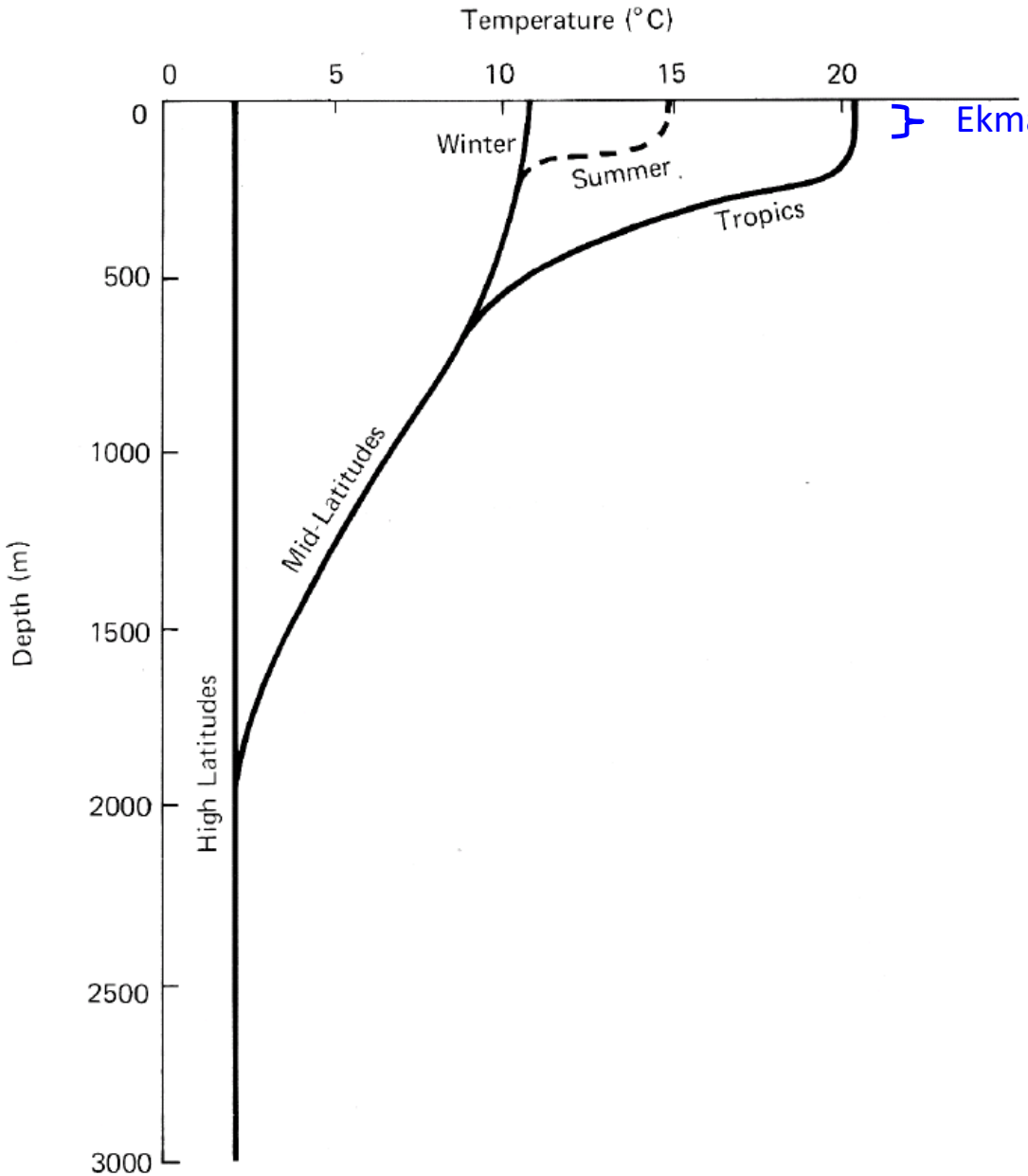
- The ocean is not homogenous, it is stratified according to density.

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

- It is made of water masses with distinctive temperature and salinity characteristics, hence different densities.

- Circulation in the deep ocean is driven by density differences among water masses.

The oceans can be divided into 2 layers



Ekman Layer

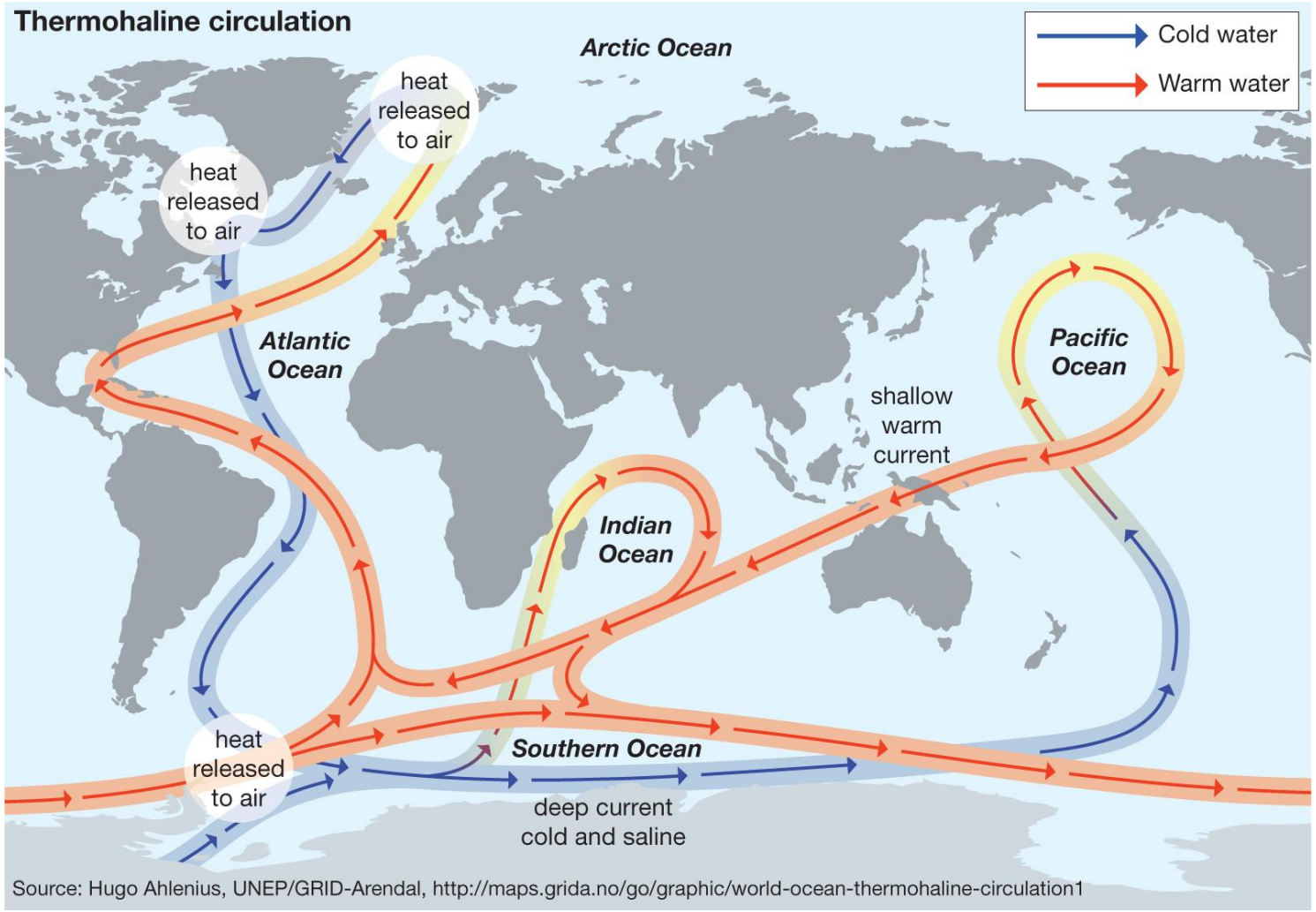
"Upper Waters" primarily wind-driven

"Deep Waters" primarily density-driven

Temperature controls

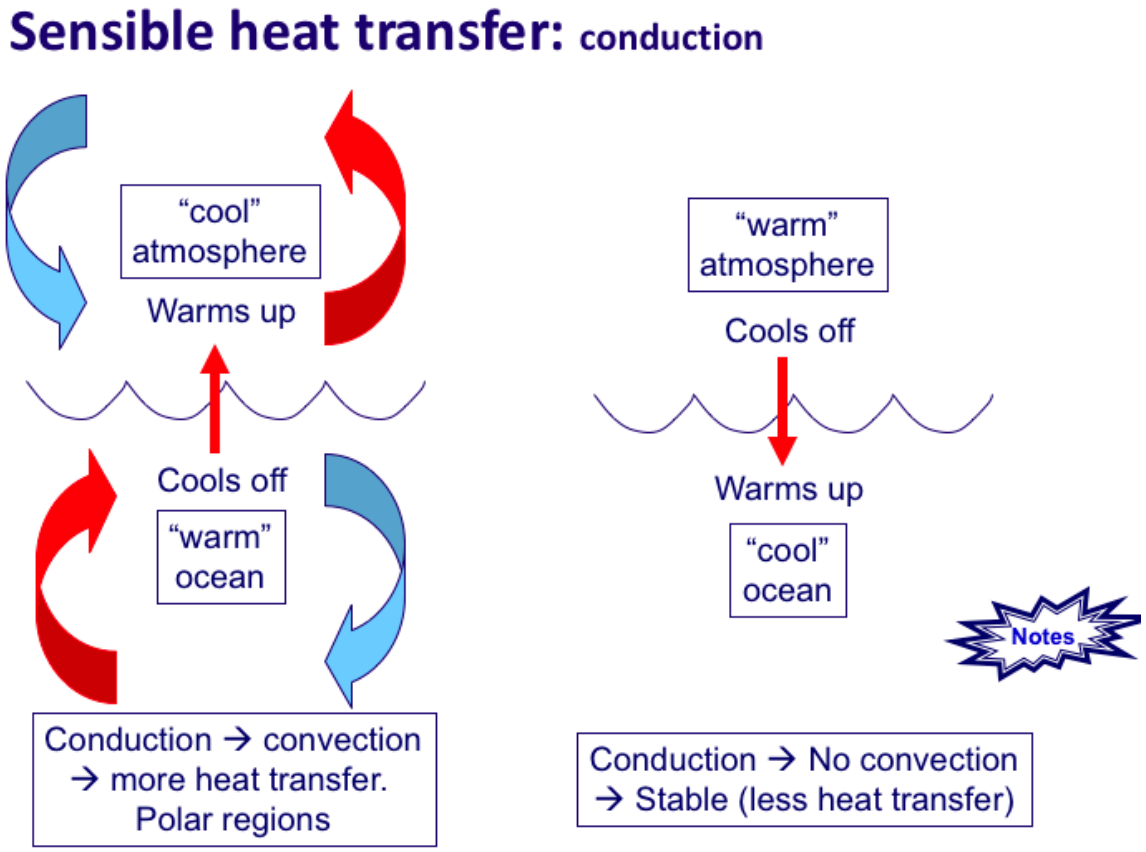
1. Solar radiation

- The ocean absorbs solar radiation at the surface.
- Solar radiation is largest in the tropics and cloud free regions
- The ocean gains heat in the tropics (between 20°S and 20°N) and loses it in the polar regions.
- For the Ocean Heat Budget , cold water flows into regions of net heat gain, and warmed water must flow away from these regions



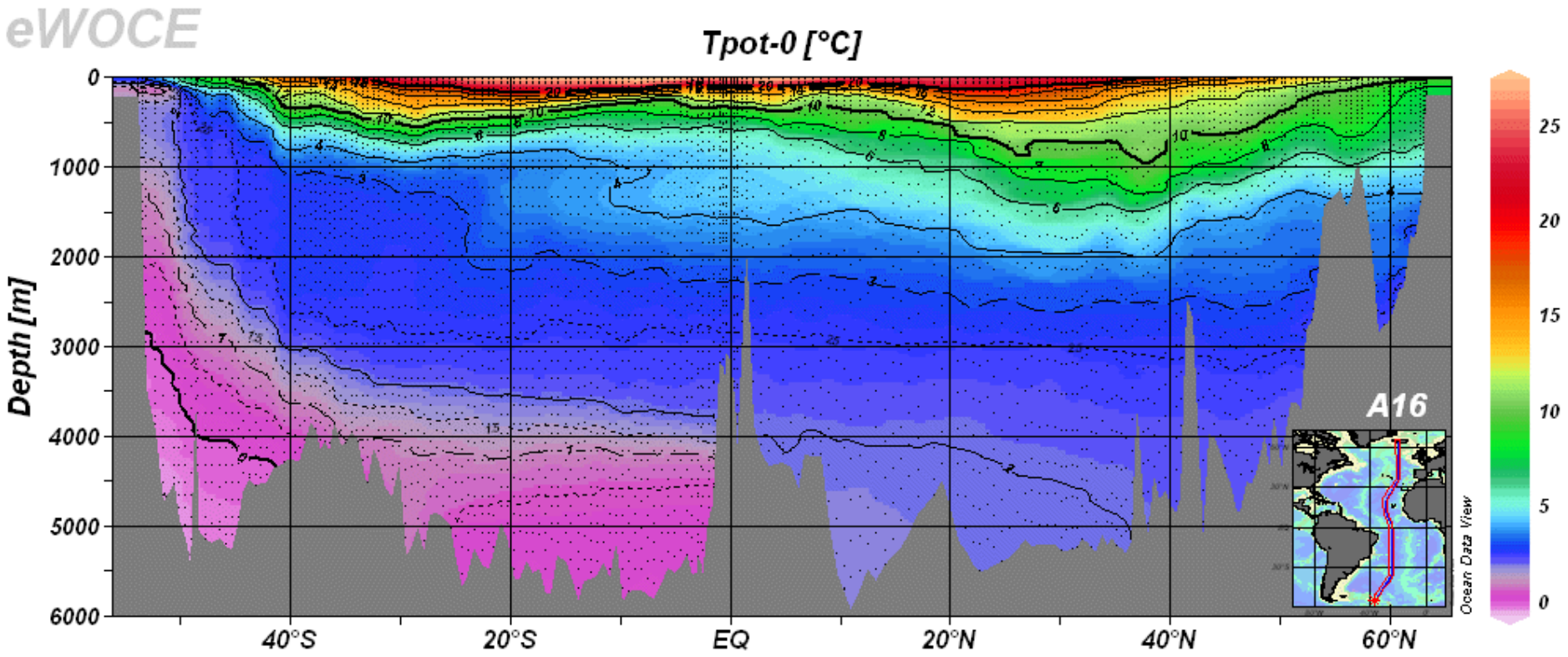
Temperature controls

2. Air-sea interaction



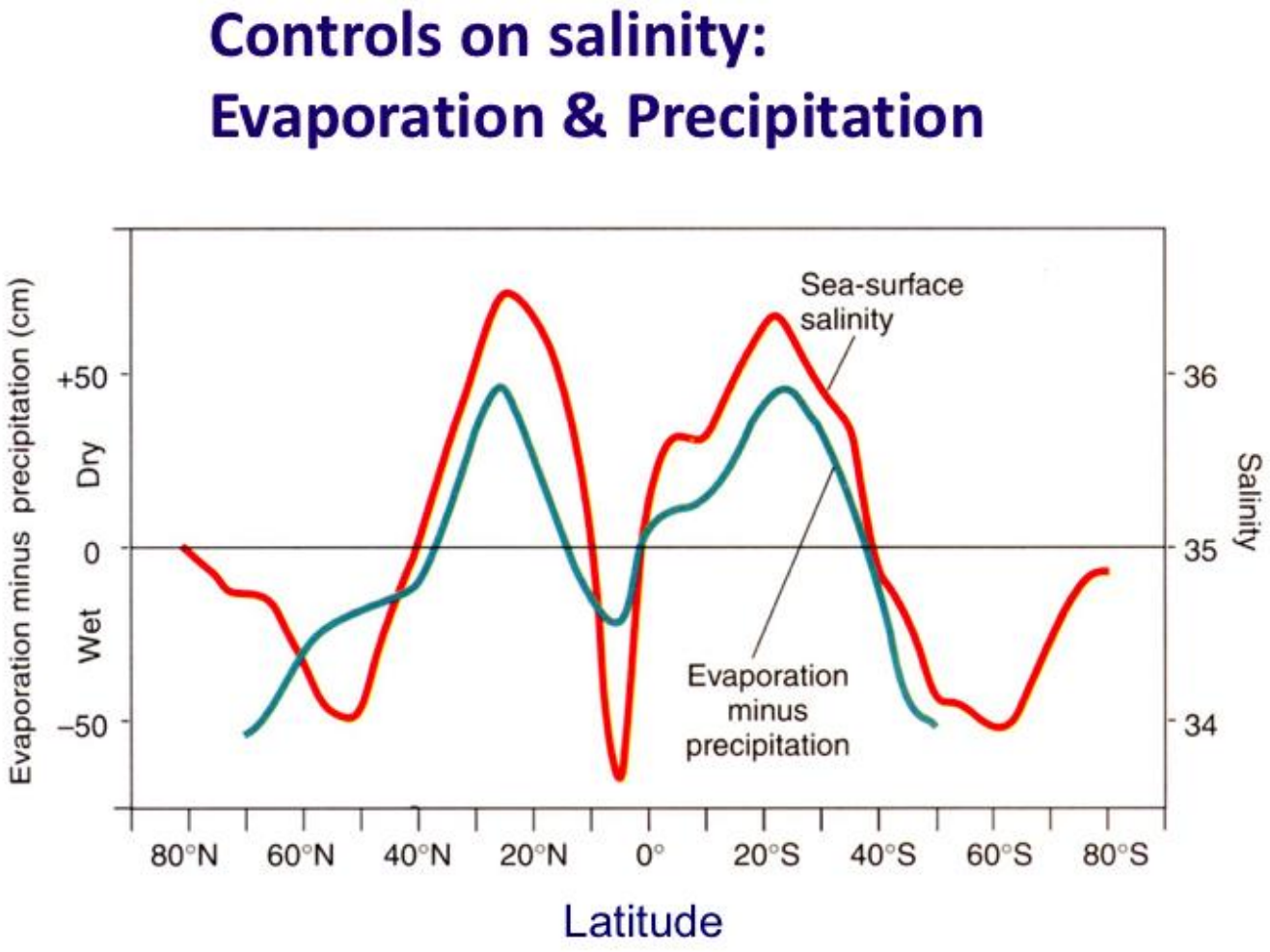
- Heat transfer between the sea and the atmosphere at the surface.
- Heat (latent heat) is lost from the sea during evaporation and gained during precipitation.
- The warm ocean heats up the relatively cooler atmosphere and vice versa.

Meridional vertical structure of temperature: Atlantic Ocean



Warm Temperature = Low Density = Surface
Cold Temperature = High Density = Deeper

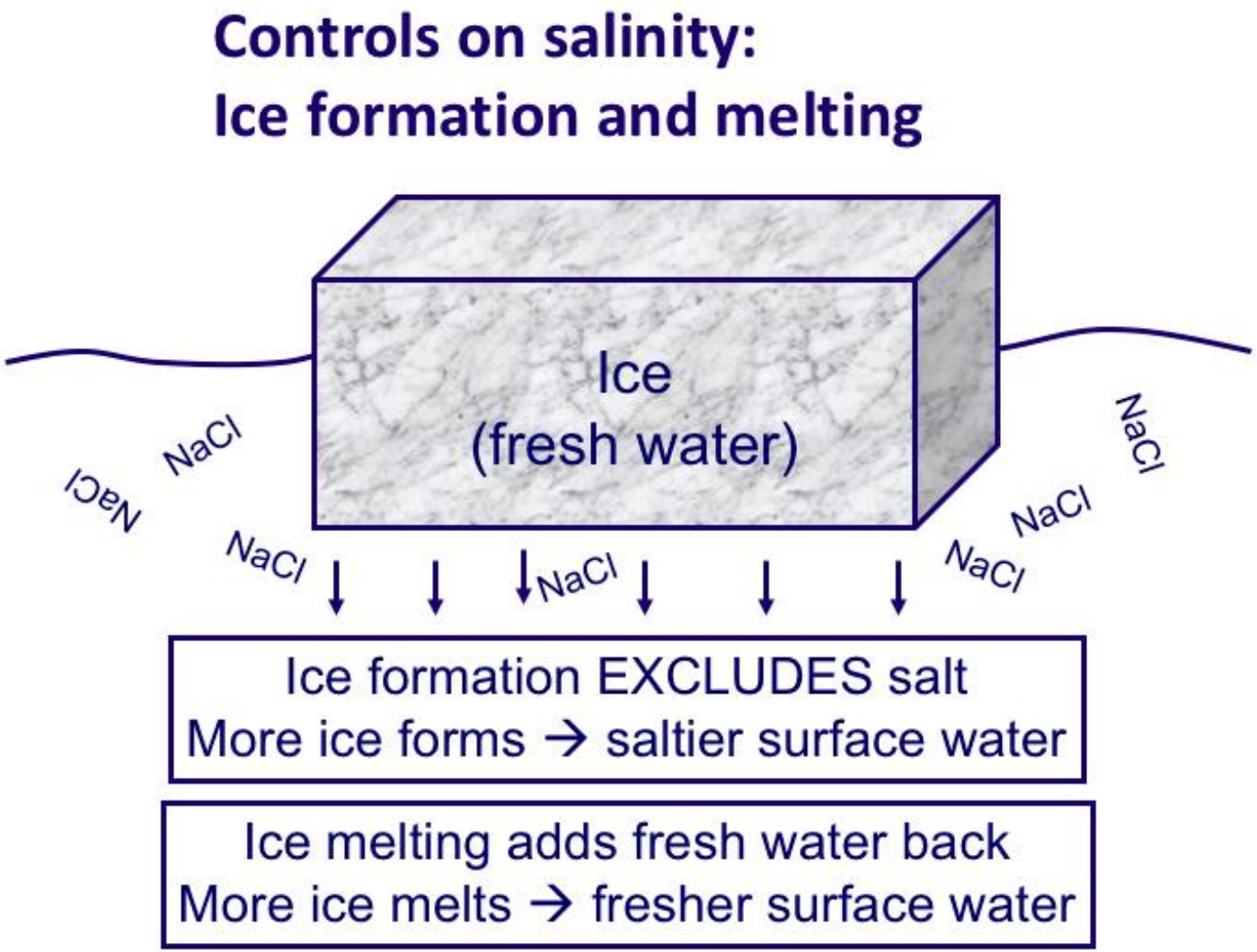
Salinity controls



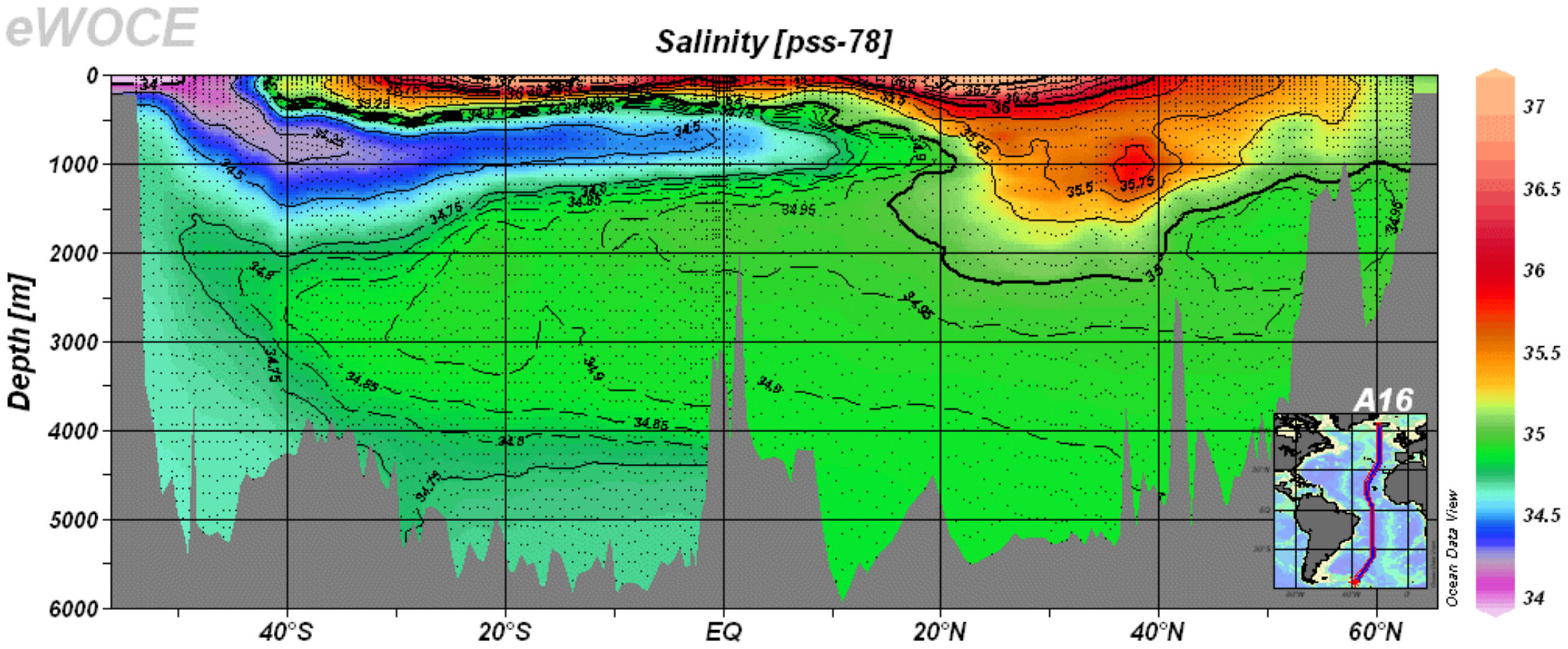
High evaporation rates than precipitation => high salinity

Low evaporation rates than precipitation => low salinity

Salinity controls



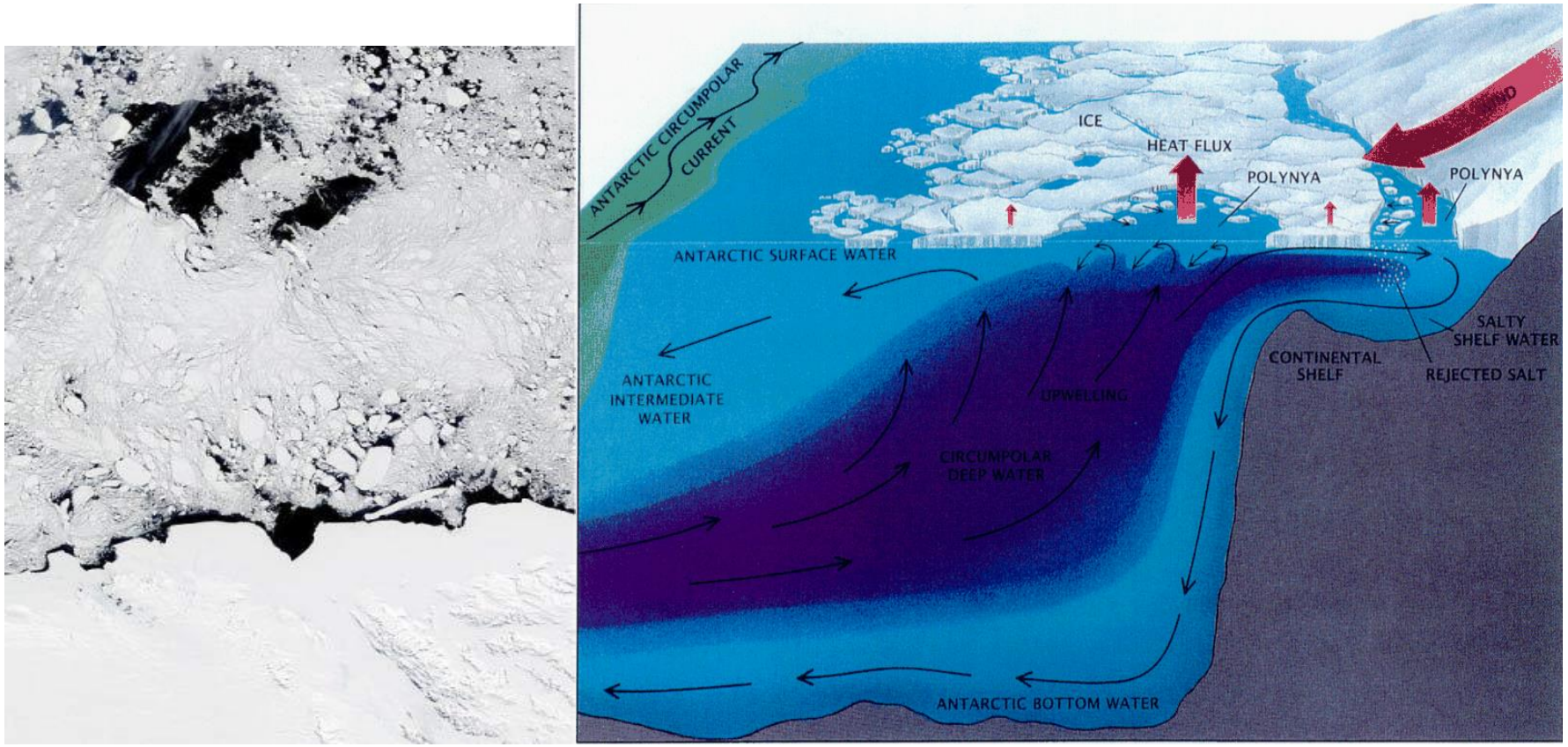
Meridional vertical structure of salinity: Atlantic Ocean



High Salinity = High Density
Low Salinity = Low Density

But why, the high salinity waters at the surface?

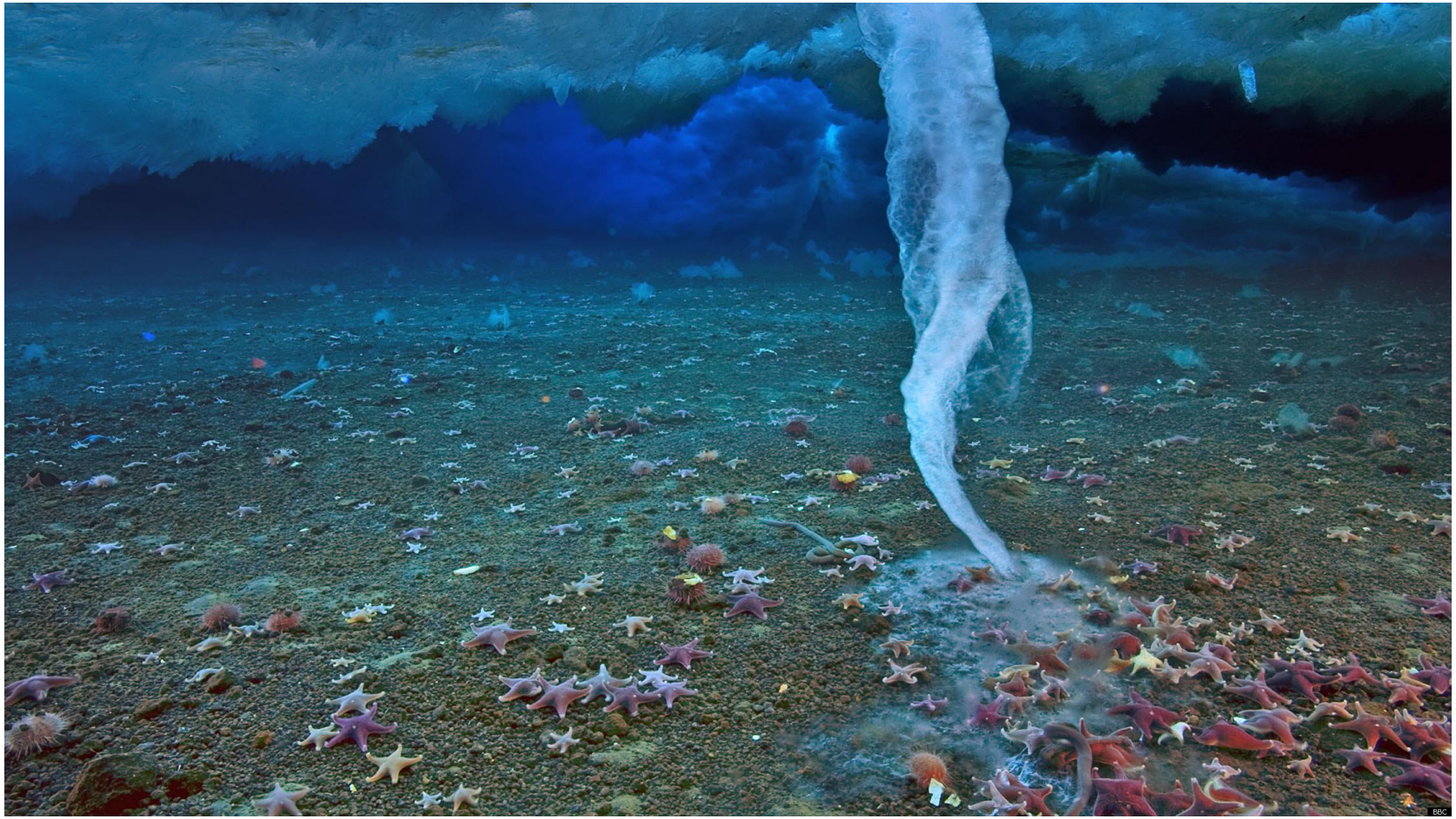
Antarctic deep water formation



Brine rejection and cold temperatures create the densest water in the ocean "Antarctic Bottom Water **(AABW)"** .

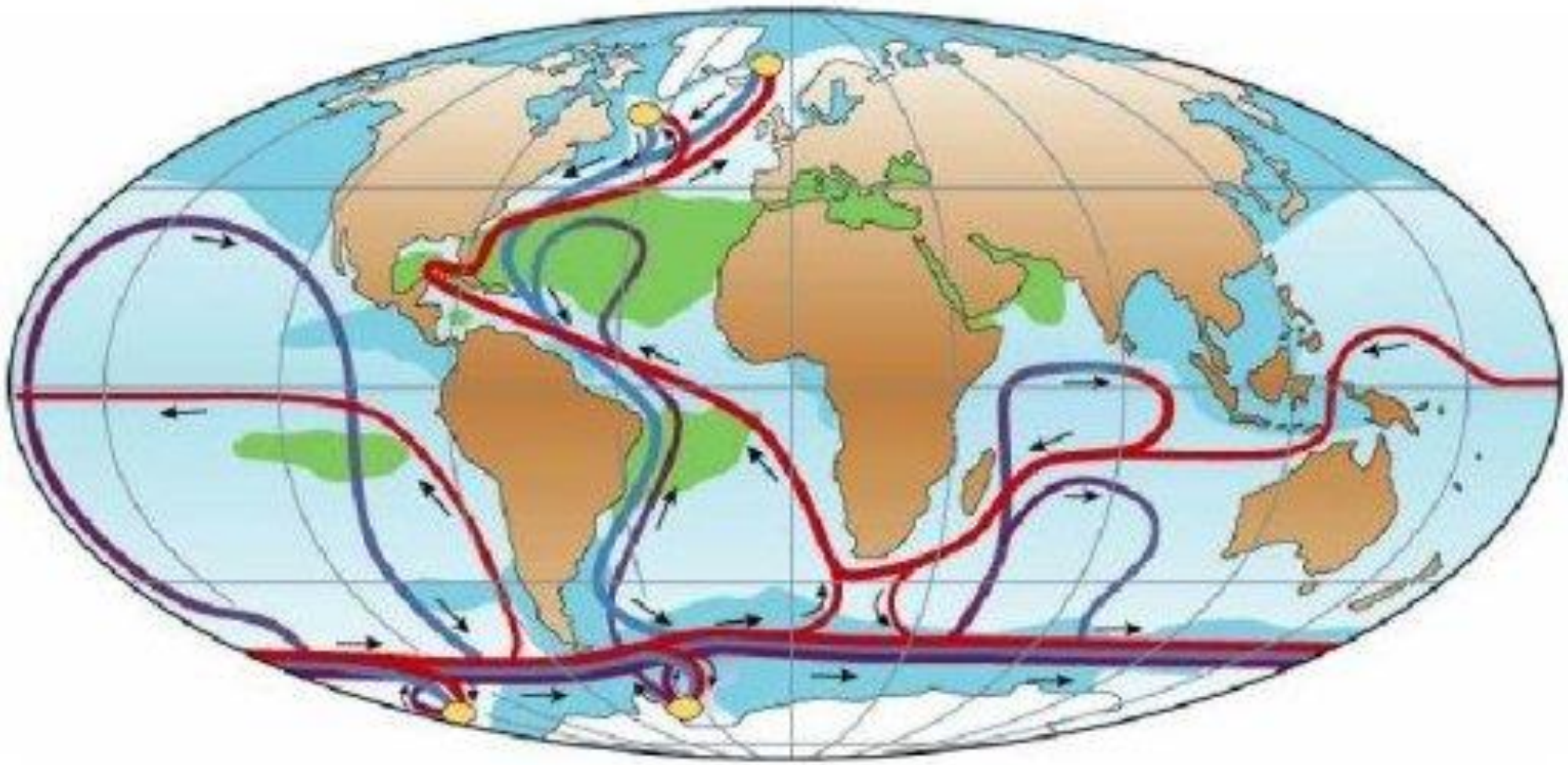
Polynyas: open water "ice factories": water at freezing point, sea ice forms, rejects brine. Winds blow sea ice offshore and keep the polynya open and continuously freezing

Brine rejection process

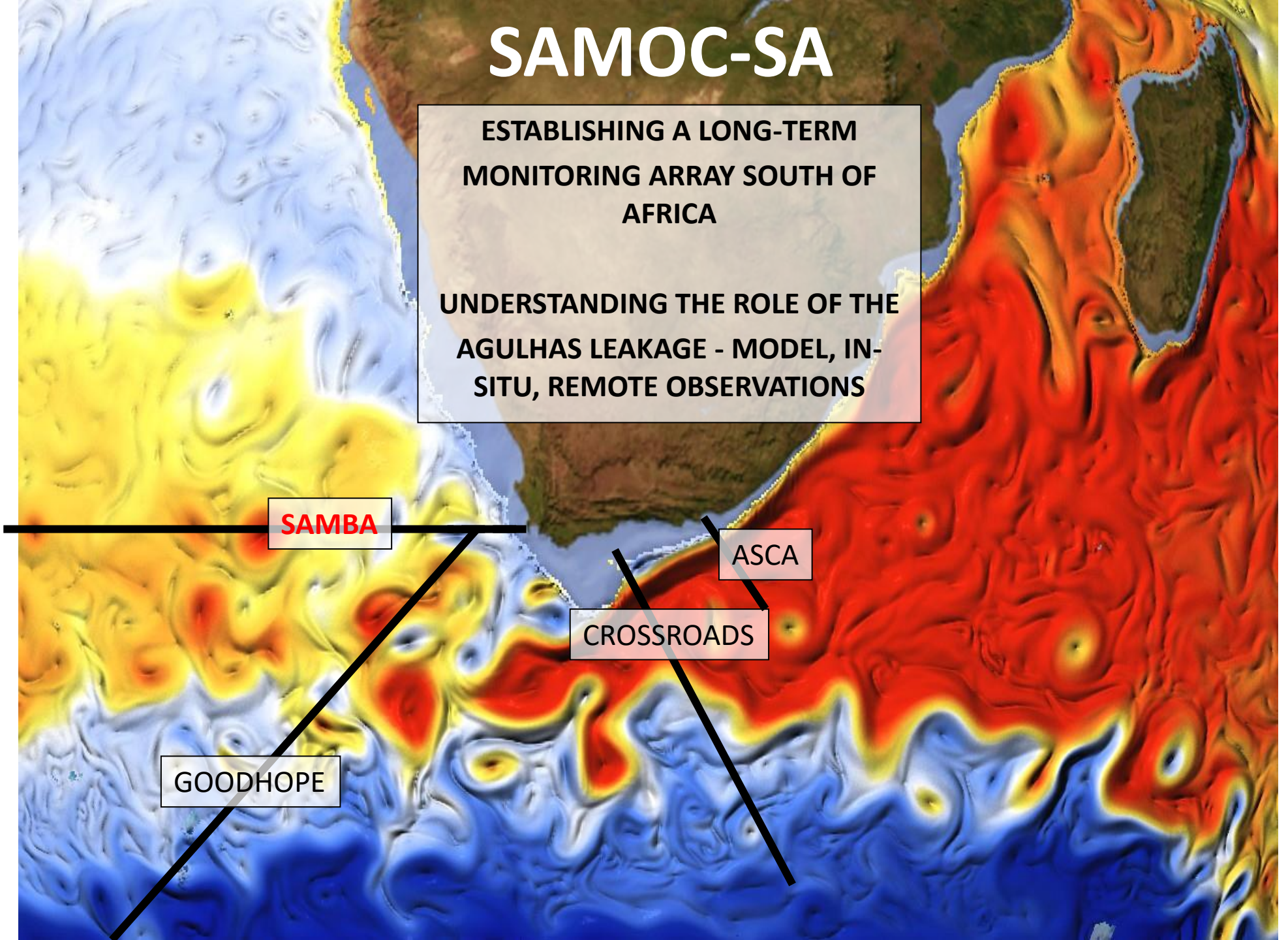


Watch the video on Vula

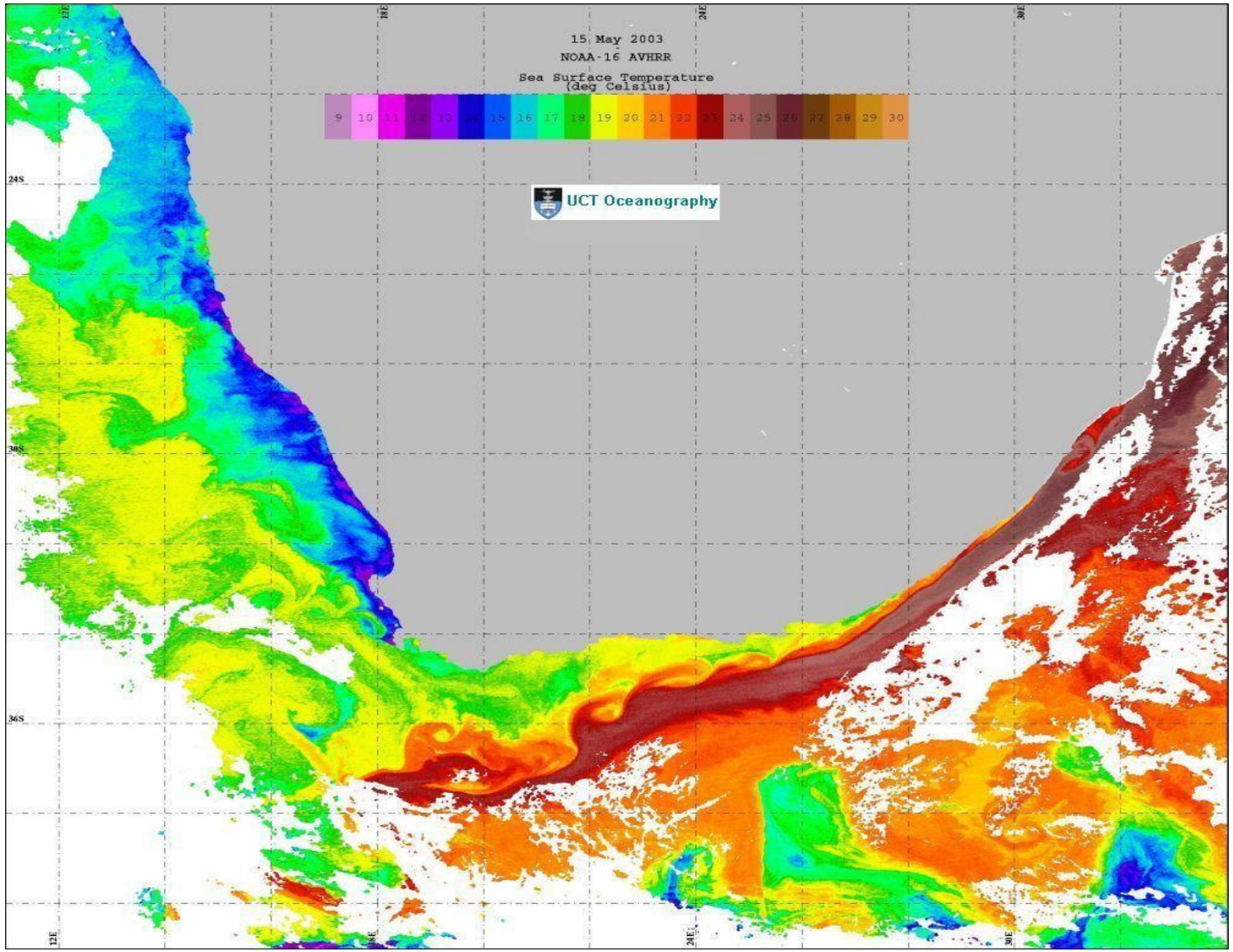
The Global Ocean Conveyer Belt = Surface circulation + Thermohaline Circulation



(Rahmstorf, Nature 2002)


SAMOC-SA
ESTABLISHING A LONG-TERM MONITORING ARRAY SOUTH OF AFRICA
UNDERSTANDING THE ROLE OF THE AGULHAS LEAKAGE - MODEL, IN-SITU, REMOTE OBSERVATIONS
SAMBA
ASCA
CROSSROADS
GOODHOPE

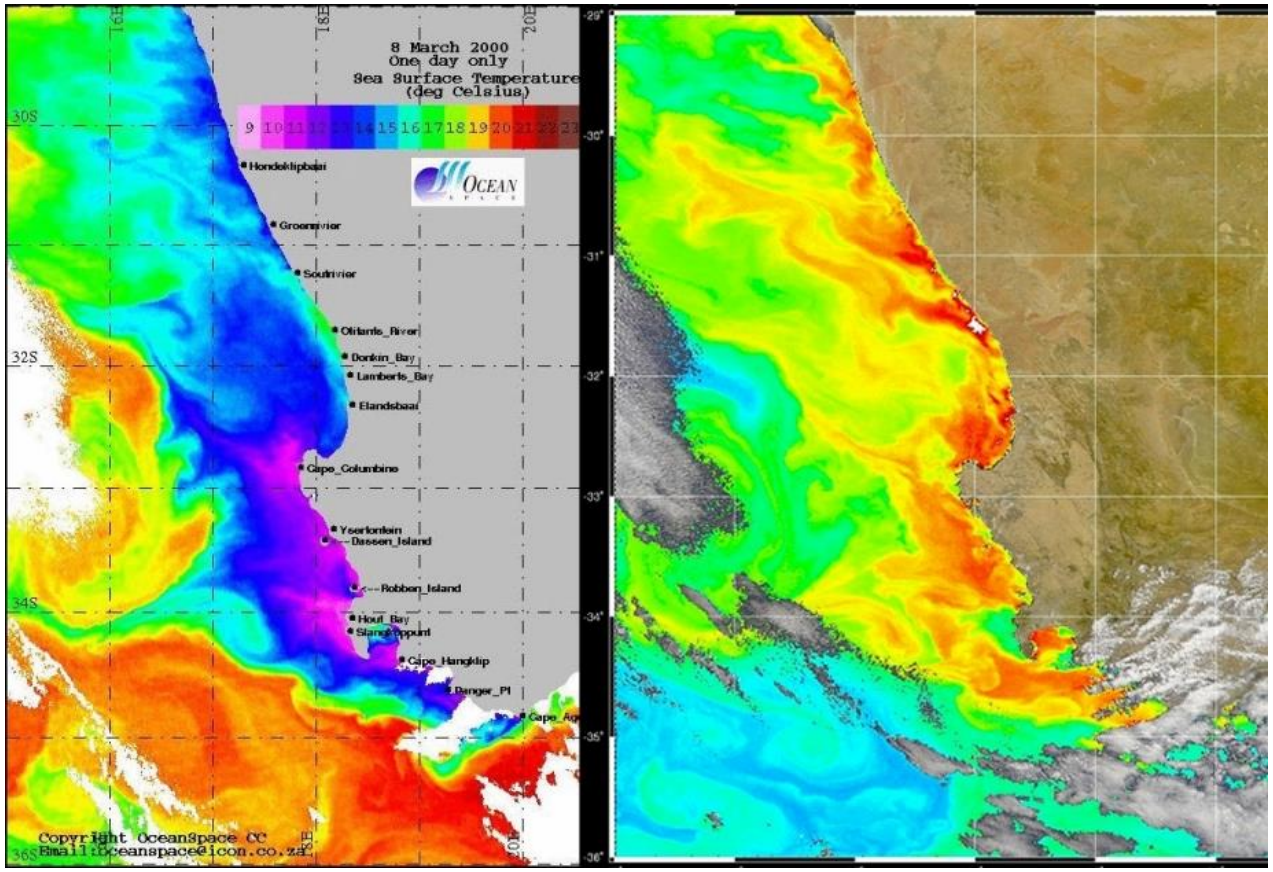
Regional Oceanography: The East meets West

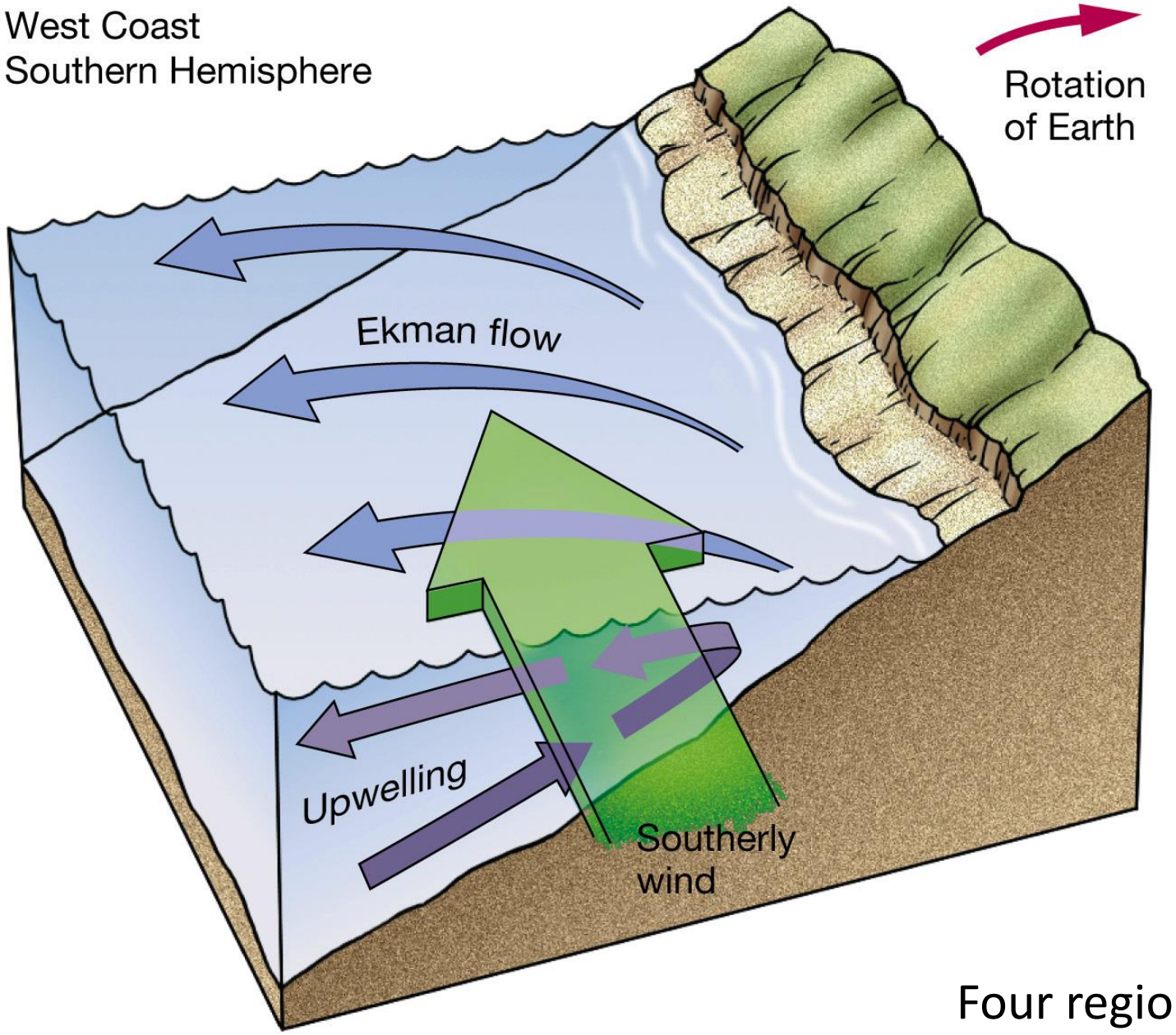


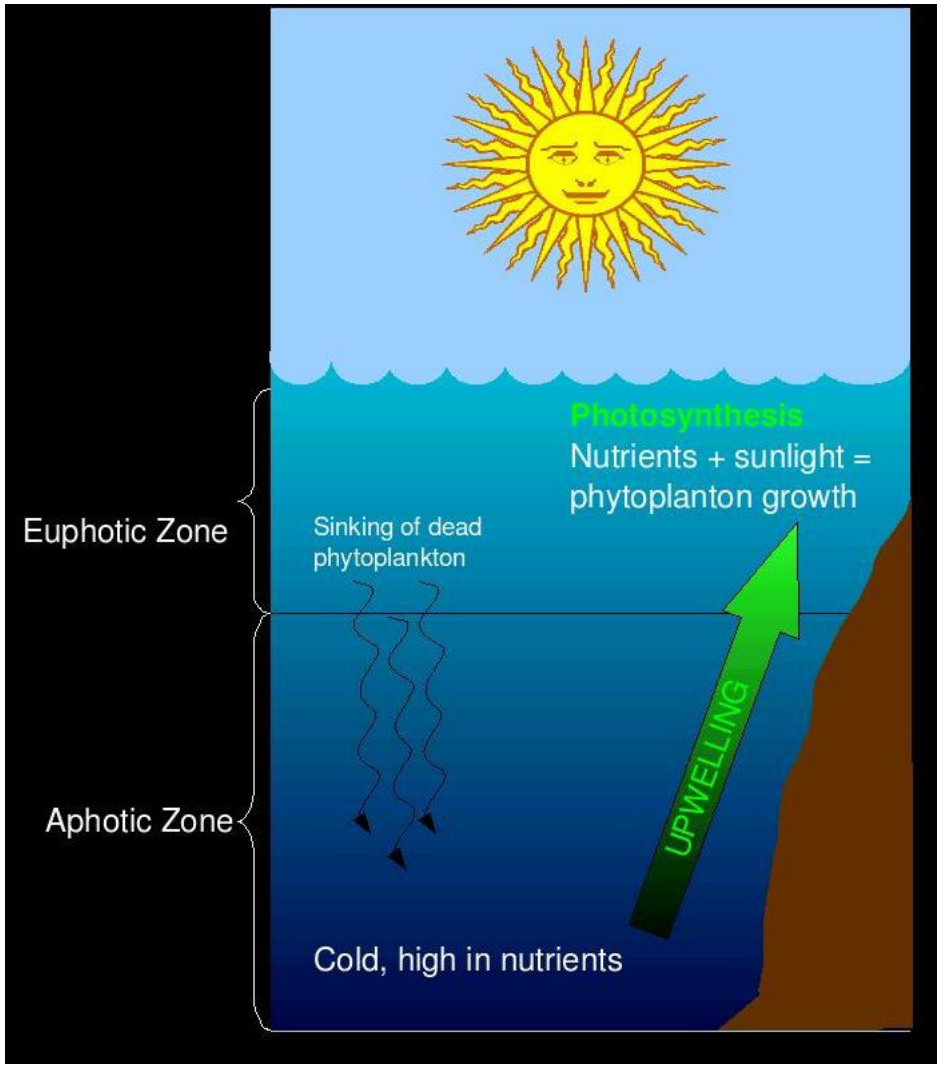
False-colour thermal infrared image portraying sea surface temperature of marine environment around southern Africa (Source: NOAA-16)

The Benguela Current

- cool, highly productive coastal waters.

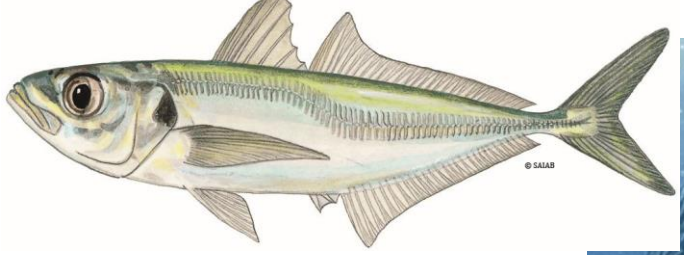


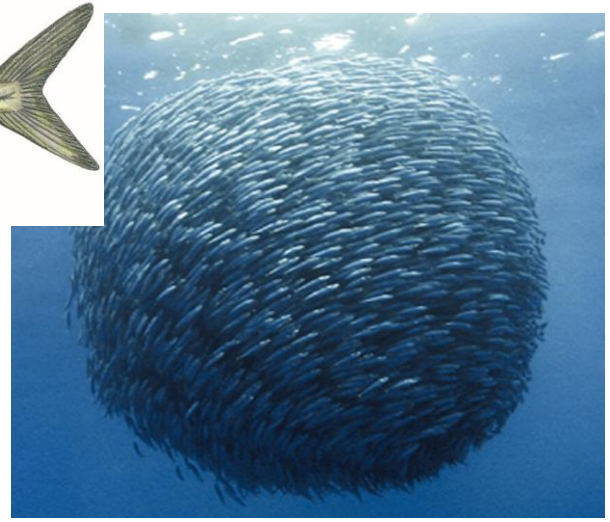


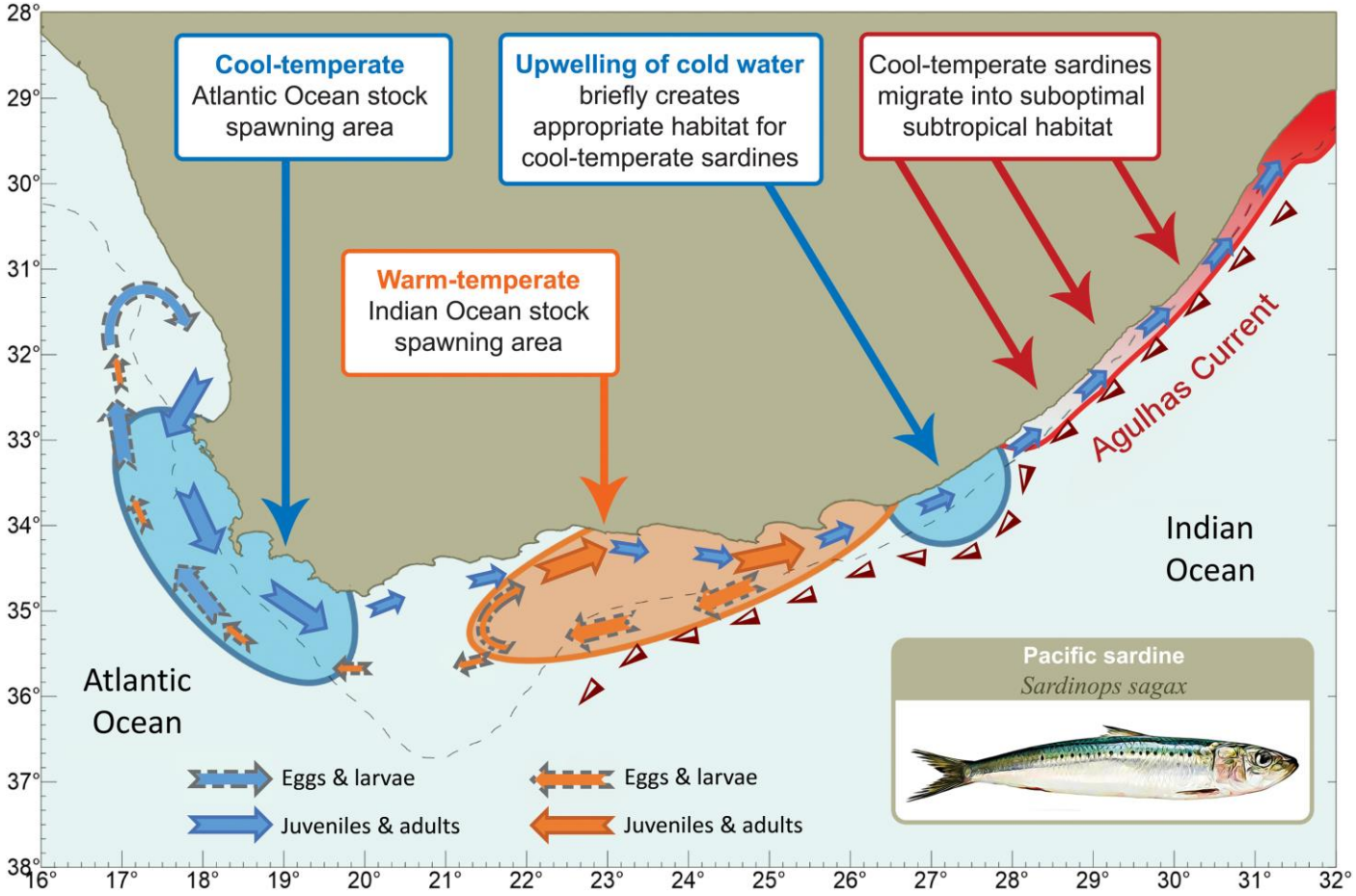


Four regions produce ~20% of global fish catch

West Coast nursery ground



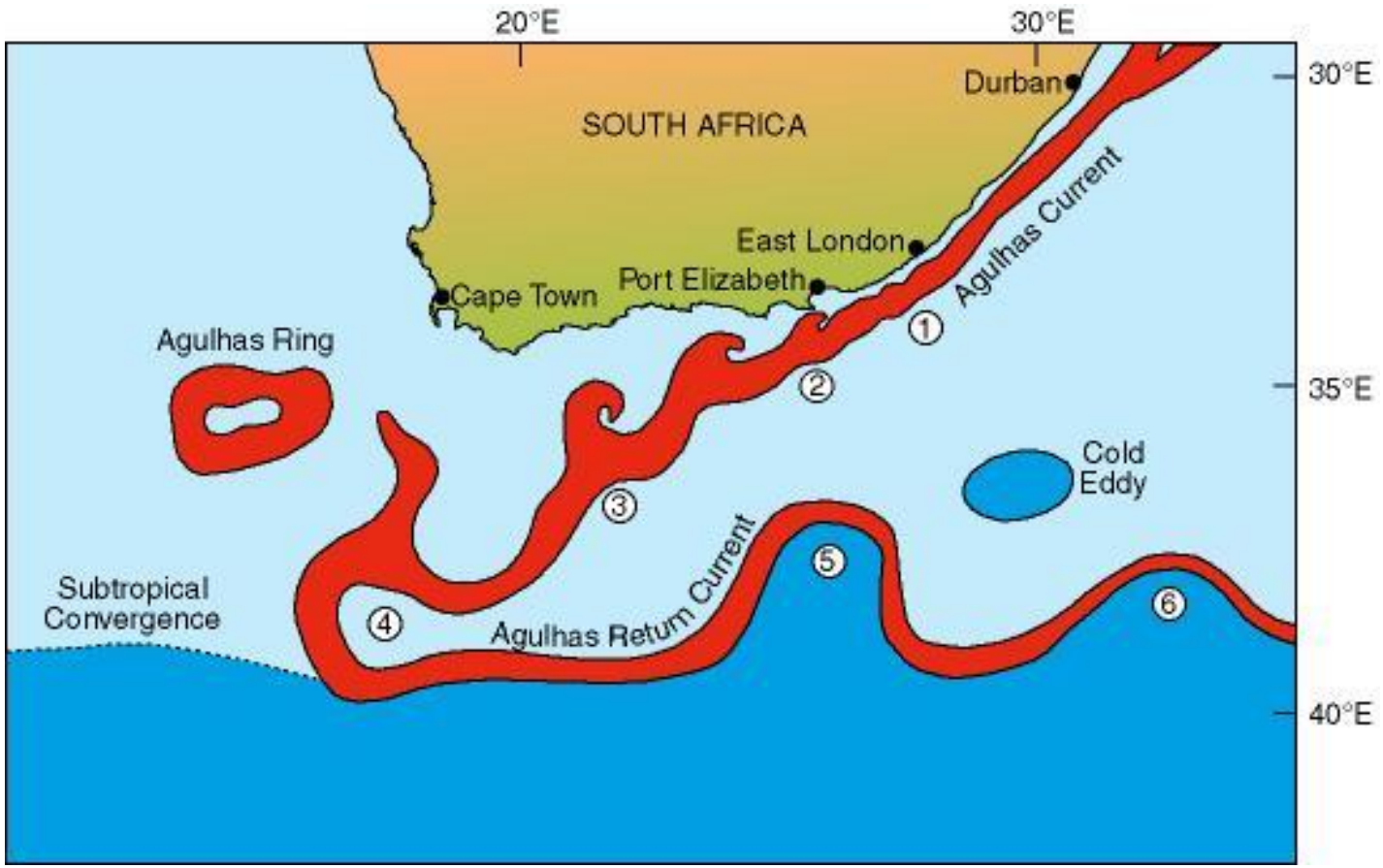




Small pelagic fish spawn on the Agulhas Bank (south coast), and their eggs and larvae are transported by the Benguela current up the west coast into St Helena Bay nursery ground.

As they mature they move migrate back to the Agulhas Bank as adults.

3. Western boundary currents typical widths of 100 km and typical speeds of 2 m s^{-1} and causes them to shed eddies frequently.



Role of Agulhas

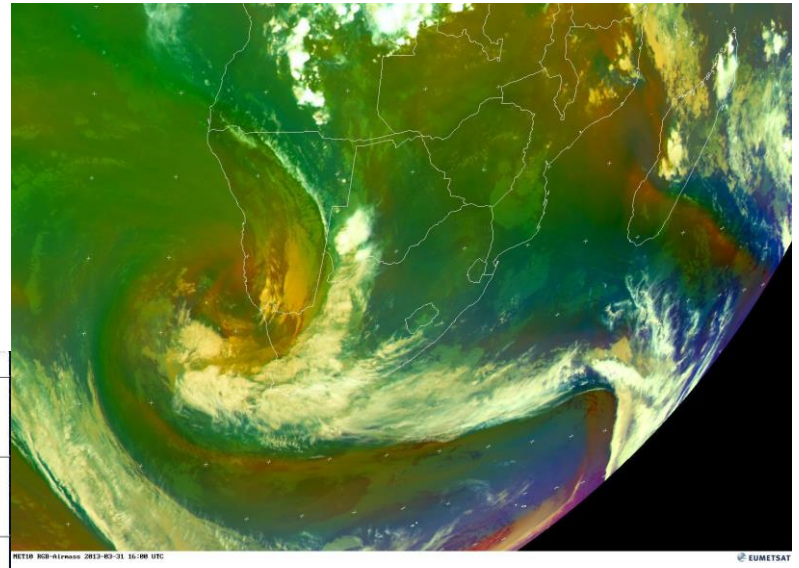
Local Climate and Weather

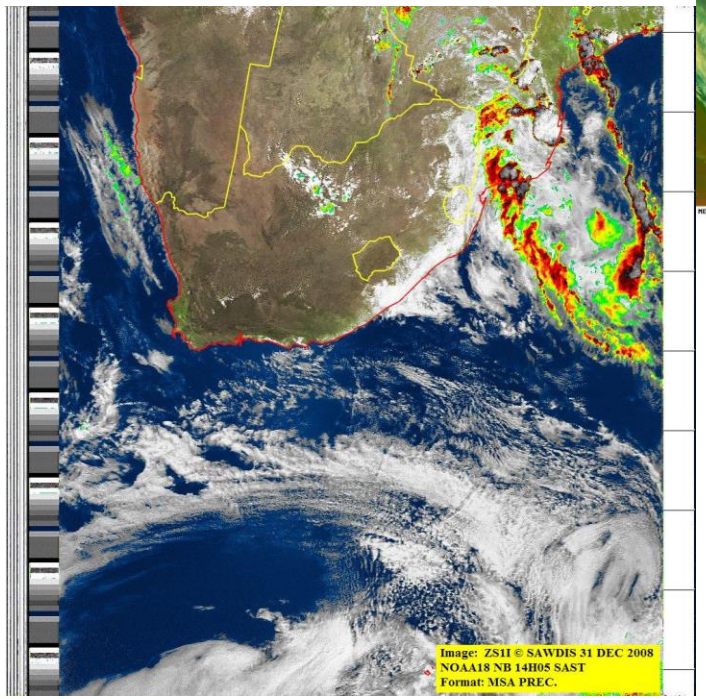
Higher temperatures in Agulhas Current leads to higher rainfall

Cumulus cloud formation over Agulhas Current

Intensification of weather systems

Modification of storm tracks





27 Mar 2021

Watch out for stranded turtle hatchlings, Western Cape beachgoers urged

news24 Nicole McCain

SHARE

The sea turtle hatchlings wash up on Western Cape beaches annually, after they are carried astray by strong currents, said the foundation in a statement.

"This is an annual occurrence as loggerhead sea turtles hatch on the beaches of northern KwaZulu-Natal and are then carried south by the Agulhas current. Due to injury, dehydration and hypothermia, some of these hatchlings unfortunately wash up onto the beaches around the Western Cape," it added.