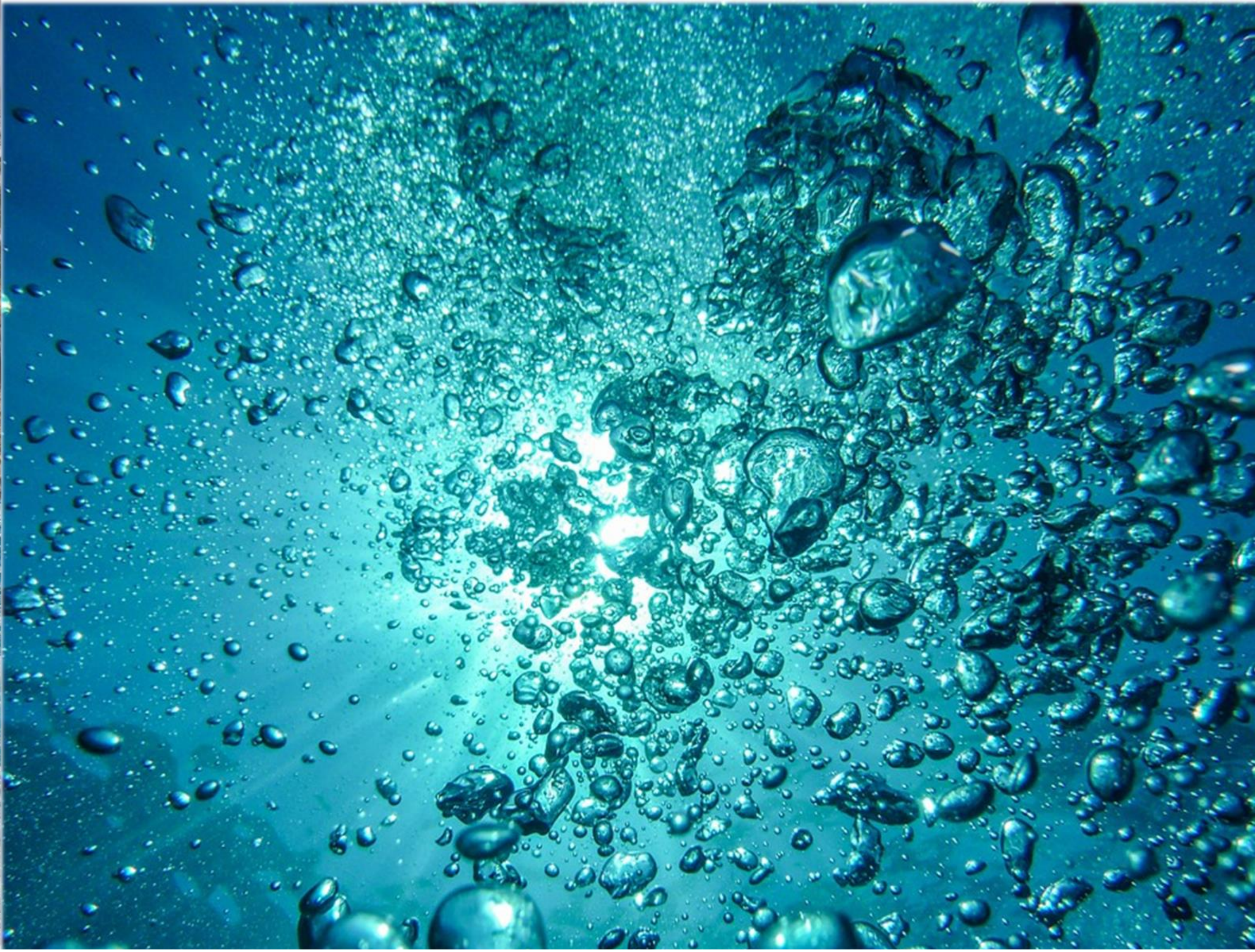

DEPARTMENT OF OCEAN SCIENCE

Overview:
Physical Characteristics of the Ocean

The Beautiful Ocean

- **The ocean is a rich and complicated system** connecting differing parts of the world and supporting abundant life forms.
- **The ocean is of importance to the environment human beings live within**, especially because the ocean can modulate the Earth's climate.
- The **connection between ocean and climate** can be understood via oceanic motions.

Physical Characteristics of the Ocean

- The Ocean: What is it & why study it
- Approaches to studying the Ocean
- Oceanic Flows
- Temperature, Salinity & Stratification
- Impacts of Stratification on Oceanic Flows
- Where and how water sinks from surface to bottom
- Where and how water rises from bottom to surface
- Mesoscale Eddies

Module Goal

- Recall the oceanic processes
- Explain how the ocean functions in relation to the climate system
- Describe certain oceanic parameters such as those about hydrography

The Ocean is the largest body of water on our planet, covering >70% of the Earth's surface. This view of Earth's horizon was taken by an Expedition 7 crewmember onboard the International Space Station (ISS), using a wide-angle lens while the Station was over the Pacific Ocean. (Image from NASA)

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The Ocean
- What Is It & Why Study It?

The Ocean….

- The Ocean covers **~70%** of the Earth's surface!
- We have barely dipped our toes in exploring the Ocean
- The Ocean provides countless benefits to our planet
- The Ocean and the weather are correlated

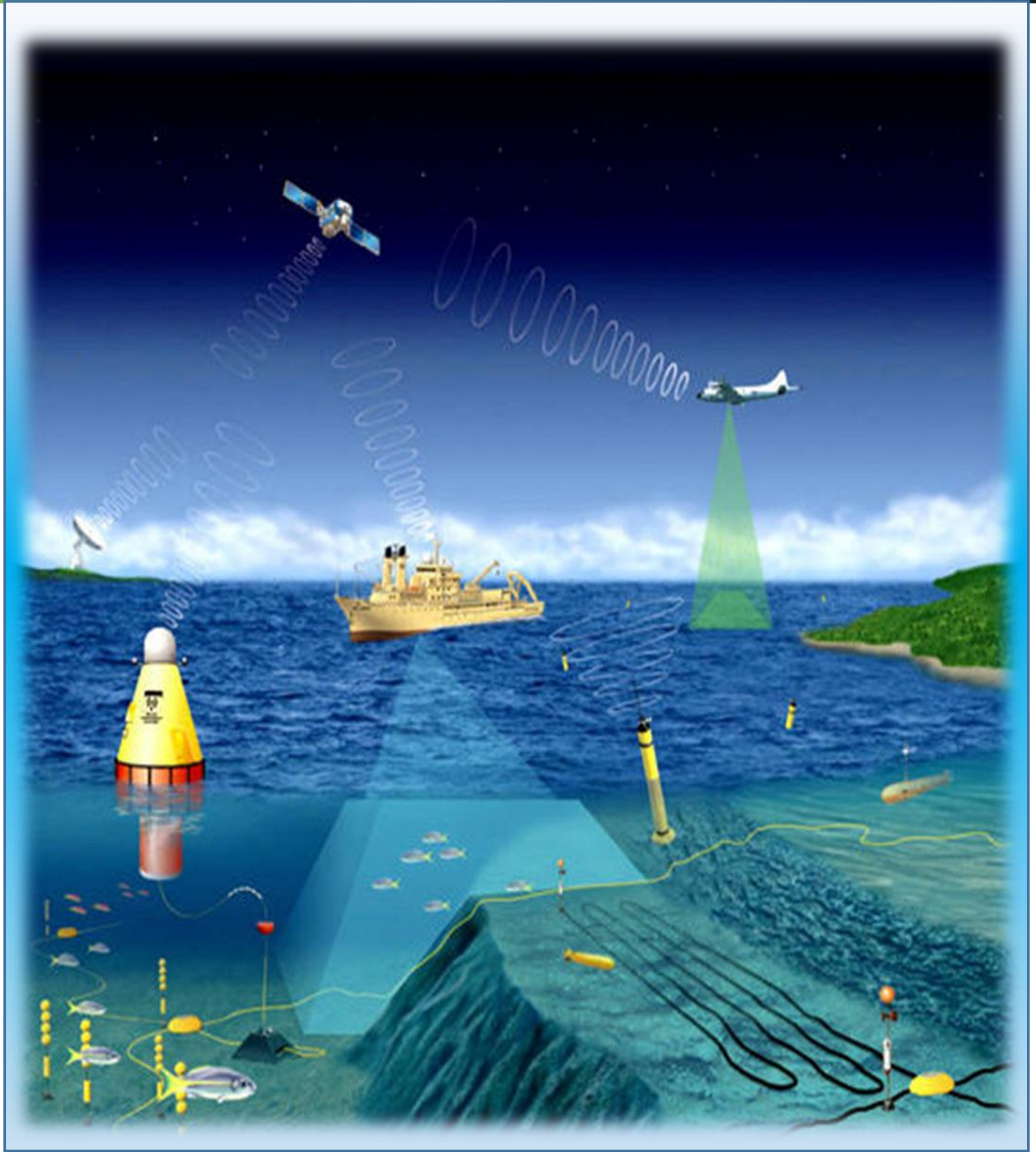


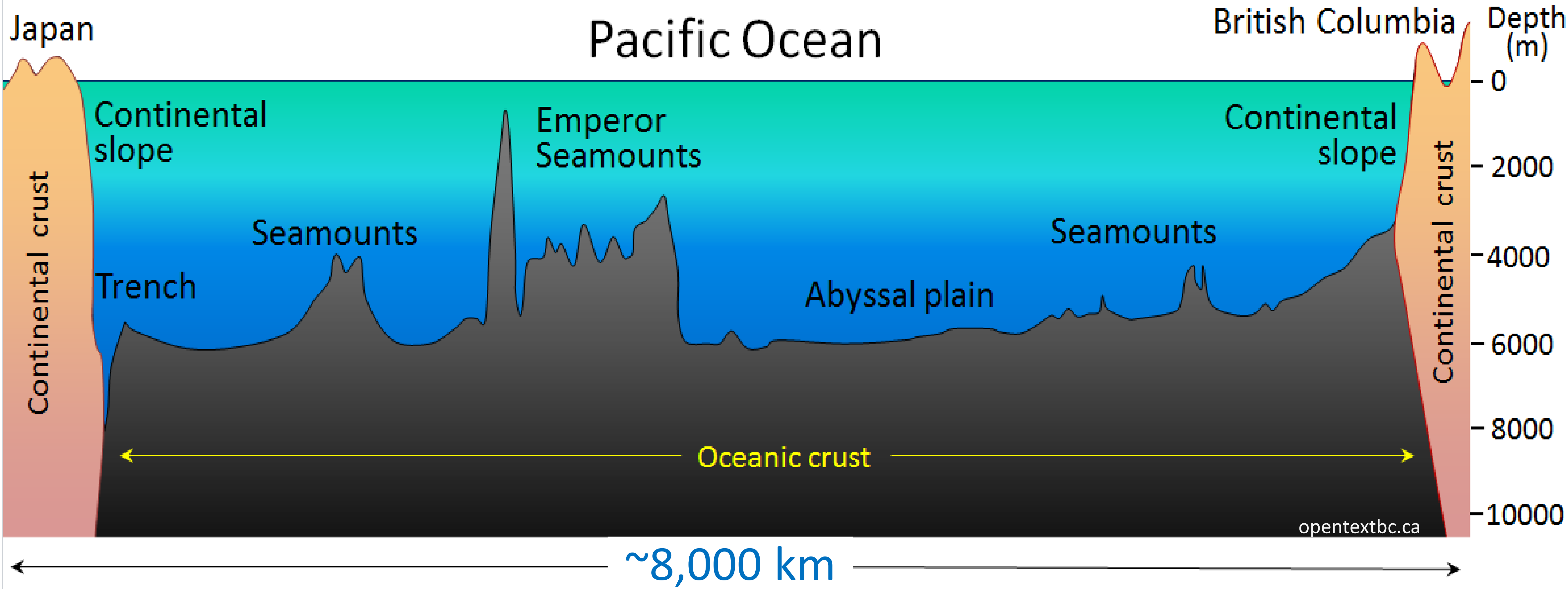
Image: NOAA

Geography of the Ocean

The world ocean can be divided into 5 major basins:

the Arctic Ocean, the Pacific Ocean, the Atlantic Ocean, the Indian Ocean, and the Southern Ocean.

The Ocean is Deep

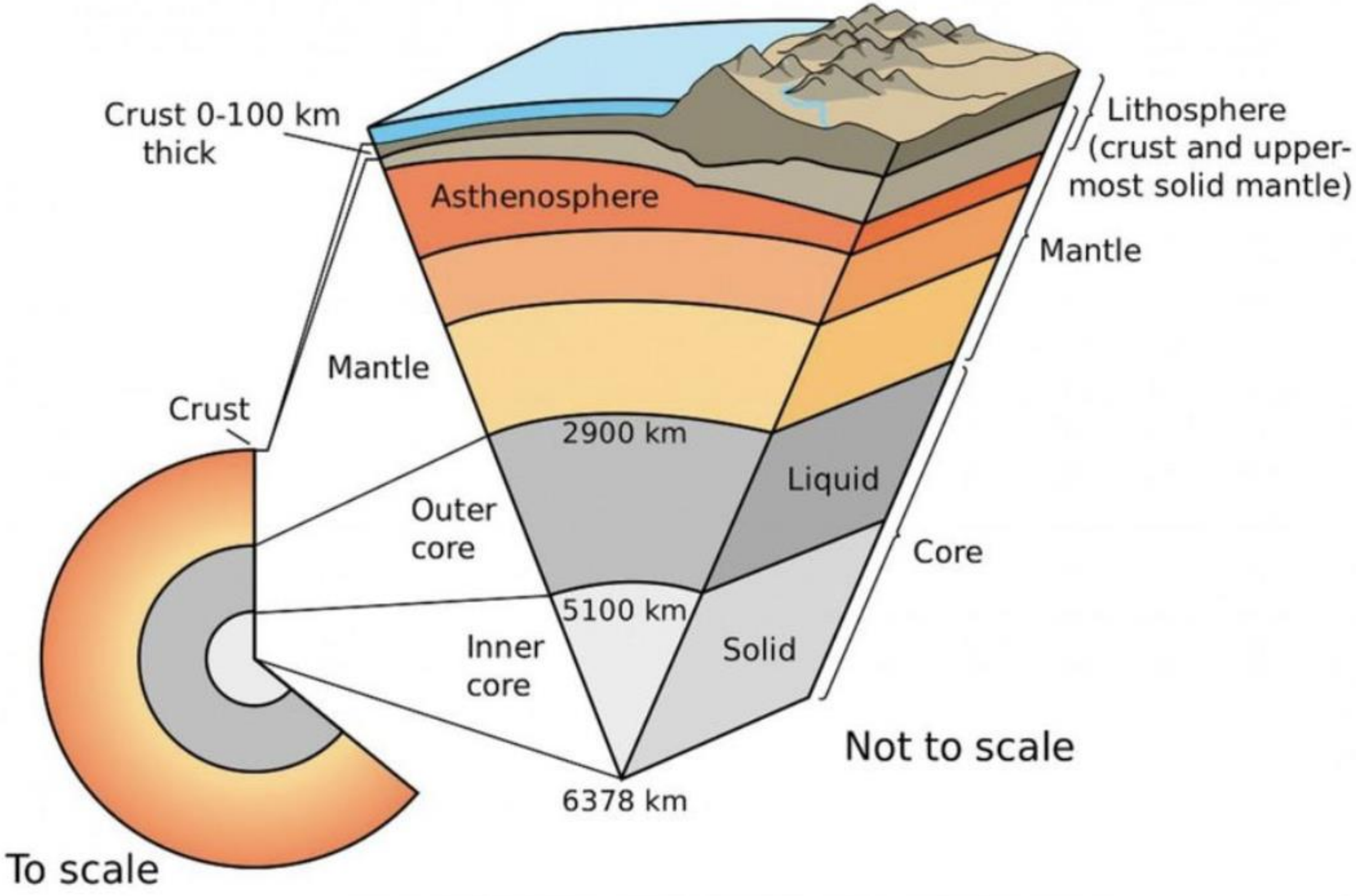


Average ocean depth: ~4 km

(Equivalent to the distance from Sheung Wan to Admiralty, or a ~8-10 minute car ride)

The Ocean is Deep, but Not as Deep as the Earth's Crust

Compared to the deep depths of the earth, the ocean is just like the skin of the earth.



A cartoon block of the layers of earth (Credit: USGS)

The Ocean is Like the Skin of the Earth

Image: Adam Lucas Design

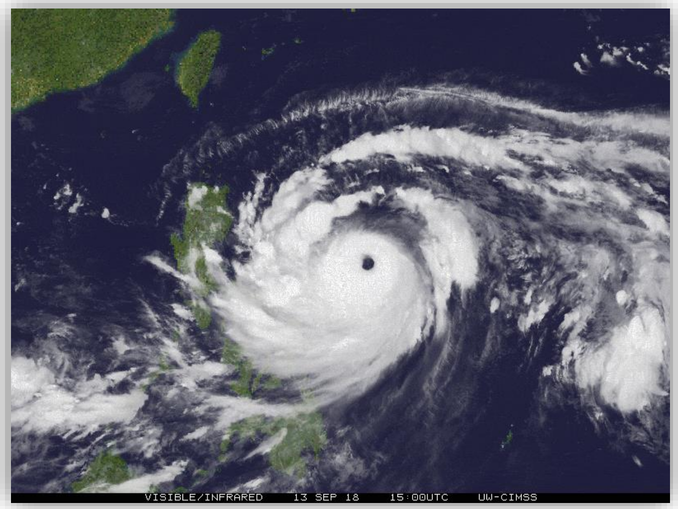
When compared with the horizontal scale (> 1,000 km), the Ocean to the Earth is equivalent to the paint on a baseball.

The Ocean has Barely been Explored

The natural giant squid was not discovered until 2004!

- **Only ~5% of the ocean has been explored**
- **90% of the ocean is deeper than 200m**, making exploration **difficult** and **expensive**

Why Do We Care about the Ocean?



Weather Prediction

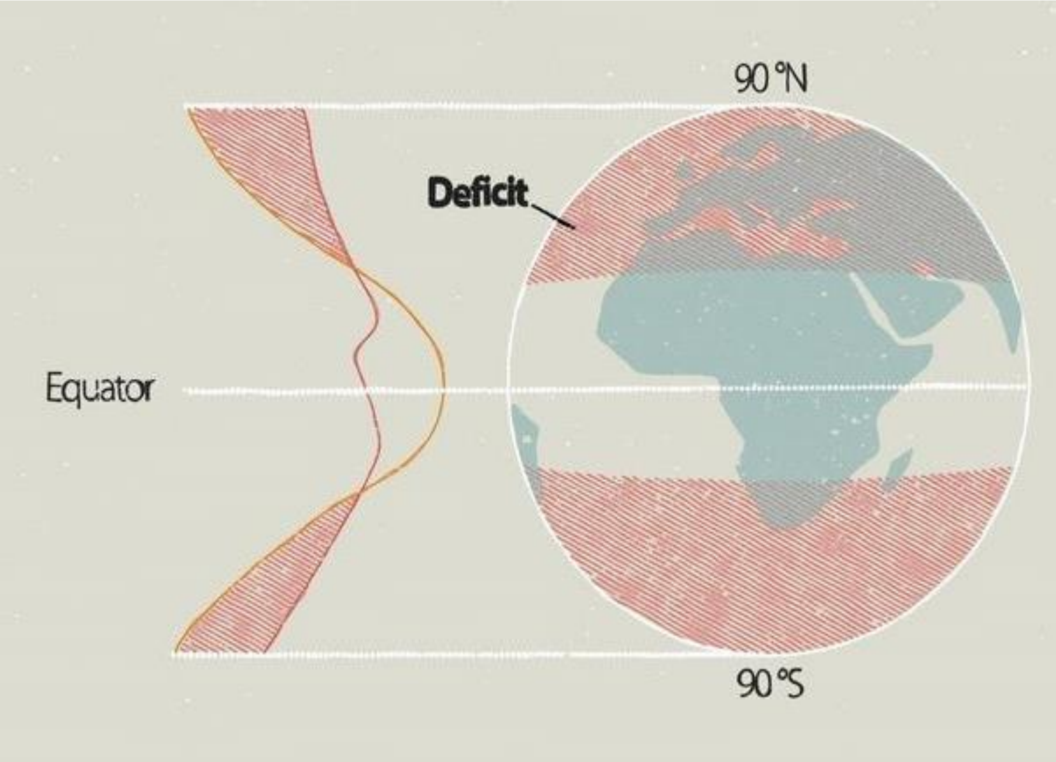
Natural Resources

Transportation

Food

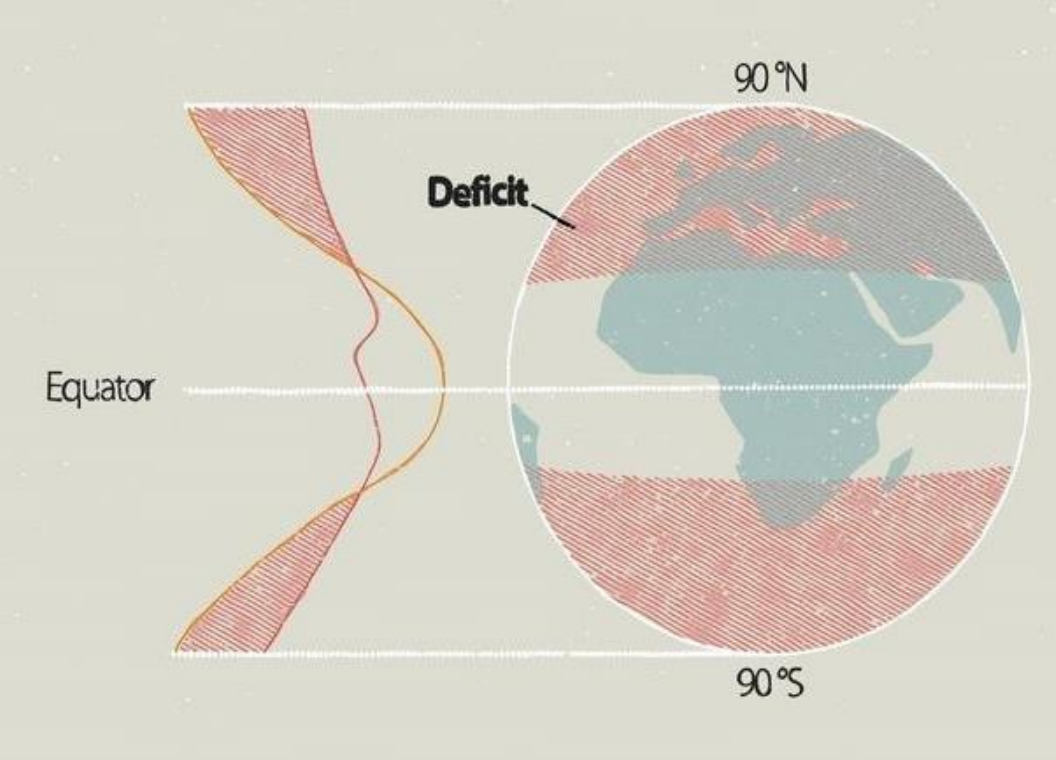
Image: Google

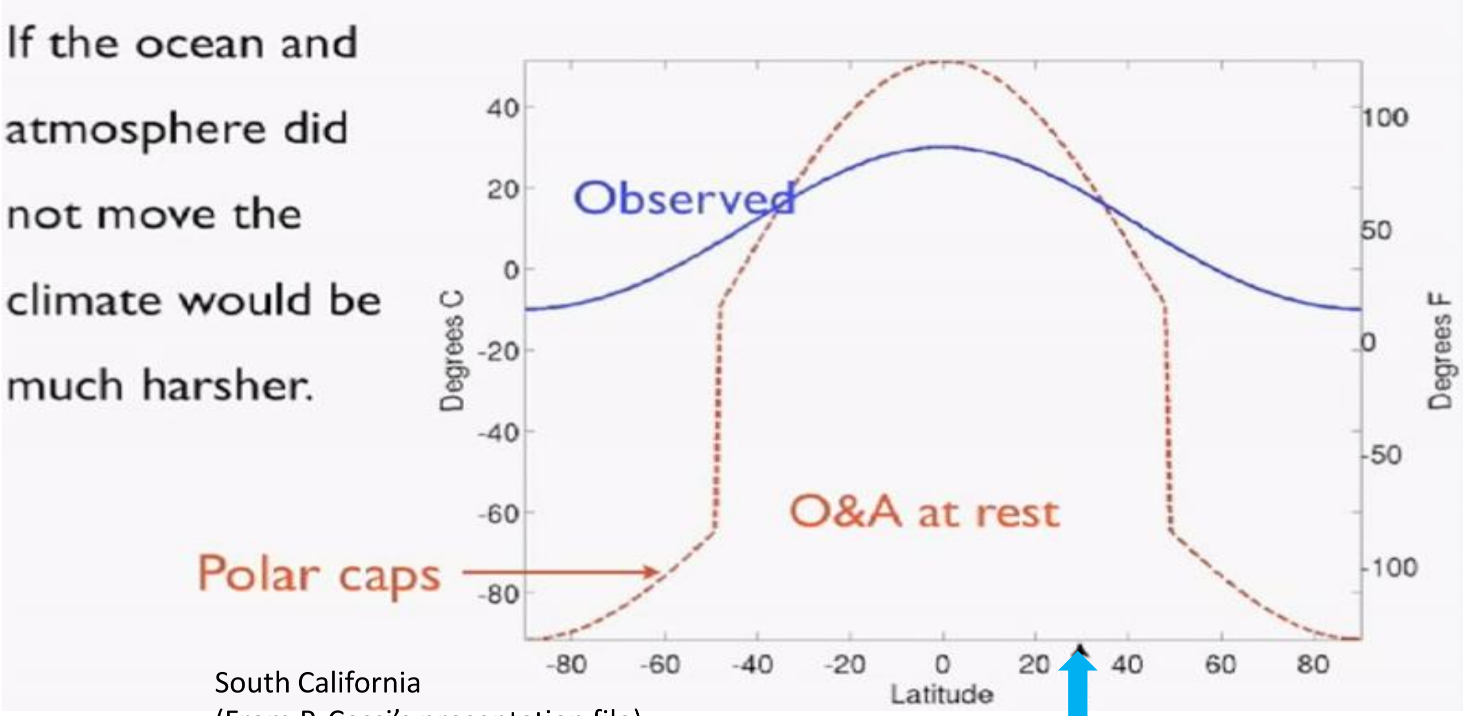
The Earth's Rotation and the Ocean Help Regulate the Climate



The Ocean and atmosphere redistribute the excessive heat received by the Earth's surface at the equator from solar radiation via ocean/atmosphere circulations.

The Earth's Rotation and the Ocean Help Regulate the Climate





South California
(From P. Cessi's presentation file)

Hong Kong

The Ocean and atmosphere redistribute the excessive heat received by the Earth's surface at the equator from solar radiation via ocean/atmosphere circulations.

Key:
- - - - **Much harsher temperatures**
—— **More moderate temperatures**

Questions – What is the Ocean and Why Study it?

1) Why should the Ocean be viewed as the Earth’s skin?

The Ocean is not deep compared to the Earth’s crust.

2) How many Ocean Basins are there?

Five.

3) Why has the Ocean been barely explored?

The deeper we go, the more refined/expensive technology we need.

4) How do the Ocean and the atmosphere contribute to the relatively mild environment we are living within?

The Ocean and the atmosphere help to redistribute heat from solar radiation.

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Approaches to Studying the Ocean

Studying the Ocean – Three Approaches

1. Observation

Collecting and analyzing real-time data from the ocean.

2. Lab Experiments

Simulating oceanic flows in a lab.

3. Modelling

Using high-performance computers to solve the equations that govern oceanic motions.

1. Studying the Ocean by Observation – *Research Vessels*

Research Vessel (RV Walton Smith from University of Miami) collects real-time data at sea.

1. Studying the Ocean by Observation – *Research Vessels*

Research Vessel (RV Walton Smith from University of Miami) collects real-time data at sea.

Measurements of temperature, salinity, pressure etc are achieved via **fine sensors such as CTD (Conductivity-Temperature-Depth) chains.**

1. Studying the Ocean by Observation – *Drifters*

Drifters measure ocean currents.

Drifters mainly move near the surface with the upper ocean currents.

1. Studying the Ocean by Observation – *Drifters*

Drifters measure ocean currents.

Drifters mainly move near the surface with the upper ocean currents.

The **looping ocean current patterns** in the Gulf of Mexico captured by **Drifters**.

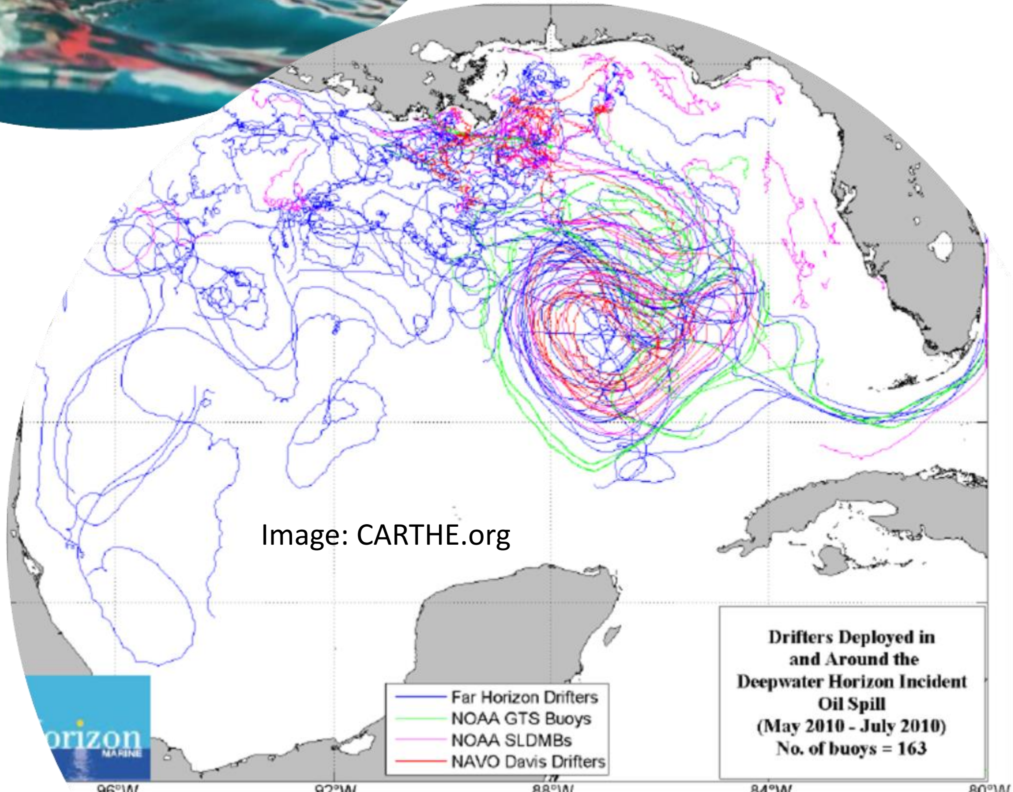
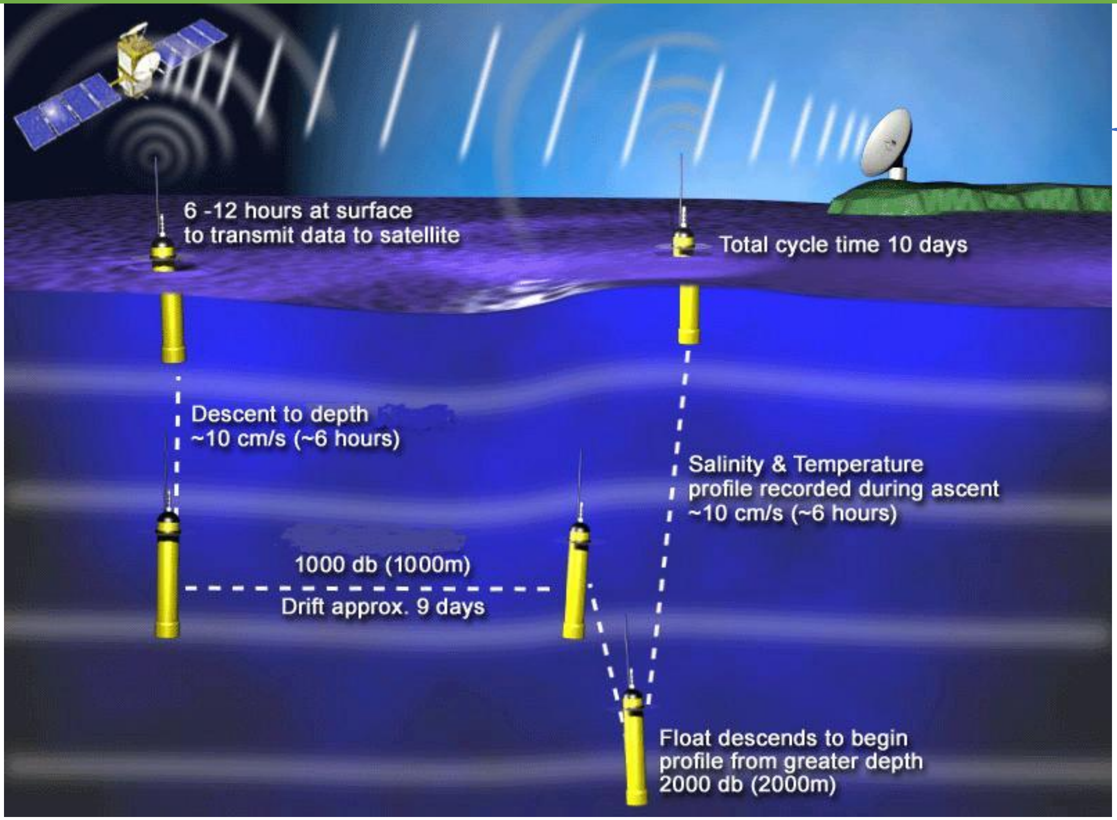


Image: CARTHE.org

1. Studying the Ocean by Observation – *Argo Floats*

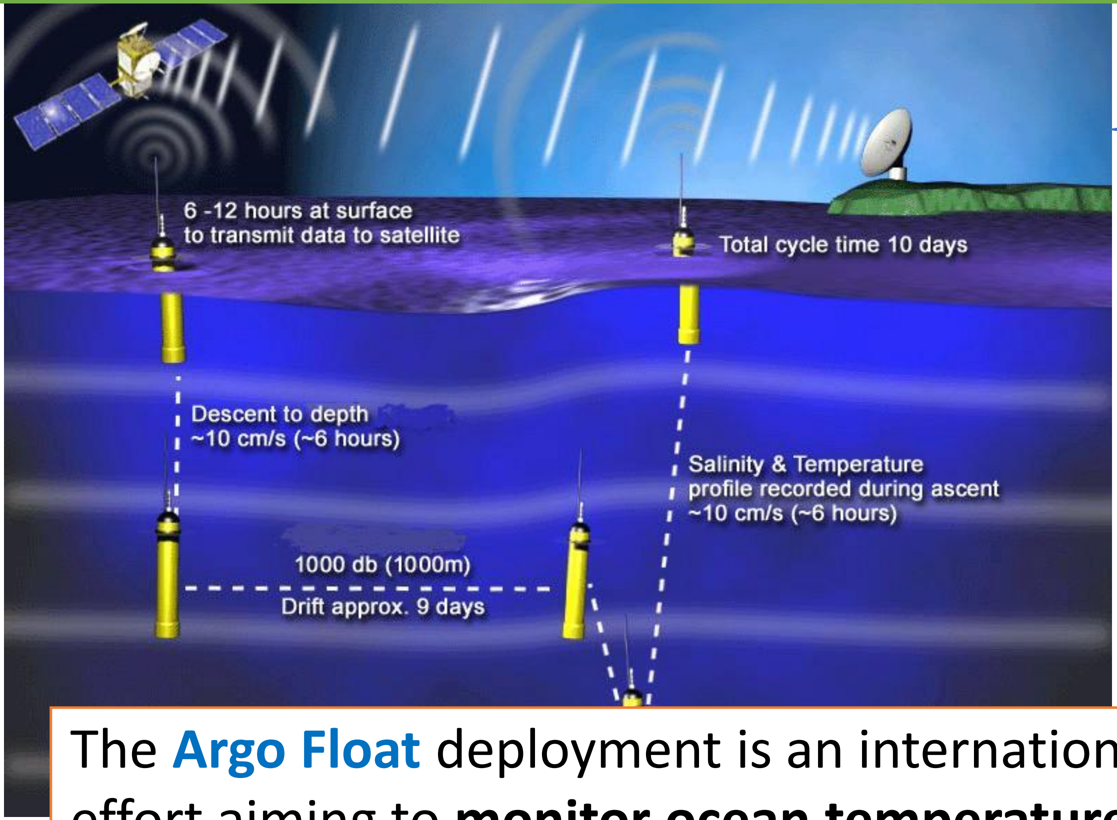


The **Argo Float** has a 10-day working cycle:

- Float at **1 km depth** for ~9 days;
- Descend to **2 km** and **rise to the surface**

While measuring the temperature and salinity in the vertical, sending the data to satellite

1. Studying the Ocean by Observation – *Argo Floats*

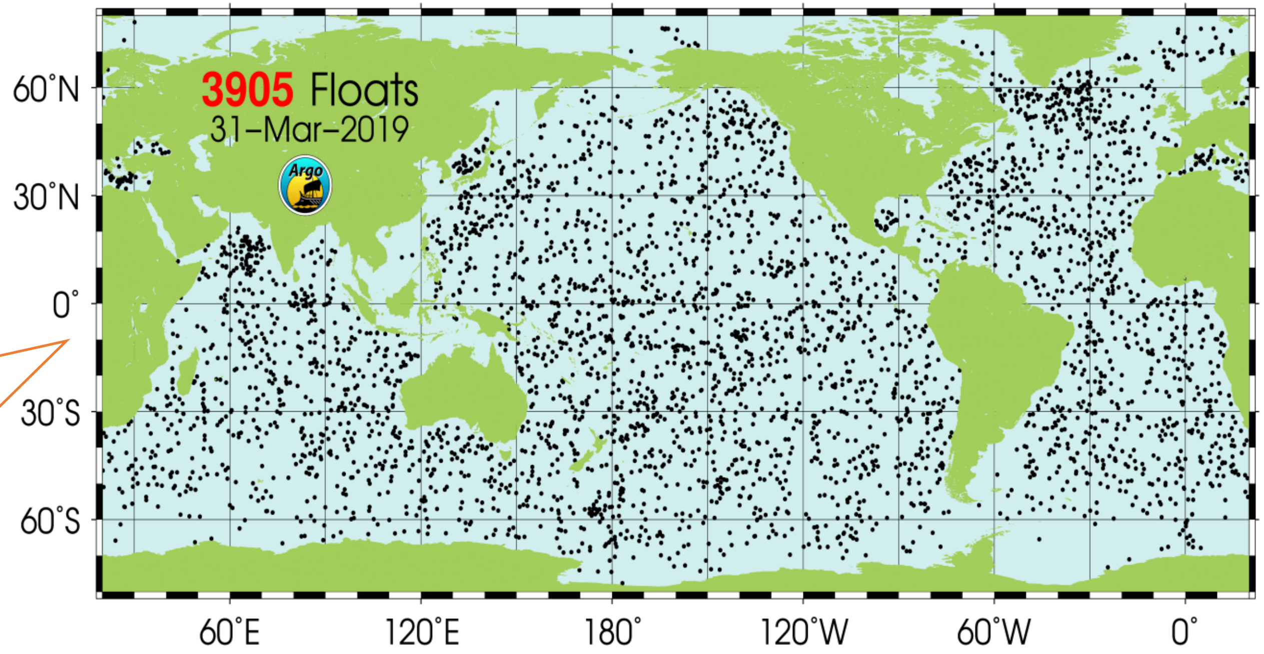


The **Argo Float** has a 10-day working cycle:

- Float at **1 km depth** for ~9 days;
- Descend to **2 km** and **rise to the surface**

While measuring the ***temperature*** *and* ***salinity*** *in the vertical, sending the data to satellite*

The **Argo Float** deployment is an international effort aiming to **monitor ocean temperature and salinity globally**. Each float is equipped with multiple sensors to collect **real-time data**.



1. Studying the Ocean by Observation – *Head-Mounted Sensors*

Google Images

Head-mounted Sensors

on sea animals

- **Tracking *biophysical* data**

- **10-300 casts per day** depending on the seal
- Able to **observe the Antarctic during winter** when sea ice keeps ships away
- Able to **swim under ice shelves**
- Relatively **low quality data**

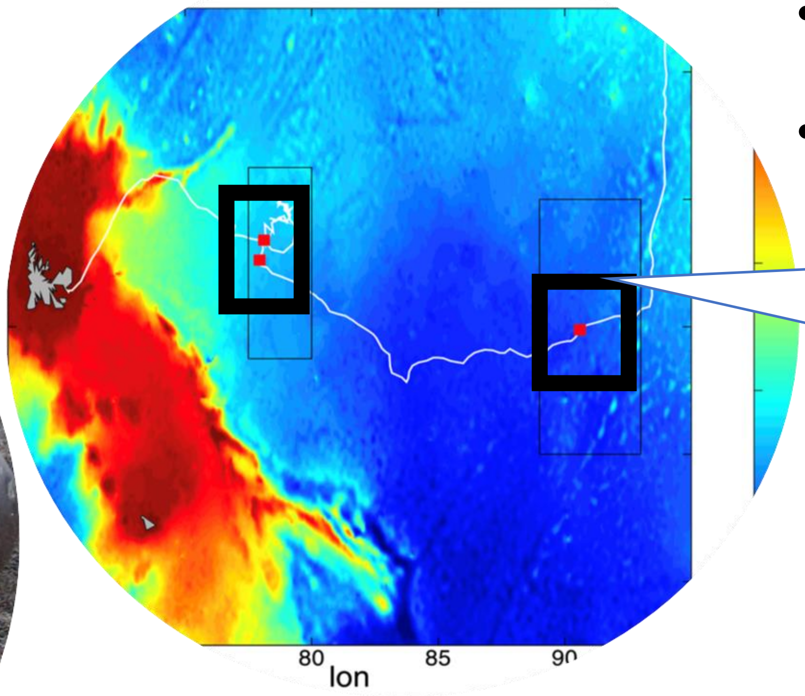
1. Studying the Ocean by Observation – *Head-Mounted Sensors*

Google Images

Head-mounted Sensors on sea animals

- **Tracking *biophysical* data**

From d'Ovidio *et al.* (2013)



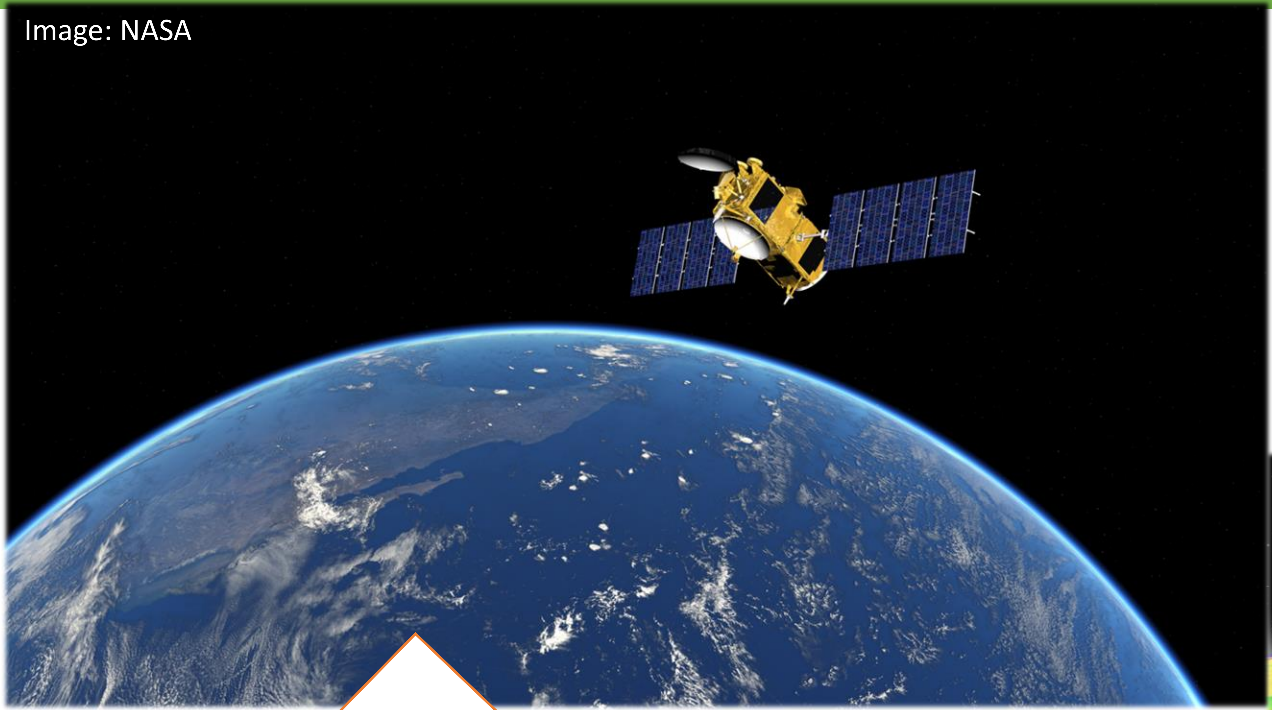
- **10-300 casts per day** depending on the seal
- Able to **observe the Antarctic during winter** when sea ice keeps ships away
- Able to **swim under ice shelves**
- Relatively **low quality data**

The pathway of a swimming seal chasing seafood carried by ocean current.

1. Studying the Ocean by Observation – *Satellite & Radar Altimetry*

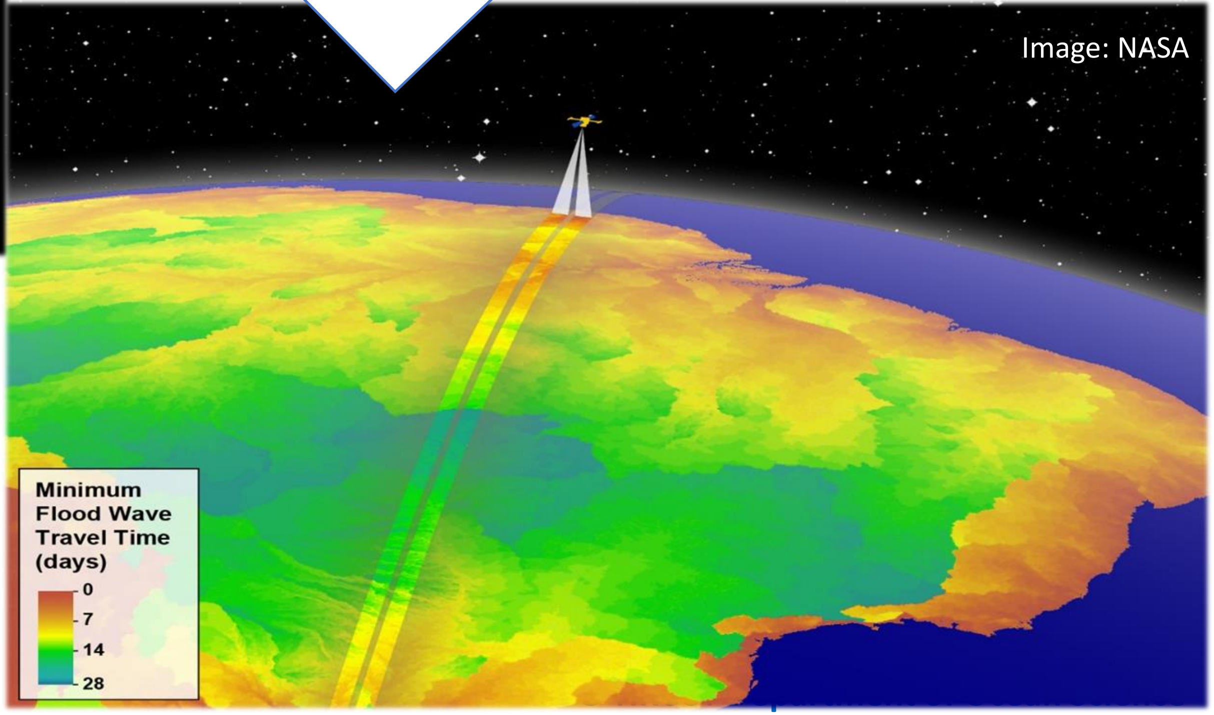
Satellite Jason-3 equipped with **Radar Altimetry**.

1. Studying the Ocean by Observation – *Satellite & Radar Altimetry*



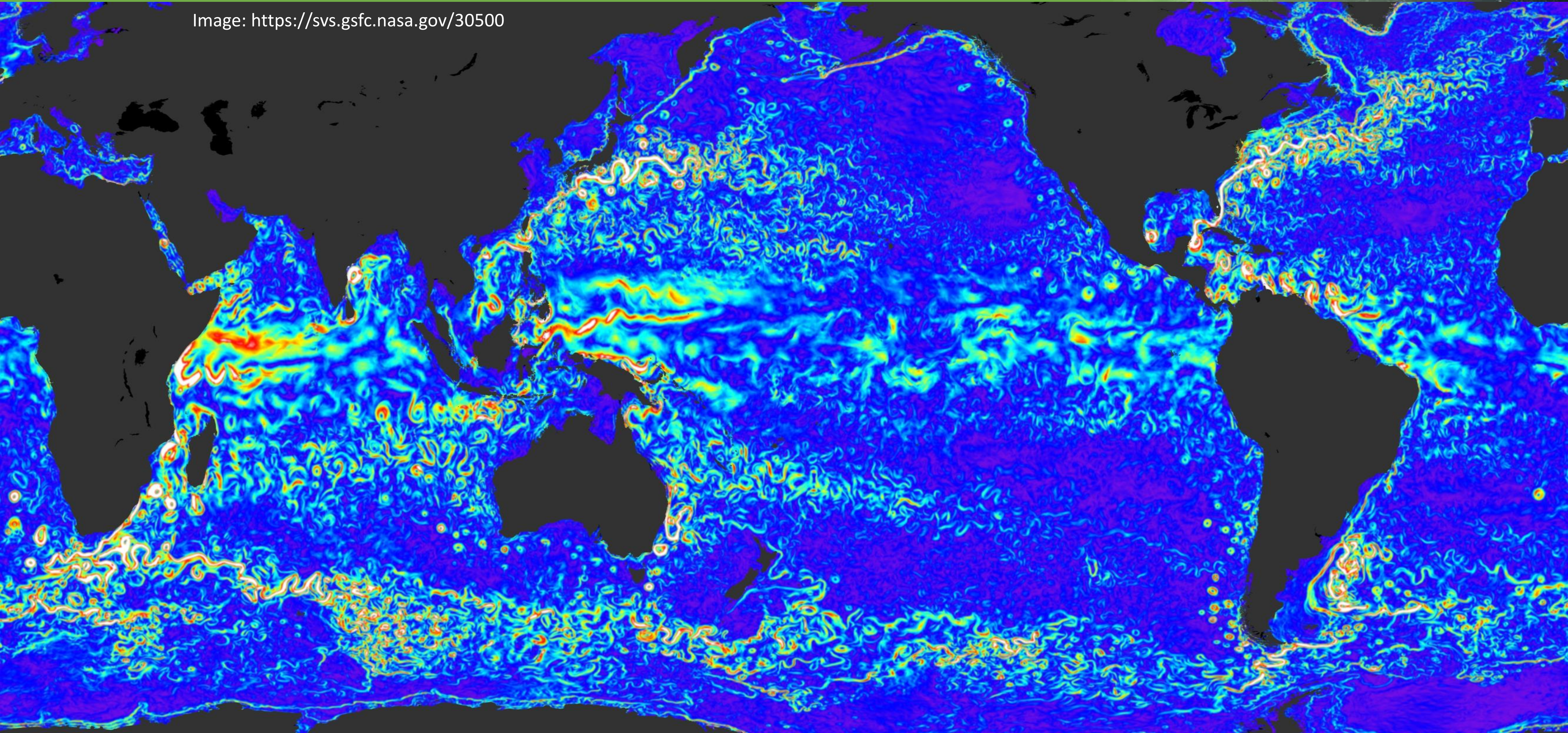
Satellite Jason-3 equipped with **Radar Altimetry**.

Satellite Altimetry measures the **sea surface height (SSH)** from space. SSH can then be used to quantify **sea level change** and the **upper ocean currents** over time.

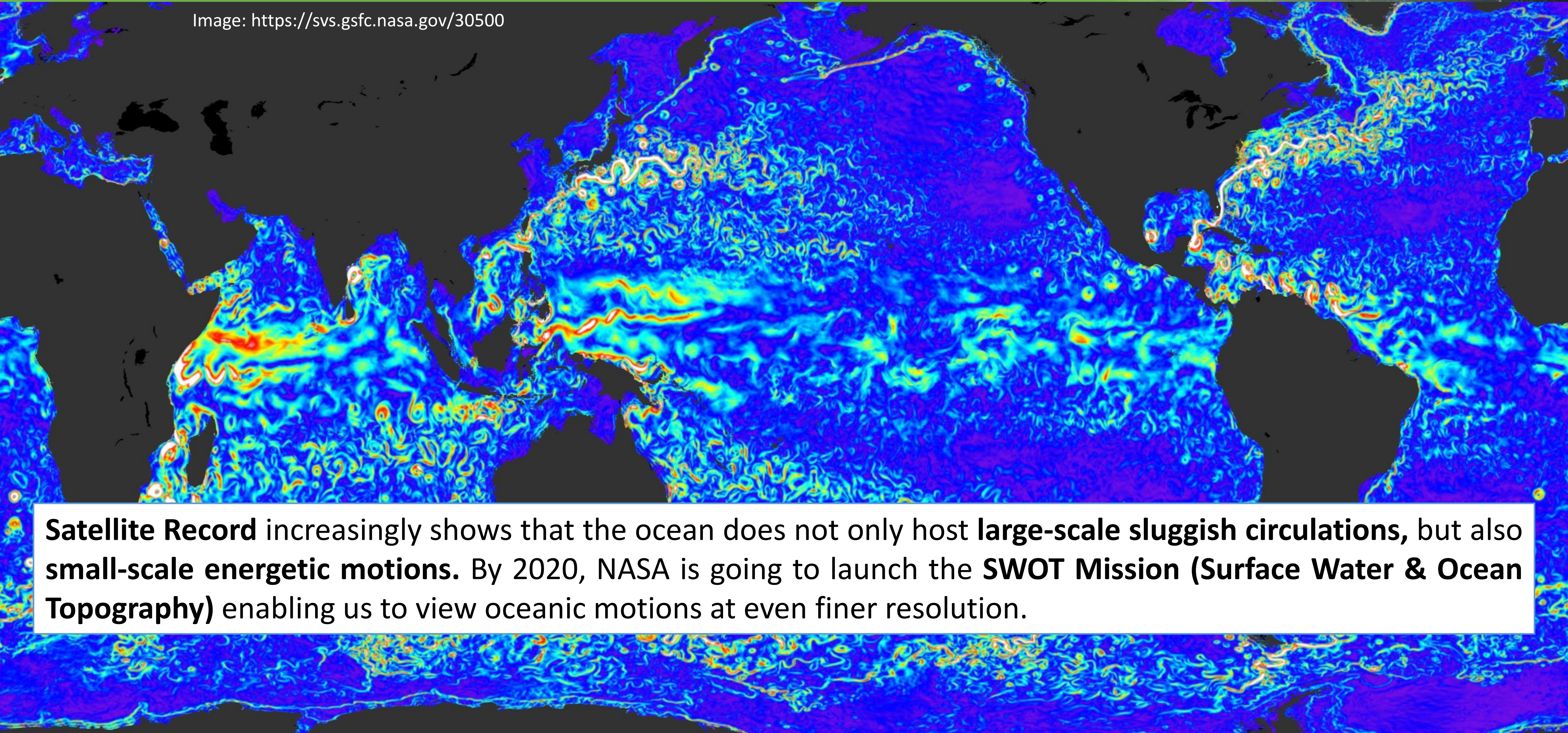


1. Studying the Ocean by Observation – *Satellite Records*

Image: https://svs.gsfc.nasa.gov/30500



1. Studying the Ocean by Observation – *Satellite Records*



Satellite Record increasingly shows that the ocean does not only host **large-scale sluggish circulations,** but also **small-scale energetic motions.** By 2020, NASA is going to launch the **SWOT Mission (Surface Water & Ocean Topography)** enabling us to view oceanic motions at even finer resolution.

Studying the Ocean – Three Approaches

1. Observation

Collecting and analyzing real-time data from the ocean.

2. Lab Experiments

Simulating oceanic flows in a lab.

3. Modelling

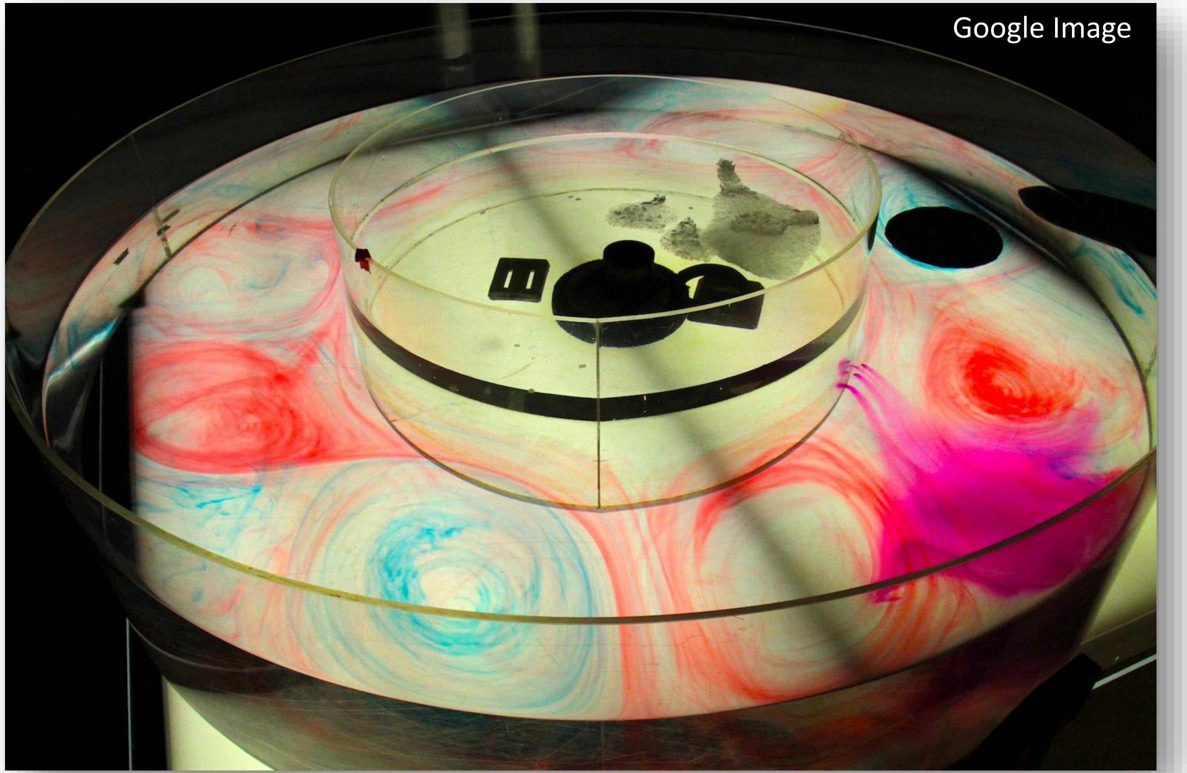
Using high-performance computers to solve the equations that govern oceanic motions.

2. Studying the Ocean by Lab Experiments – *Water Tanks*

Water Tanks to ***mimic*** ocean behaviors.

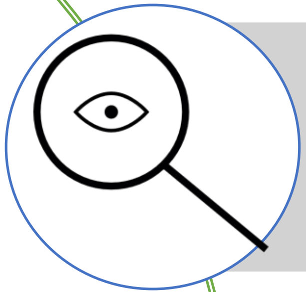
A **Water Tank** at the University of Miami simulating **storm events**.

A rotating **Water Tank** simulating the **fluid on the rotating Earth**.



Google Image

Studying the Ocean – Three Approaches



1. Observation

Collecting and analyzing real-time data from the ocean.

2. Lab Experiments

Simulating oceanic flows in a lab.

3. Modelling

Using high-performance computers to solve the equations that govern oceanic motions.

3. Studying the Ocean by Modelling – *High-Performance Computers*

$$R_o\left[\frac{\partial \mathbf{u}_\mathrm{h}}{\partial t} + \mathbf{u}_\mathrm{h}\cdot\nabla\mathbf{u}_\mathrm{h} + \frac{1}{Ri}\max(R_o^{-1},1)w\frac{\partial \mathbf{u}_\mathrm{h}}{\partial z}\right] + \max(1,R_o)\nabla\Phi + f\mathbf{k}\times\mathbf{u}_\mathrm{h} = \frac{1}{Re}\nabla^2\mathbf{u}_\mathrm{h} + \mathbf{S}_h;$$

$$\frac{1}{Ri}\frac{H^2}{L^2}\left[\frac{\partial w}{\partial t} + \mathbf{u}_h\cdot\nabla w + \frac{1}{Ri}\max(R_o^{-1},1)w\frac{\partial w}{\partial z}\right] + \frac{\partial\Phi}{\partial z} - b = \frac{1}{Re}\nabla^2 w + S_v;$$

$$\frac{\partial b}{\partial t} + \mathbf{u}_h\cdot\nabla b + \frac{1}{Ri}\max(R_o^{-1},1)w\frac{\partial b}{\partial z} + w\frac{N^2}{N_0^2} = \frac{1}{Pe}\nabla^2 b + S_b;$$

$$\nabla\cdot\mathbf{u}_\mathrm{h} + \frac{1}{Ri}\max(R_o^{-1},1)\frac{\partial w}{\partial z} = 0;$$

$$\rho = \rho_0\left[1 - \frac{\bar{b}(z) + b(x,y,z,t)}{g}\right],\quad \Phi = \frac{p}{\rho_0},\quad N^2 = \frac{\partial\bar{b}}{\partial z},\quad b = b(s,\theta,p);$$

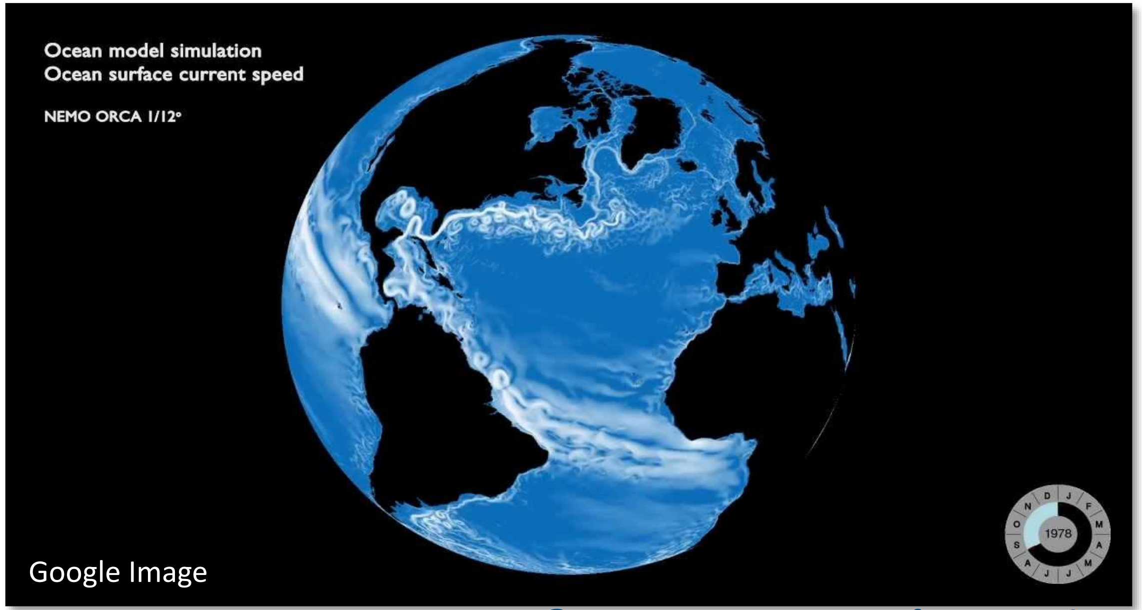
$$R_o = \frac{U}{fL},\quad Ri = \frac{N^2H^2}{U^2} = \frac{1}{Fr^2},\quad Bu = R_o^2 Ri = \frac{L_d^2}{L^2},\quad L_d = \frac{NH}{f},\quad Re = \frac{UL}{\nu},\quad Pe = \frac{UL}{\kappa}.$$

Input

High-Performance Computers (HPC)

- Recruiting thousands of CPU cores to **solve the equations that governs the oceanic motions**, which are too complicated to solve by human brains

Output



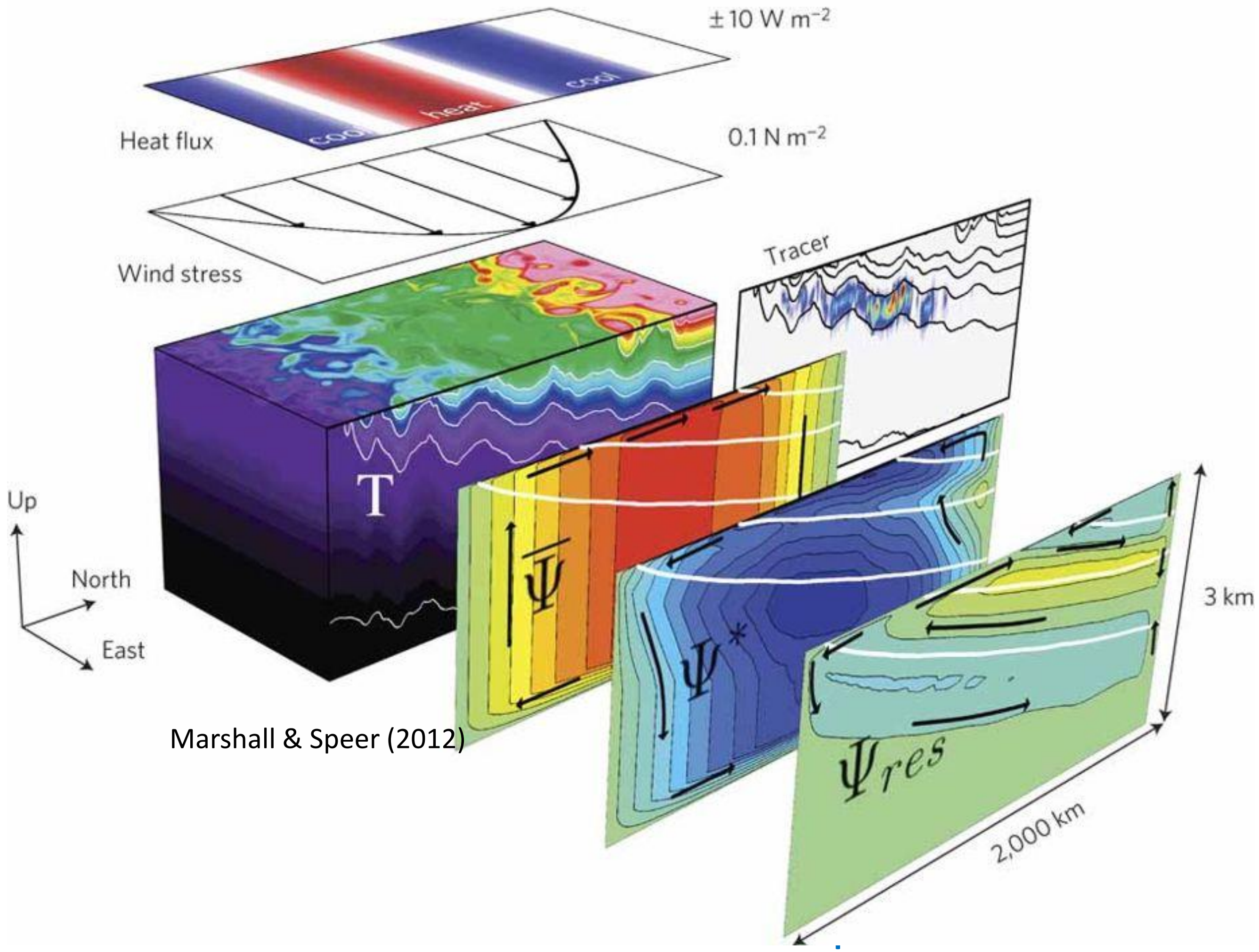
3. Studying the Ocean by Modelling – *Process-Oriented Modelling*

Why Modelling?

Cheaper! Hiring a ship can cost 500,000 HKD per day…

To understand the **physics of the ocean circulation**, oceanographers commonly use the **Process-oriented Model**, which helps to isolate different processes that impact the ocean circulation.

A **Process-oriented Model** of an ocean current with heat and wind being fixed parameters

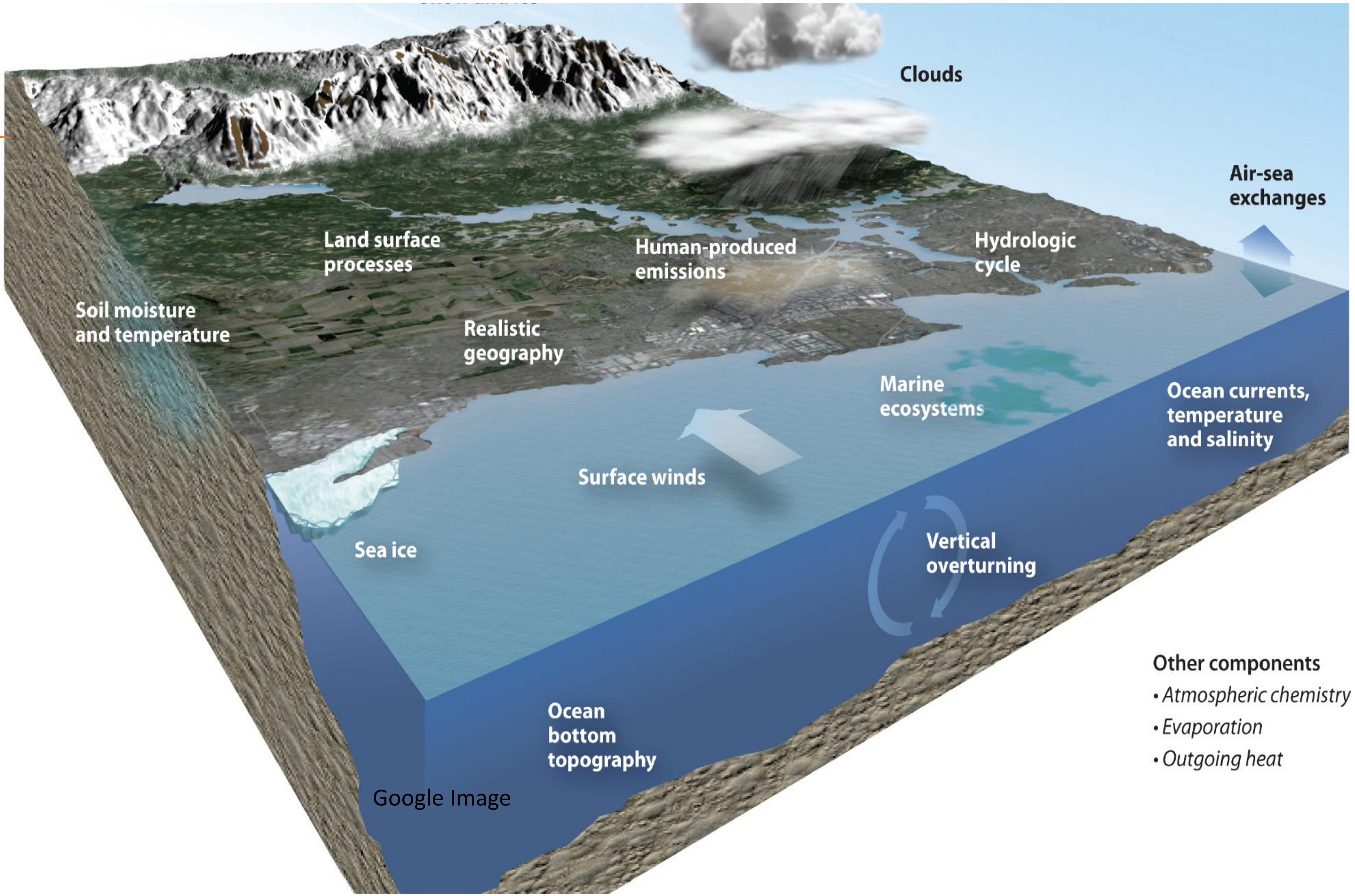


Marshall & Speer (2012)

3. Studying the Ocean by Modelling – *Realistic Modelling*

Realistic Model

To **make predictions** about the future requires a **complete description of ocean physics** in a **Realistic Model**, which provides more **geographic** and **atmospheric** details.

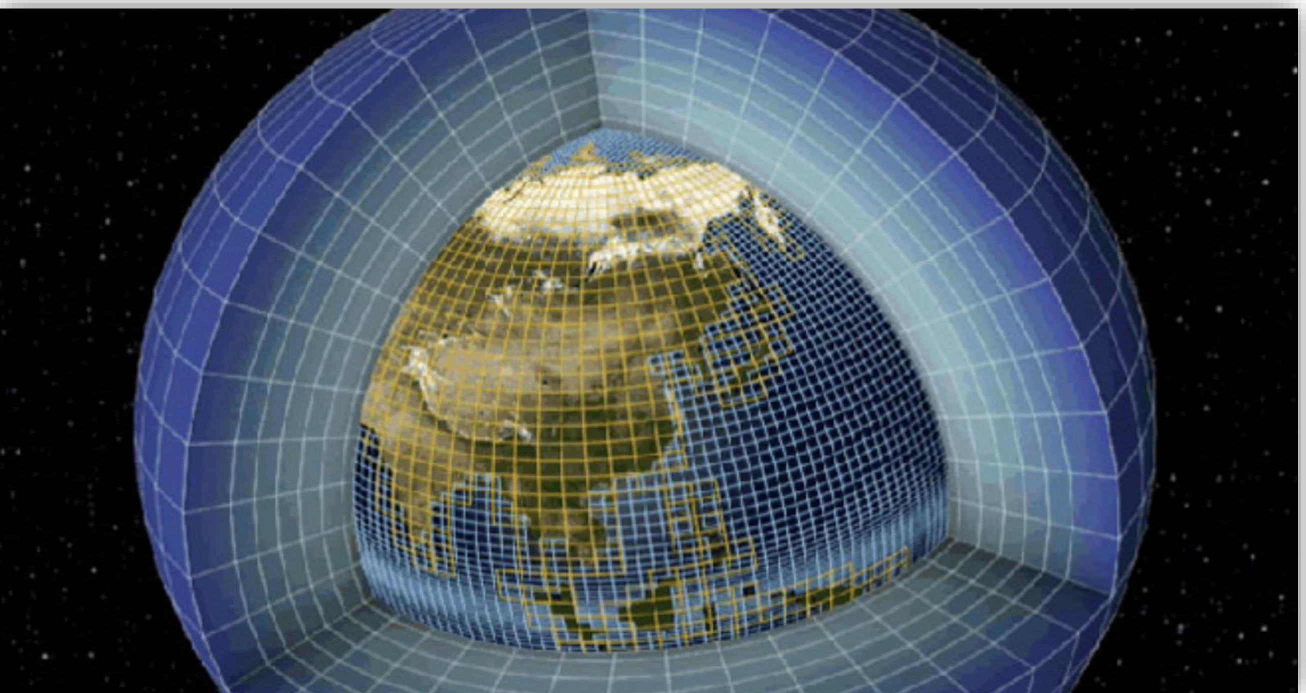


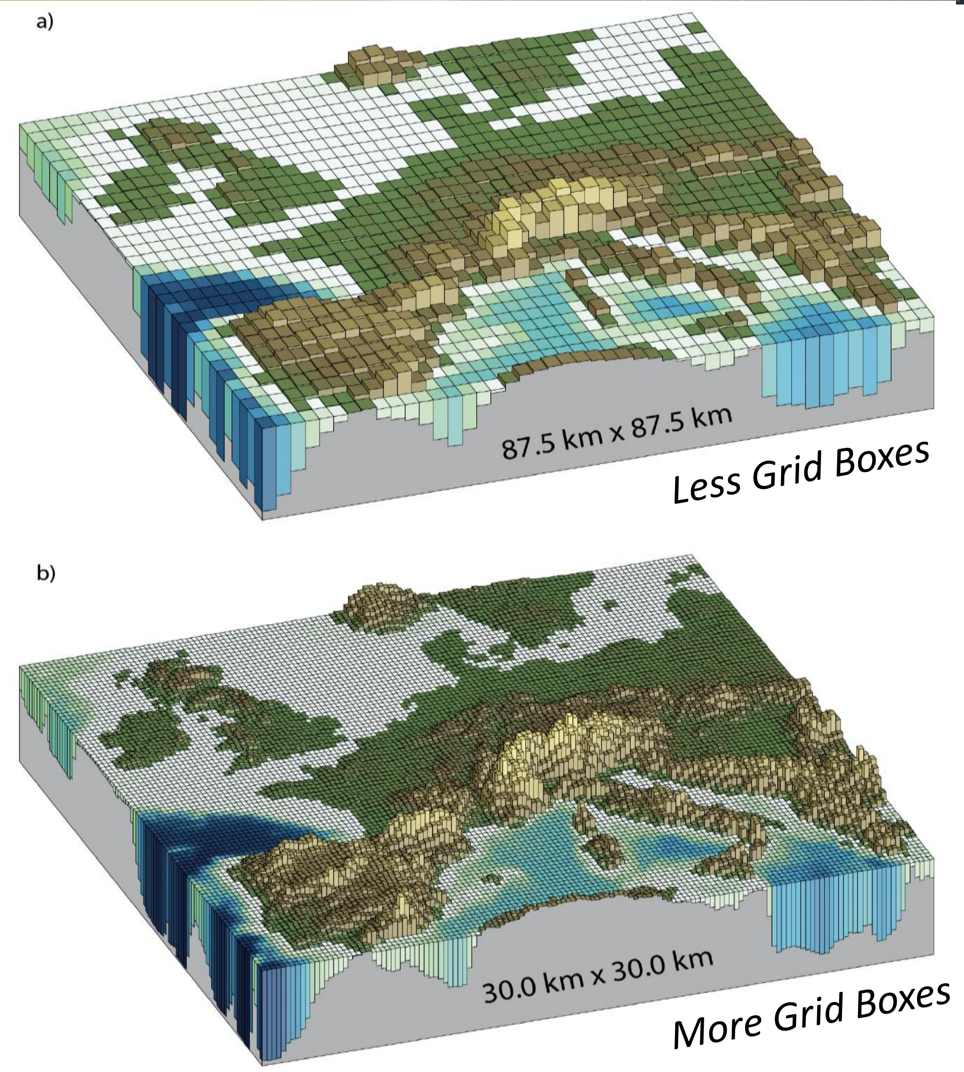
Google Image

3. Studying the Ocean by Modelling – *Grid Boxes*

To solve the equations of motion using **High-Performance Computers (HPC)**, the ocean has to be **discretized** — represented on a finite number of **Grid Boxes** in space or like pixels on your phone camera.

Resolution matters — Commonly used climate models generally has a resolution of ~100 km, which is fairly coarse.





Google Image

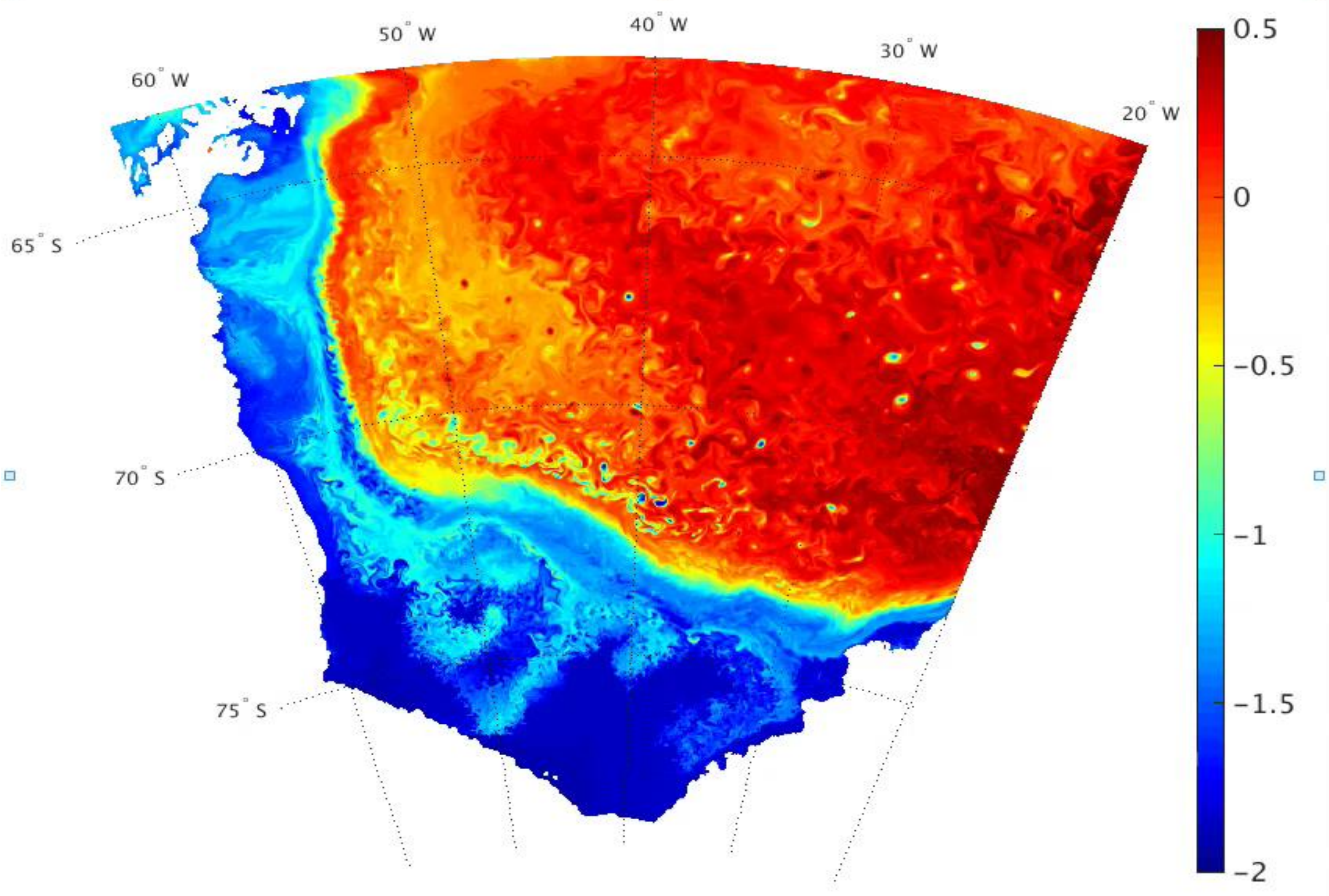
3. Studying the Ocean by Modelling
– *Ocean Temperature and Flow*

A **Flow Feature** is resolved if using smaller grid boxes has little impact on its behavior. Typically this is achieved once the length scale of the flow is larger than the size of grid boxes.

This clip shows ocean temperatures 230 m below the surface in a sector of Antarctic called *Weddell Sea*.

Black contours correspond to ocean depths of 500 m, 1,000 m, 2,000 m, and 3,000 m.

[Data from a recent global simulation at unprecedentedly high resolution (1/48 degree), run by NASA.]



Studying the Ocean – Three Approaches

1. Observation: Collecting & analyzing real-time data from the ocean
Sea going vessels & sensors, floats & drifters, satellite measurements.

2. Lab Experiments: Simulating oceanic flows in a lab
Water tanks to simulate ocean behaviors and movements.

3. Modelling: Using high-performance computers to solve equations that govern the oceanic motions
Process-oriented models, realistic models.

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What Creates Oceanic Flows?

What Creates Oceanic Flows?

- **(Upper Ocean) Wind-driven Circulation**
  - Process in which **surface winds push ocean water.** These winds create their motions.
- **(Mid-latitude) Ocean Gyres**
  - **Wind-driven circulations that are confined by continental lands.** They form a loop and reside in the mid-latitude basins (Pacific, Atlantic, and Indian Oceans).
- **(Southern Ocean) Circumpolar Currents**
  - **Wind-driven circulations that circulate around the globe** (unblocked by lands). A typical example is the Antarctic Circumpolar Current (AKA. the ACC).

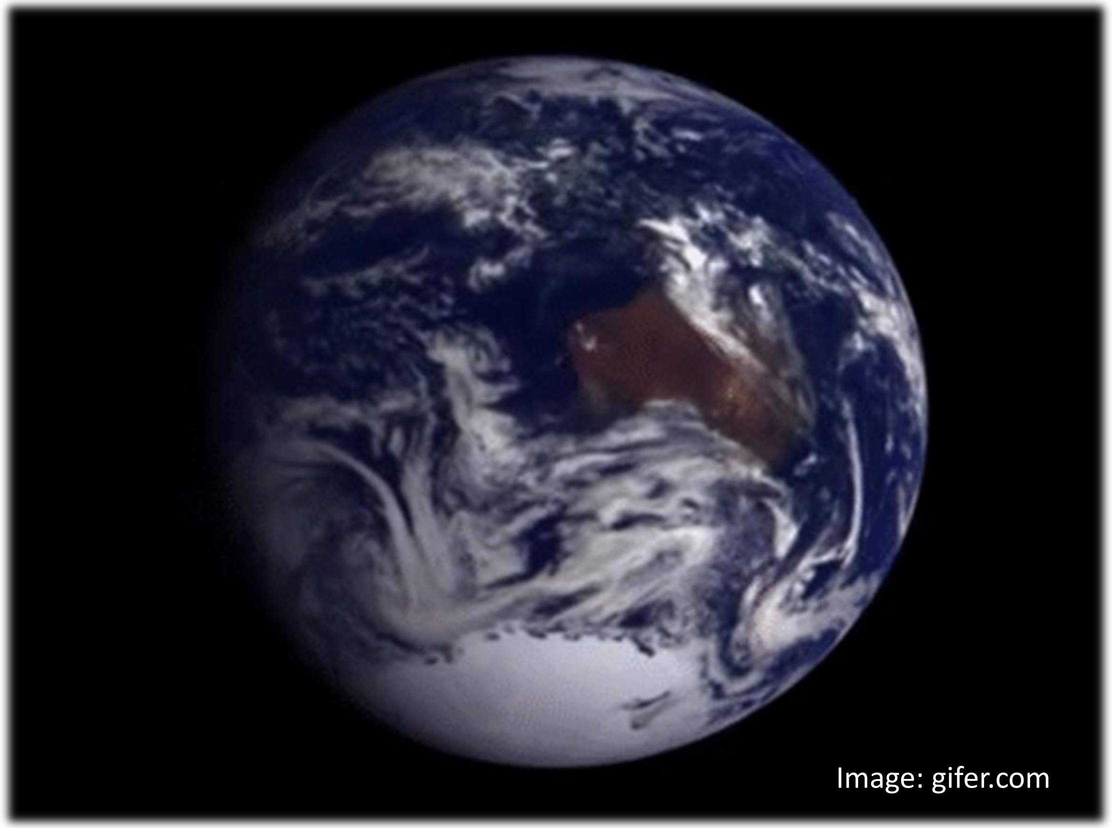
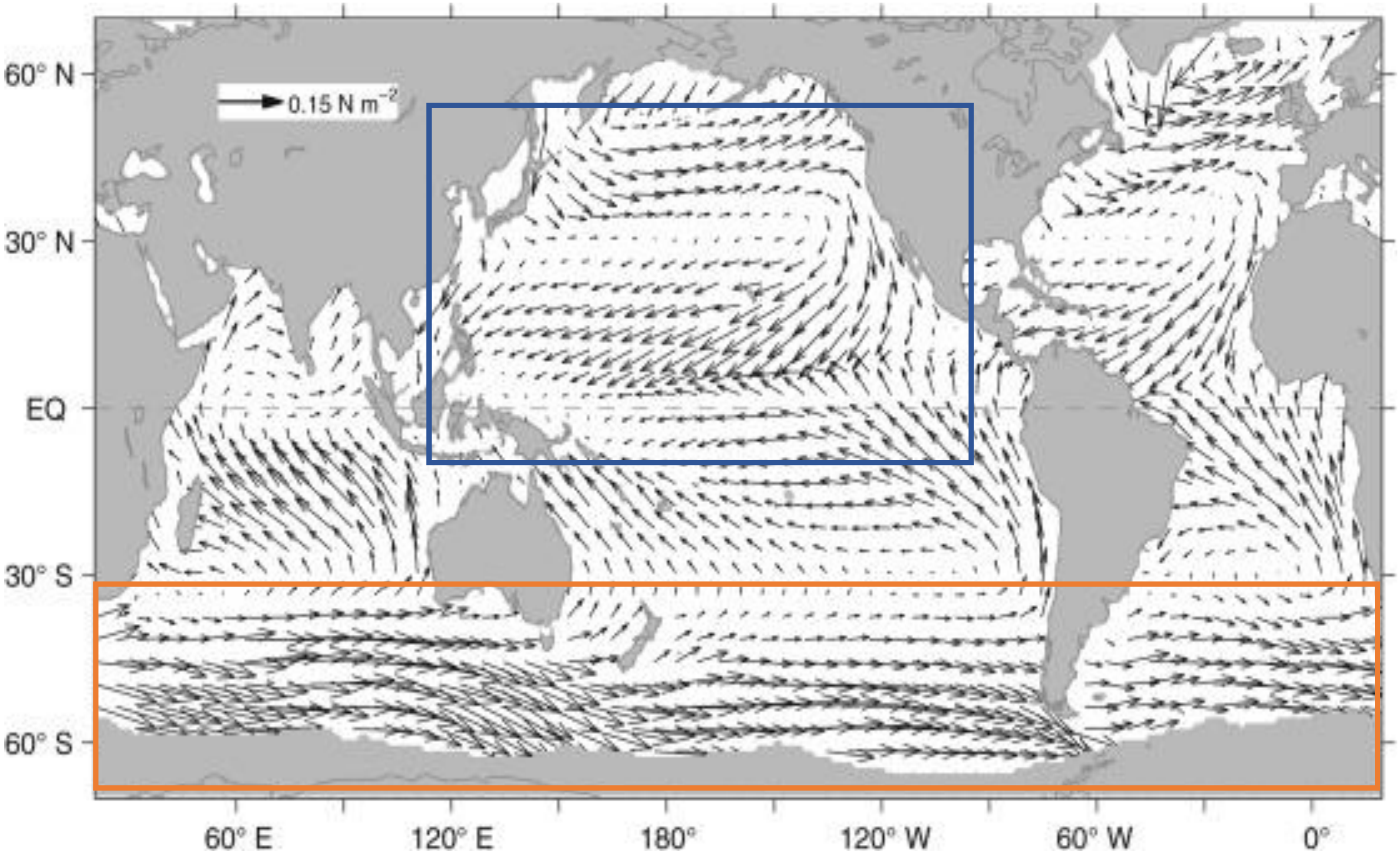


Image: gifer.com

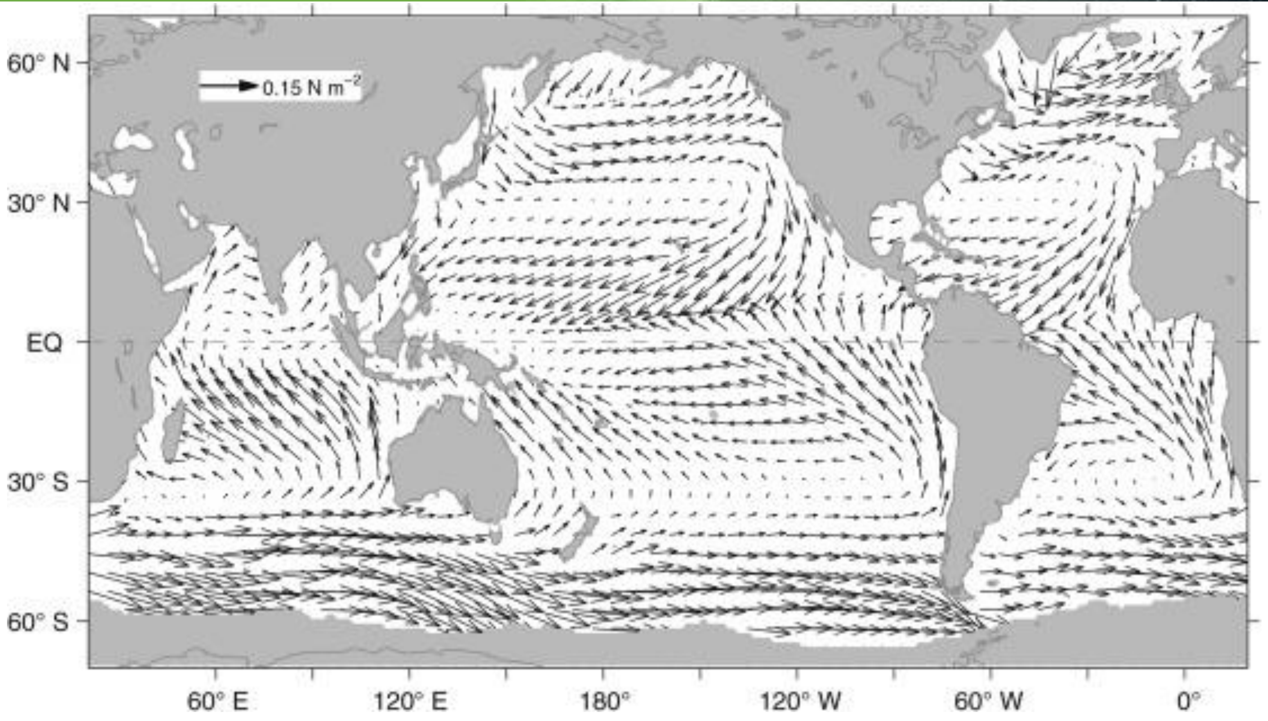
Winds over the Ocean

- **Mid-latitude**
  - Winds at sea surface form loops over mid-latitude ocean basins

- **Southern Ocean**
  - Over the Southern Ocean, “Westerly” wind is prevalent, which blows from west to east around the entire globe



Global Wind Pattern



The global map of wind-driven ocean circulations.
Most wind-driven ocean circulations flow in the same direction of the winds.

Global Wind Pattern

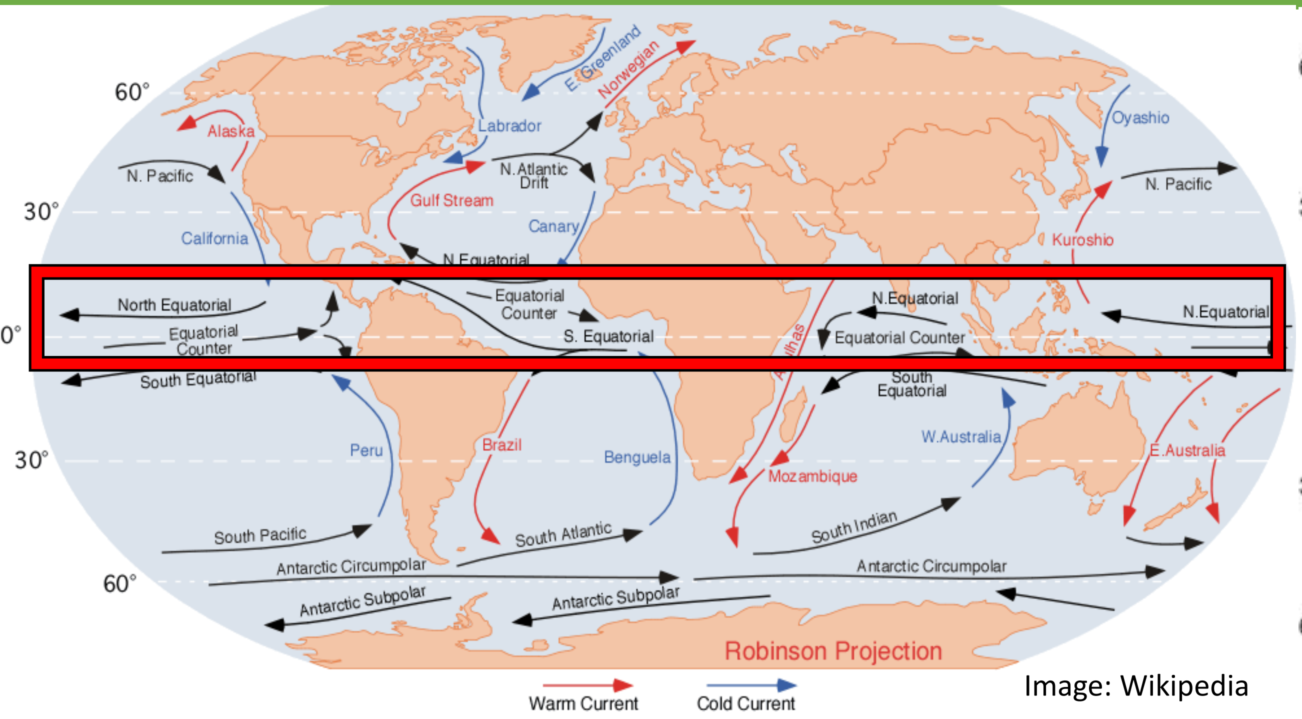
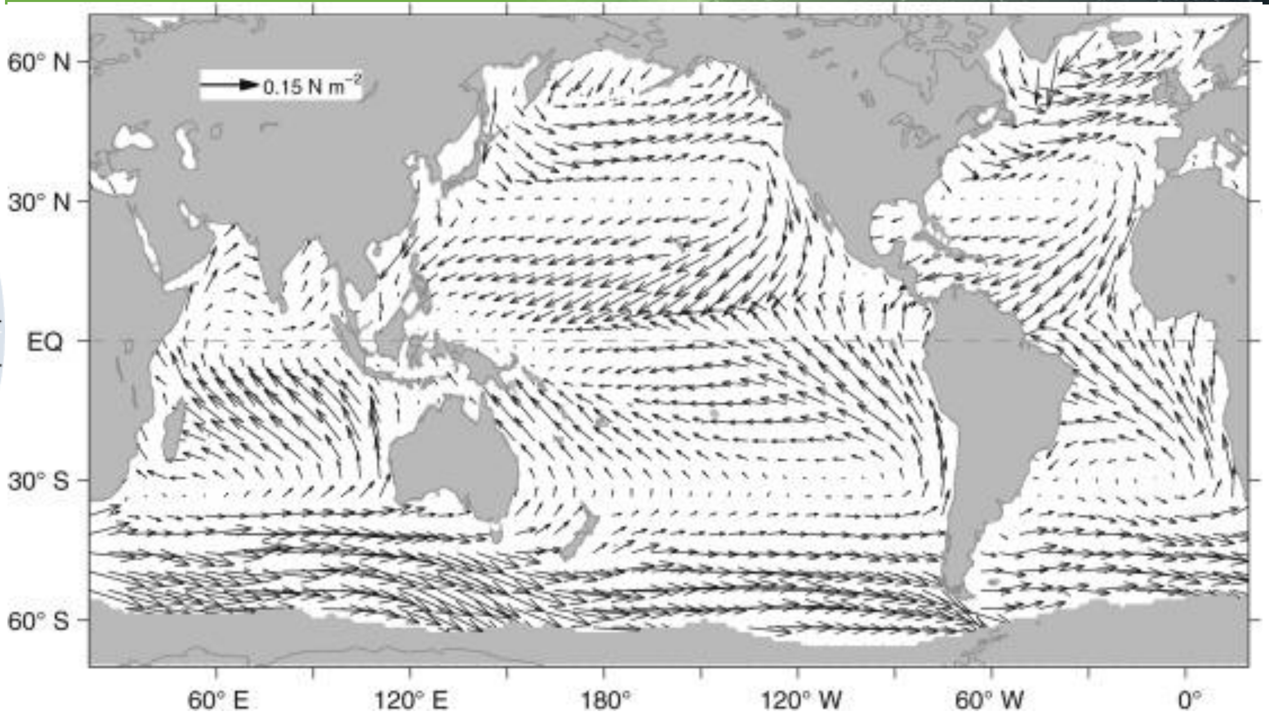


Image: Wikipedia



A **counter example** is the **Equatorial Counter Current** which flows in the **opposite direction of the wind**. It may be intuitive to imagine that the winds are dragging water forward (apart from equator), *but the actual physics are much more complicated.*

The global map of wind-driven ocean circulations. **Most wind-driven ocean circulations flow in the same direction of the winds.**

Geography of Wind-Driven Circulation – Ocean Gyres

In general, the wind-driven circulations are "curled" at mid-latitude, also called Ocean Gyres.

An **Ocean Gyre** is composed of **warm** and **cold** currents.

If it flows **poleward**, it is a **warm current** that *transports heat from South to North*.

A **cold current** flows **equatorward** and transport cold water towards lower latitudes. The net effect is *excessive heat being carried from North to South*.

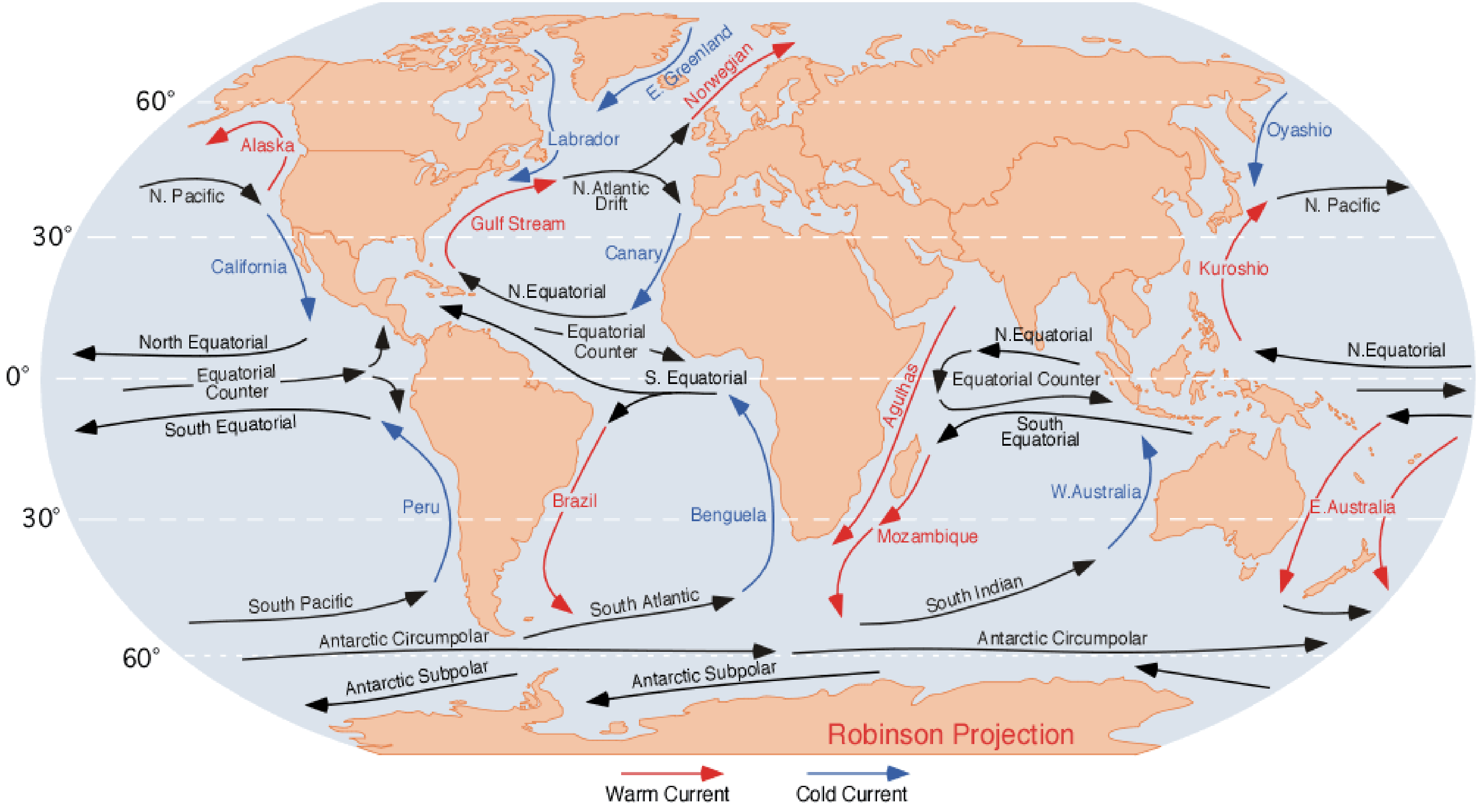
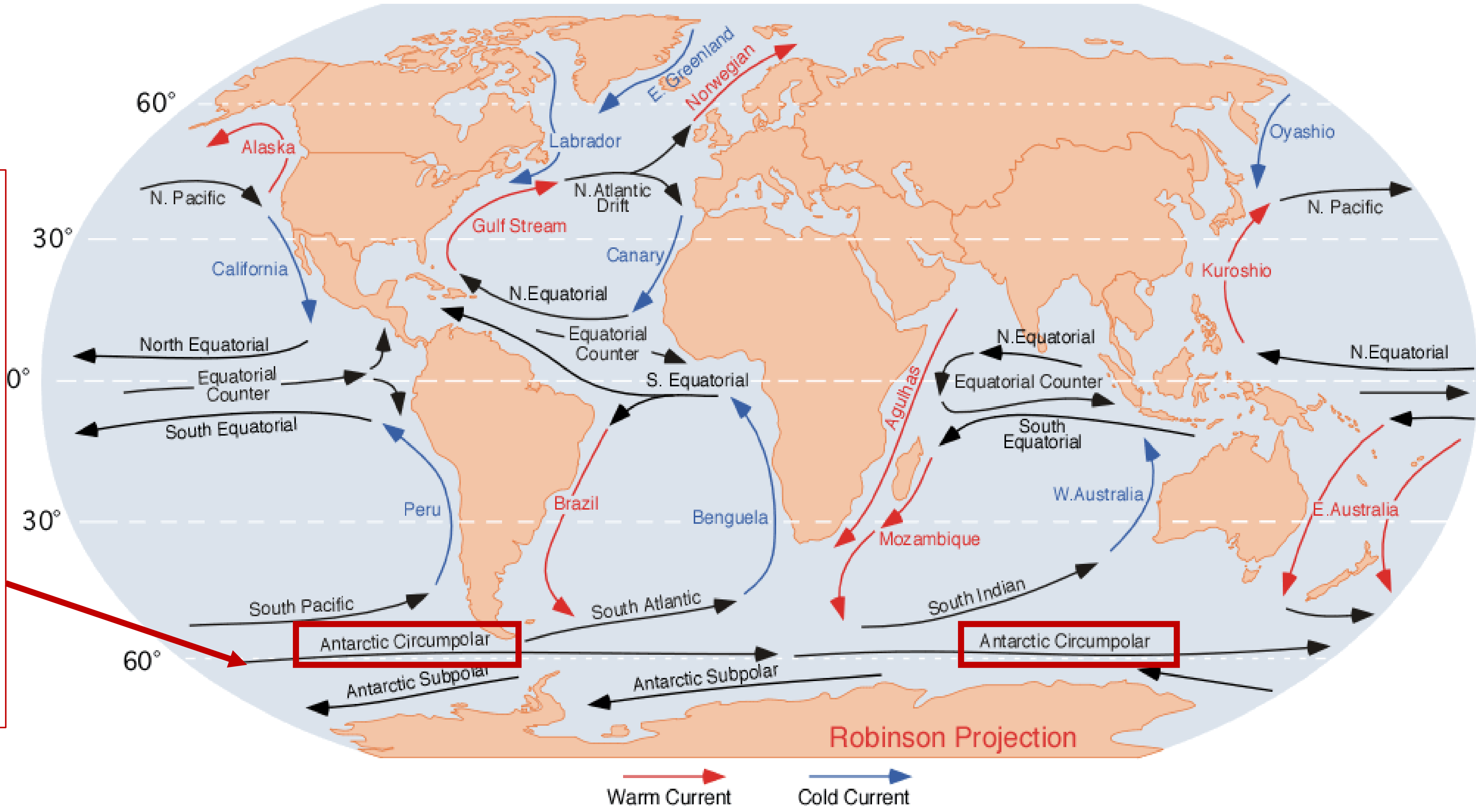


Image: Wikipedia

Antarctic Circumpolar Current (ACC)

An ocean current that flows **clockwise from West to East around Antarctica**.

The ACC is the typical path for the **Southern Ocean**, which is different from other oceans.



From Wikipedia

Questions – What Creates Oceanic Flows?

1) **What creates Oceanic Flows?**

- Wind-driven Circulation: Surface winds push surface water
- Ocean Gyres: Looping wind-driven circulation because it is blocked by continental land
- Circumpolar Current: Wind-driven circulation not blocked by land that circulates around the globe

2) **How do Ocean Gyres adjust heat distribution of the ocean?**

Via warm/cold currents.

The previous segment does not tell us the influence of the ocean's physical properties to the ocean circulation, which are rather crucial.

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The Ocean
– Temperature, Salinity & Stratification

Temperature, Salinity & Stratification

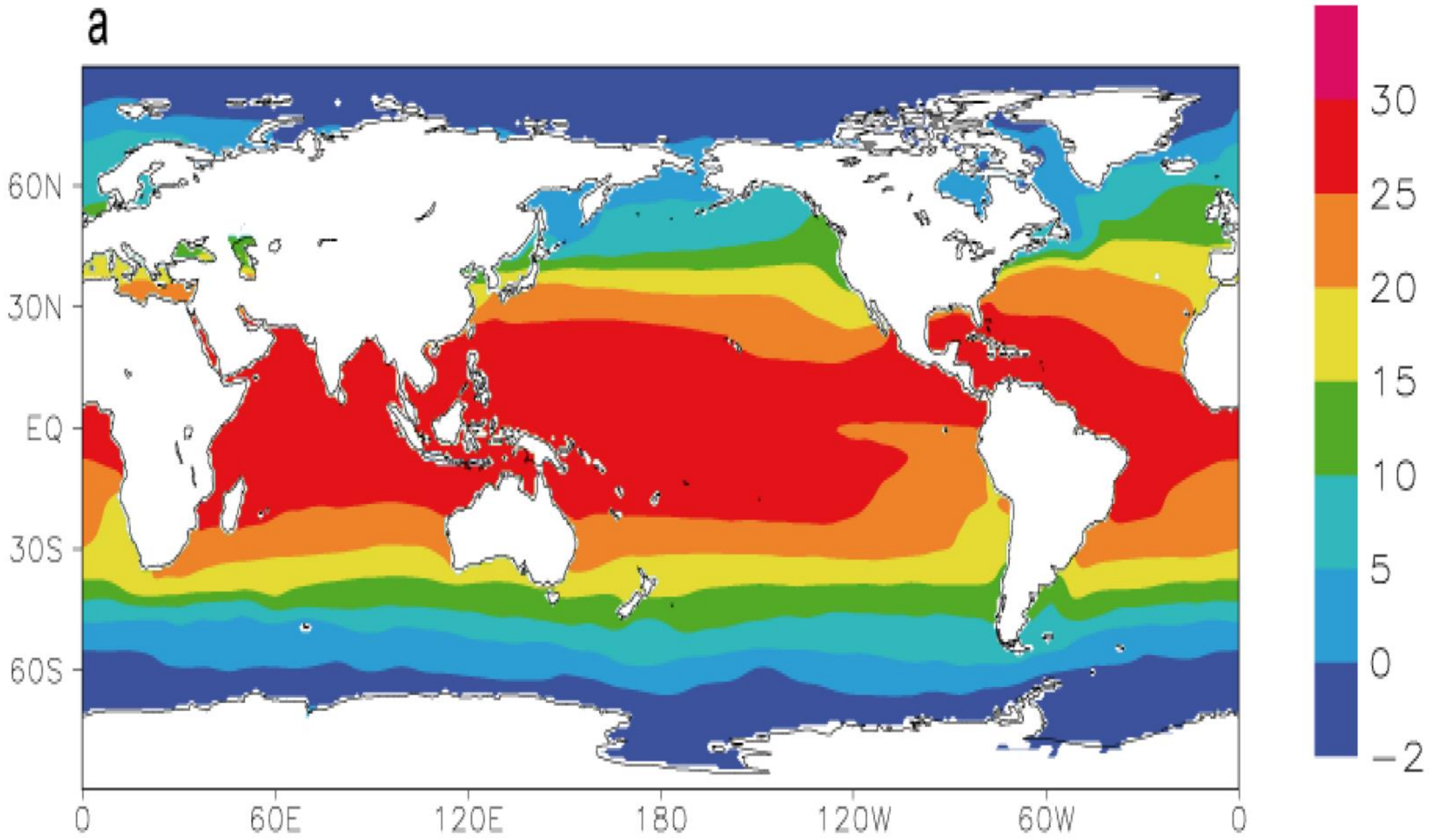
KEY TERMS

- Sea Surface Temperature (SST)
- Sea Surface Salinity (SSS)
- Ocean Temperature
- Ocean Salinity
- Ocean Density

Stratification: Ocean Stratification occurs when ***water with different properties*** such as salinity, density and temperature form ***layers***, which act as ***barrier for water mixing***.

The Sea Surface Temperature (SST)

- **Sea Surface Temperature (SST) decreases from low latitude to high latitude**. This pattern is quite **zonal** (i.e. changes little with longitude).
- The SST pattern can be easily understood via the distribution of solar radiation: **equatorial regions receives much more heat than polar areas.**

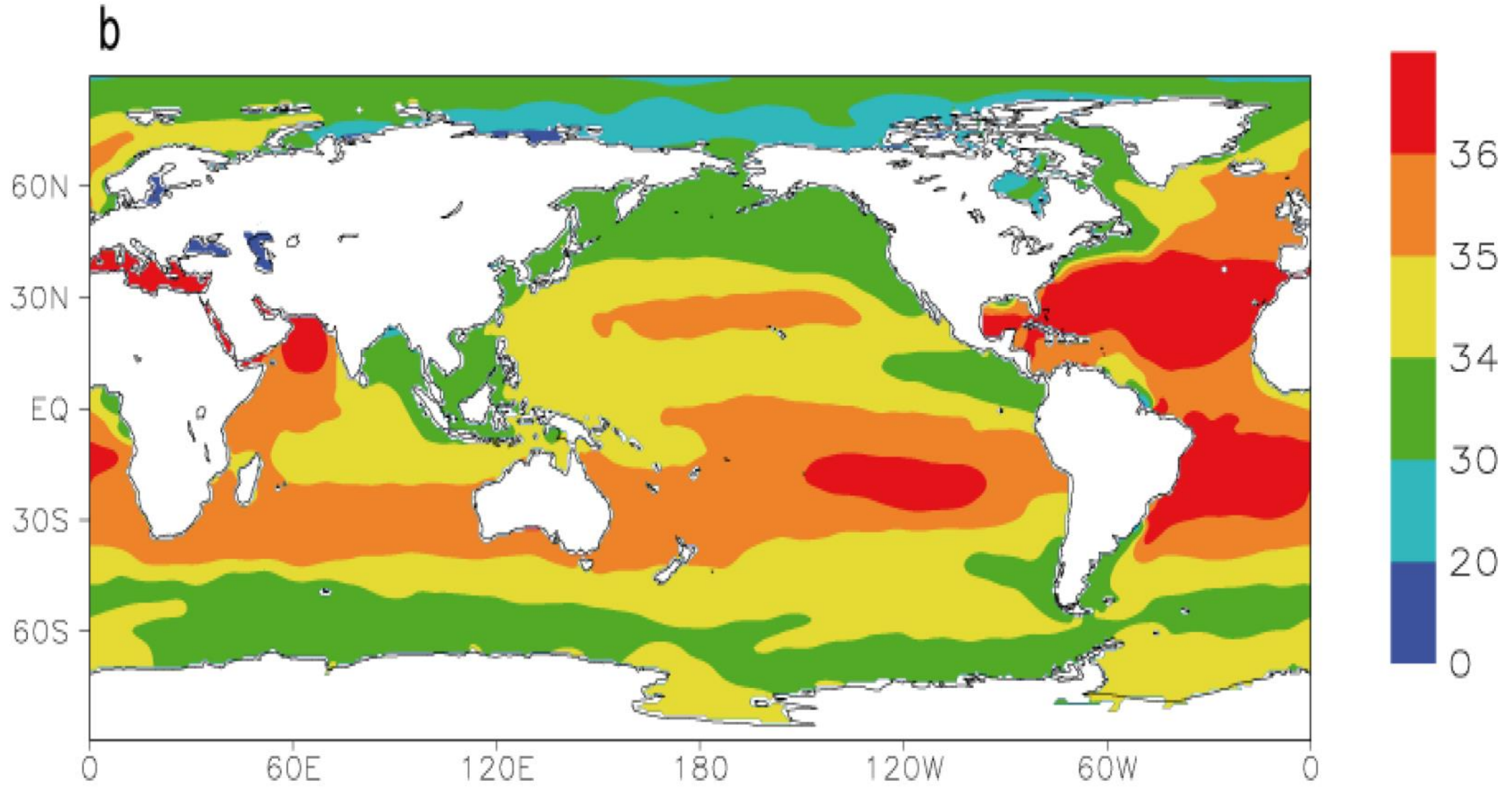


Mean Sea Surface Temperature

Image: www.climate.be

The Sea Surface Salinity (SSS)

- The **Sea Surface Salinity (SSS)** measures **how much salt the ocean contains at surface spatially**.
- The **saltiest** regions are mainly in the **subtropical** areas. These are also where **deserts** are formed on land.
- Over most of the ocean the only **surface flux of salt** are due to **precipitation and evaporation.**
- In **polar** regions there are also **substantial salt fluxes** due to **sea ice freezing and melting**.



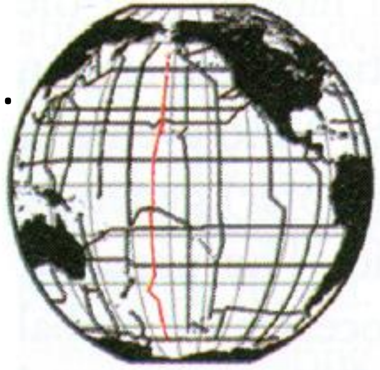
Mean Sea Surface Salinity

Image: www.climate.be

The Ocean Temperature

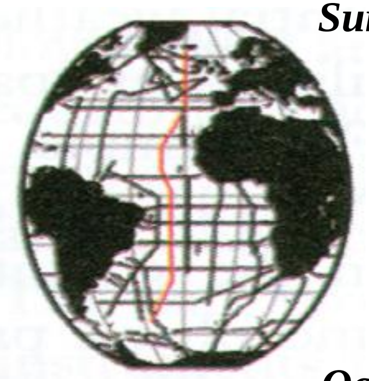
The Ocean Temperature appears to be **bowl-shaped** along a depth/meridional transect, ***decreasing*** **from the equator towards the poles** and **from the surface towards the depth,** regardless of which ocean basin we focus on.

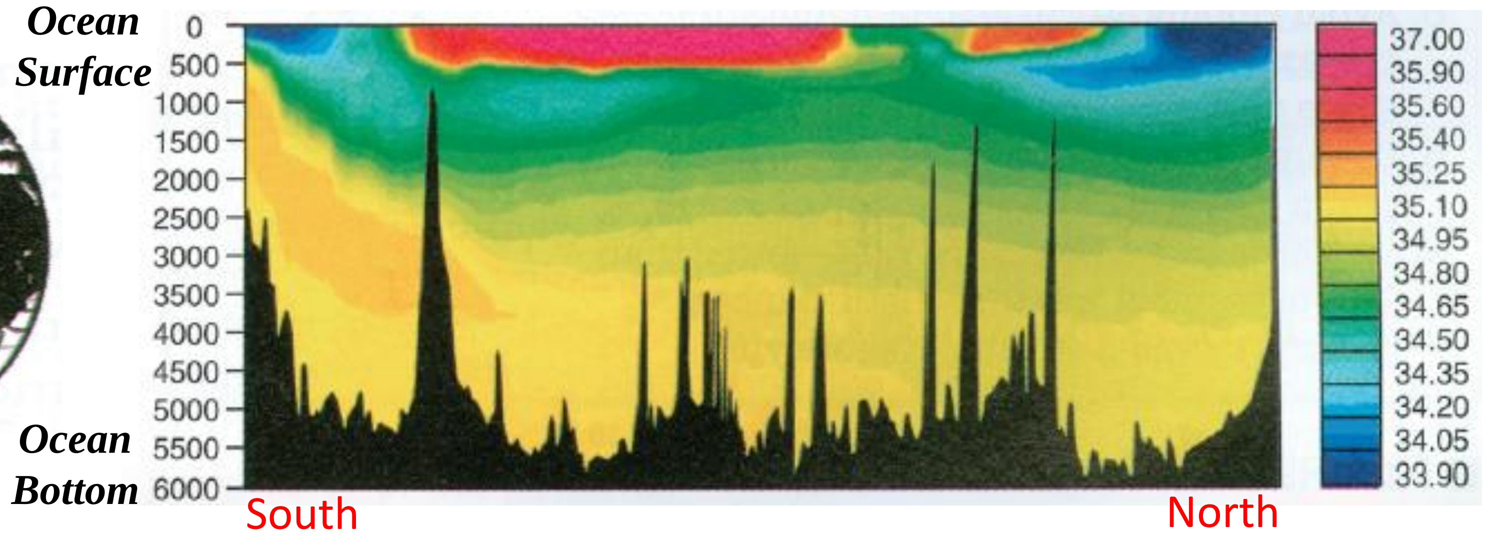
Image: A. L. Stewart



The Ocean Salinity

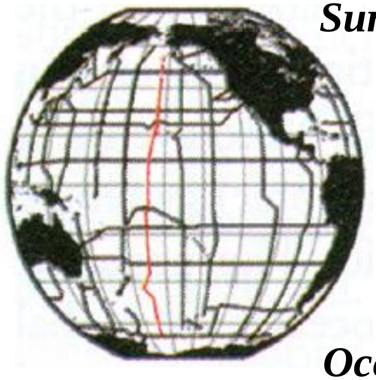
The Ocean Salinity shares **a similar "bowl shape" with ocean temperature** along a depth/meridional transect.

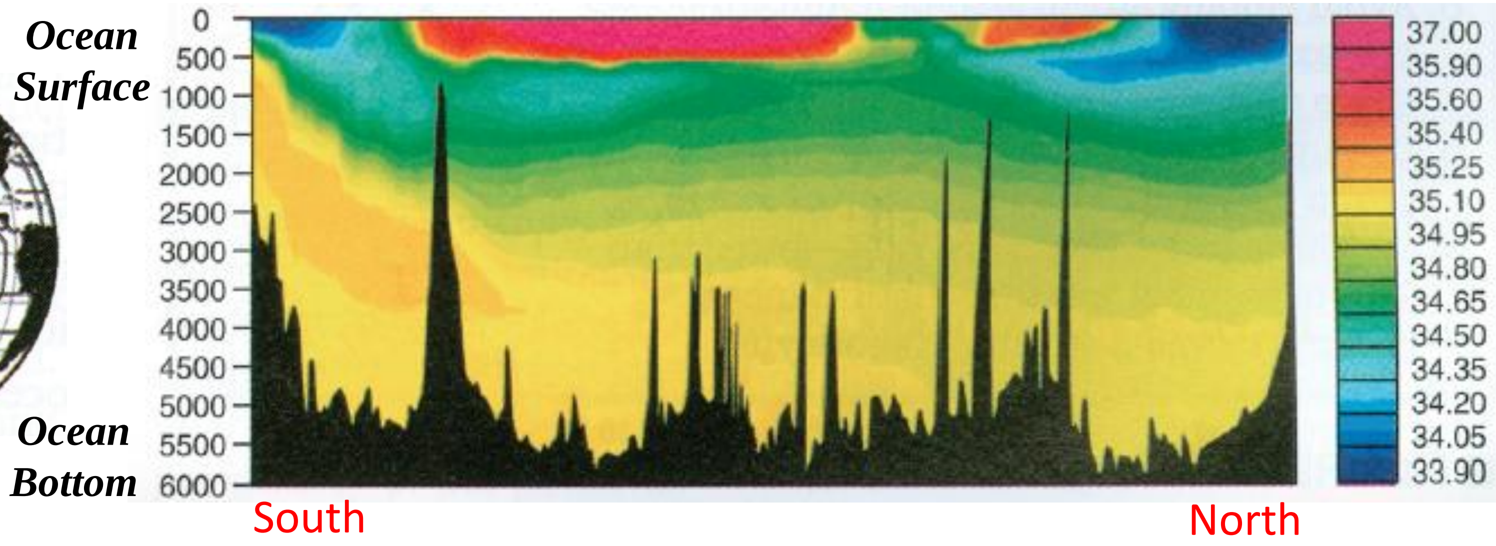




The **saltiest** part is, however, located in the **subtropical** regions.

Salinity **decreases from surface to 1500m-2000m** then **increases again below 1500m-2000m**





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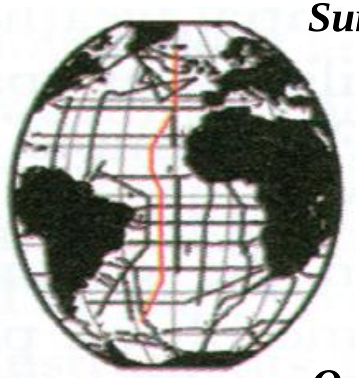

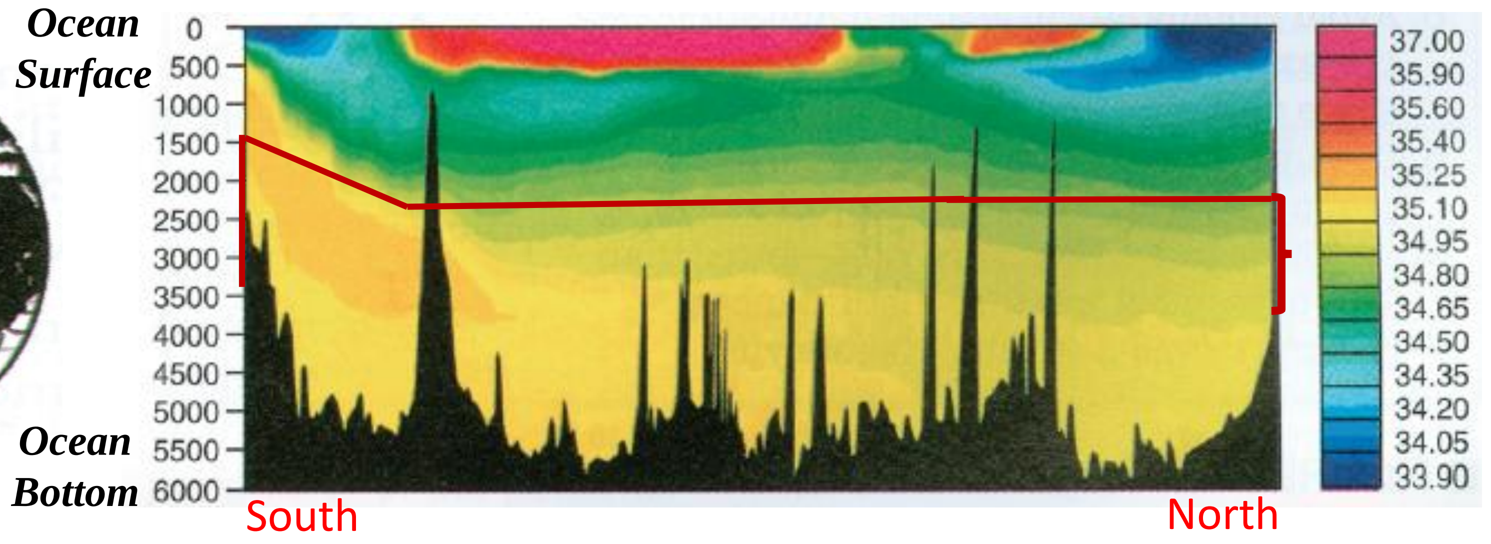

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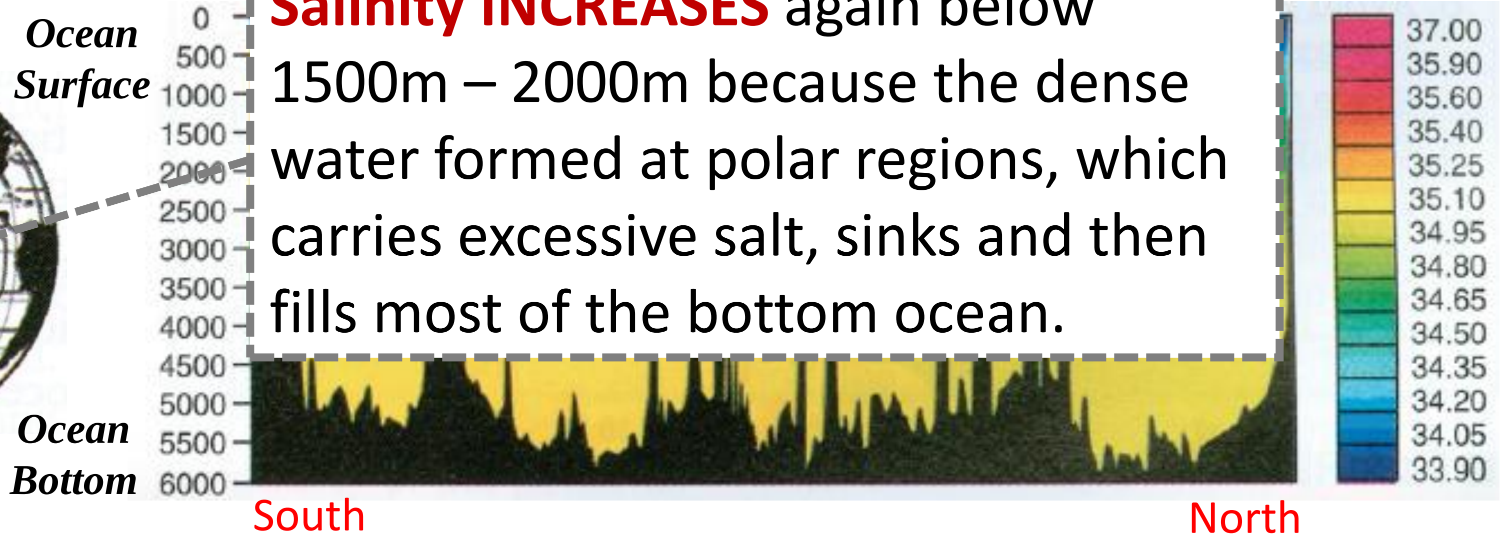
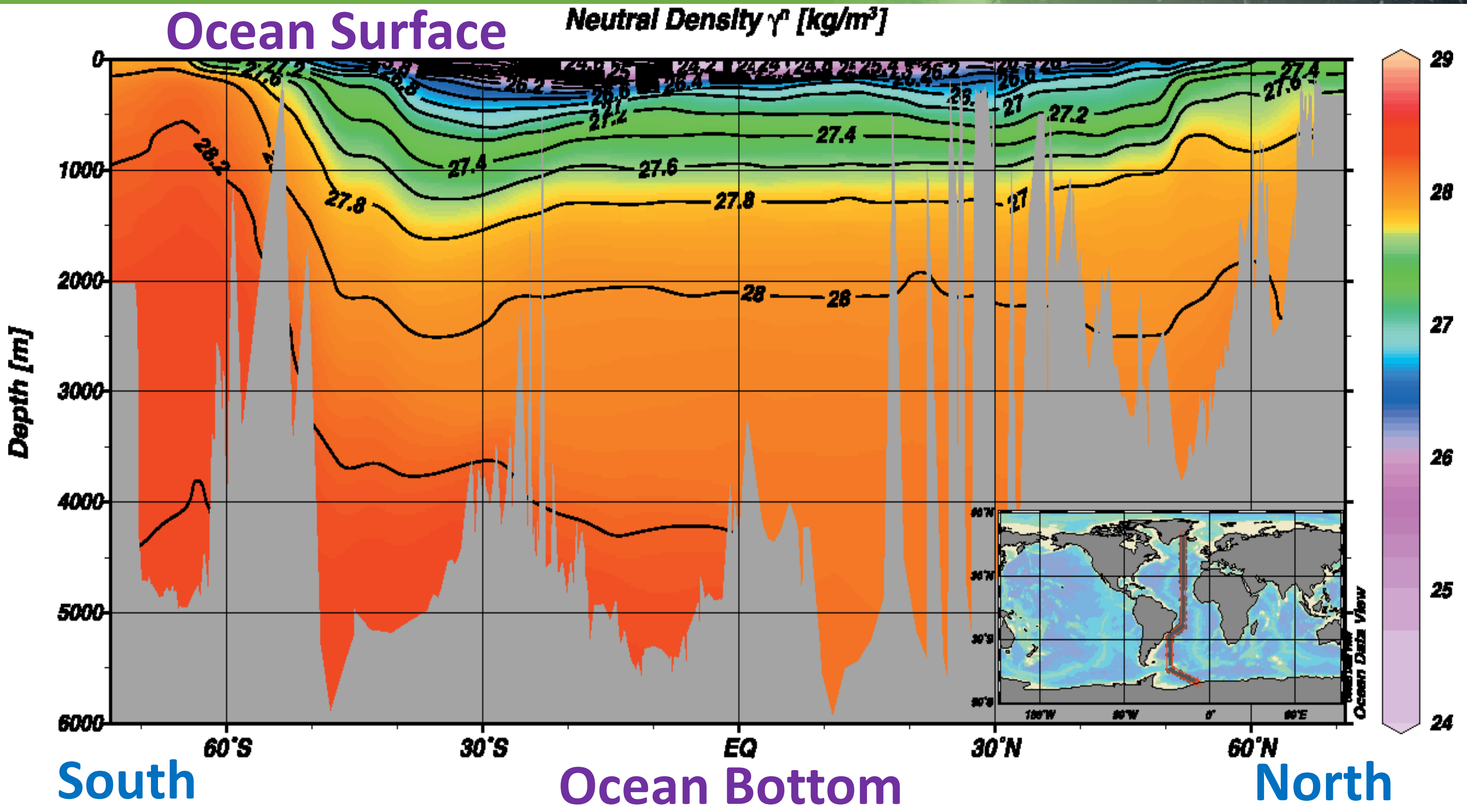


Salinity INCREASES again below 1500m – 2000m because the dense water formed at polar regions, which carries excessive salt, sinks and then fills most of the bottom ocean.

The Ocean Density

- The Ocean Density is **determined by both temperature and salinity**, and thus shares the bowl-shaped pattern along a depth/meridional transect.
- The density **increases towards high latitude and deeper ocean.**
- The **Ocean Stratification** refers to the **stacked-layer structures of the ocean properties**.
  - In the **ocean interior**, the temperature and salinity (thus the stratification) are **rather stable.**



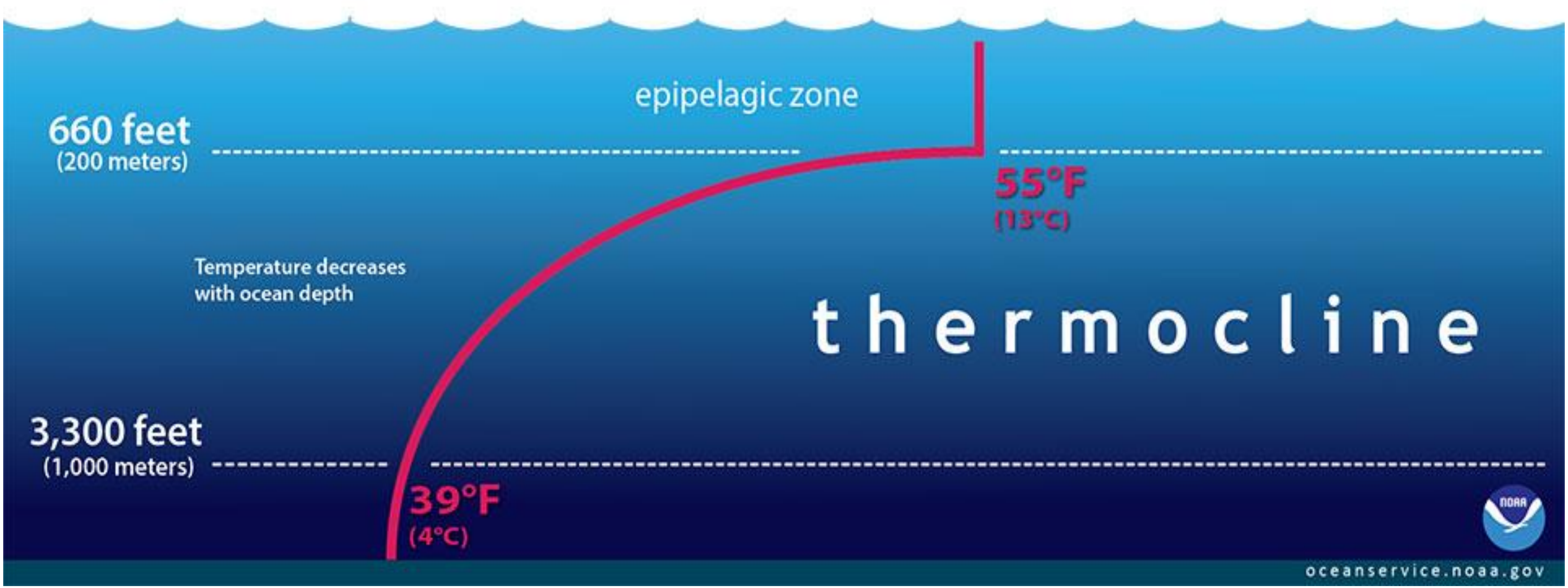
Summary – Ocean Temperature, Salinity & Stratification

- Temperature decreases from the equator towards poles, and from surface towards bottom.

- Salinity peaks at surface subtropical regions, and decreases towards poles and the ocean bottom.

- Both temperature and salinity exhibit zonal patterns at sea surface, and bowl-shaped structures.

- **Stratification** – the layered structures of oceanic properties.



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Impacts of Stratification on Oceanic Flows

Impacts of Stratification on Oceanic Flows

KEY TERMS

- **Ocean Subduction**
  - **Seawater sliding from surface ocean to deeper ocean**
  - **Bowl-shaped**

Wind-Driven Ocean Circulation in 2D

Ocean currents are not only on the surface, it *runs deeper* than what the map can show.

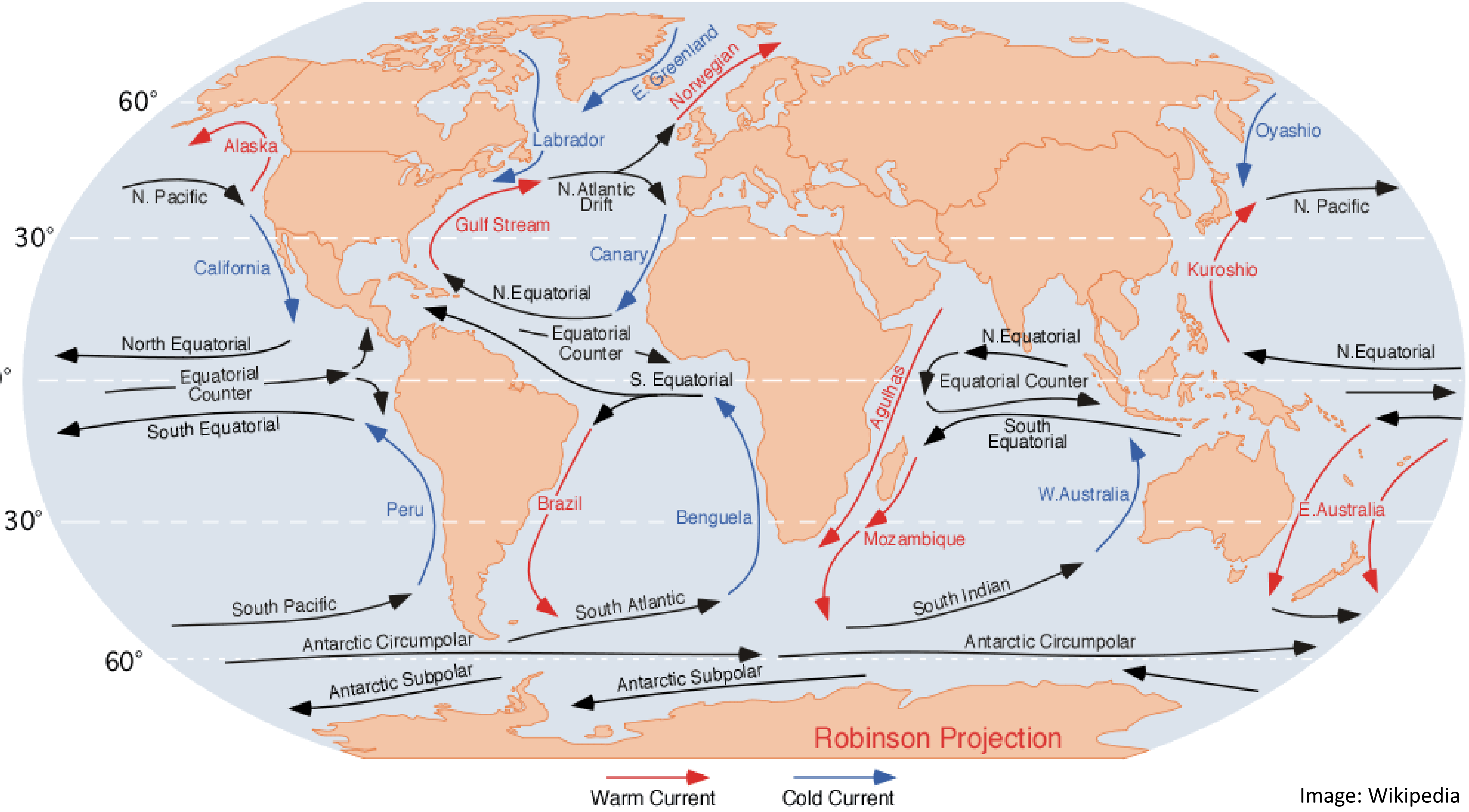
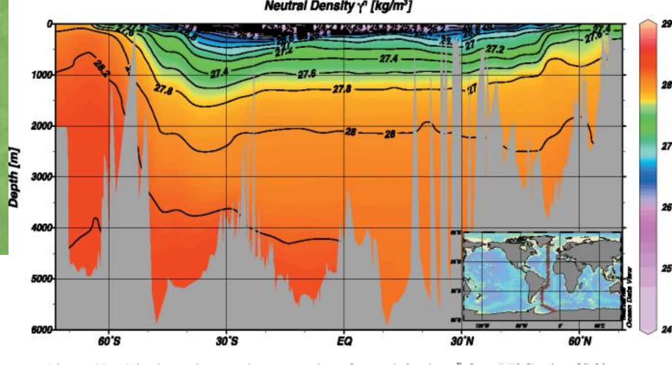


Image: Wikipedia

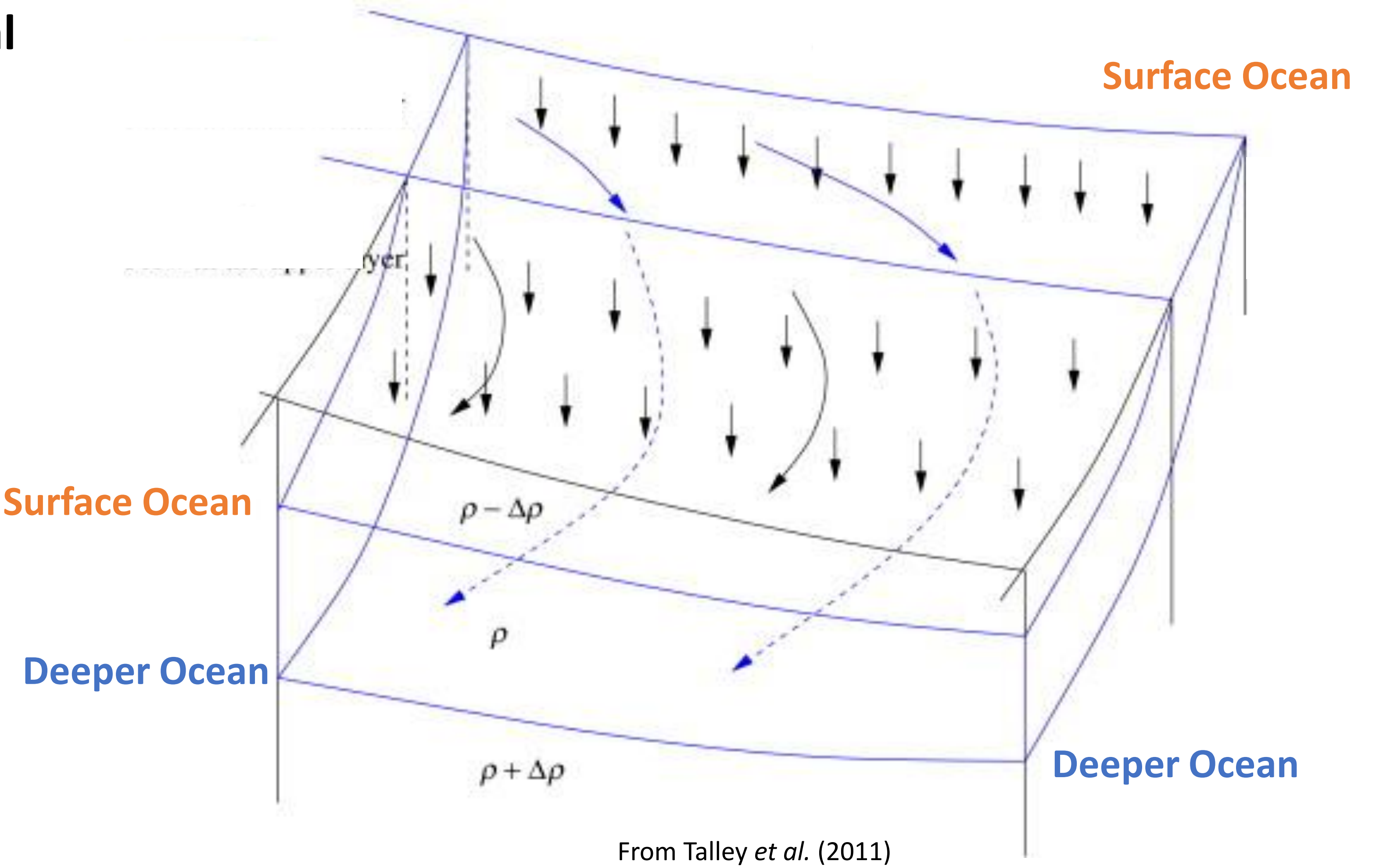
The Ocean Gyre in 3D



A more realistic illustration of the ocean gyre.

Seawater tends to maintain its thermal dynamic properties in the ocean.

- **Ocean currents** do not stay on constant depths, but rather **slide down the "bowl" of ocean density**.
- **Subduction pumps dissolved carbon from the atmosphere into the ocean interior**, and has important **climatological implications**.

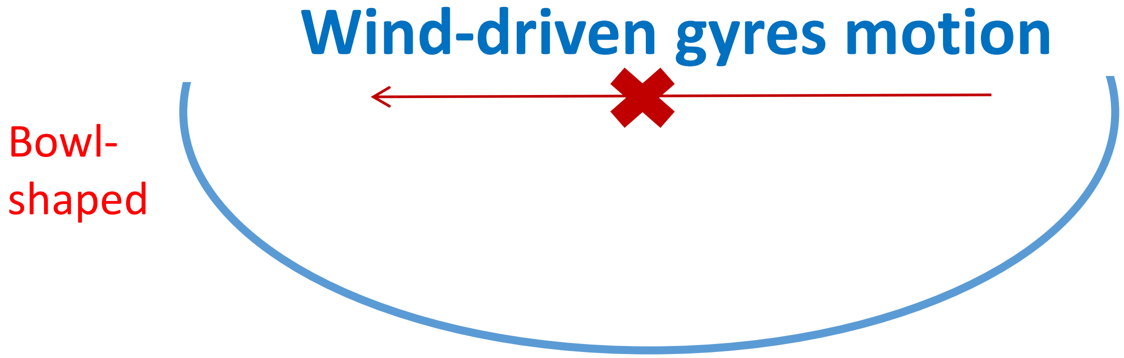


From Talley *et al.* (2011)

Question

What is the impact of Ocean Stratification to Wind-driven Gyres?

- **(1) Ocean Stratification:** Sea water mainly follows **constant density surfaces**, rather than constant depths.
- **(2) Ocean Subduction:** Wind-driven Gyres actually run deeper **by sliding down** the bowl of ocean density



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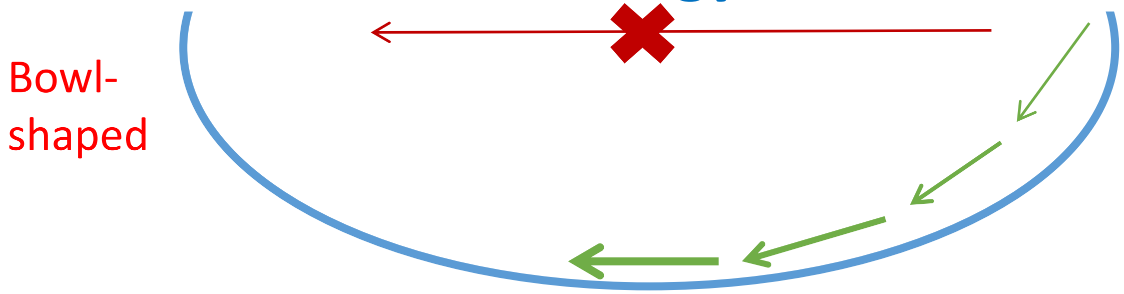
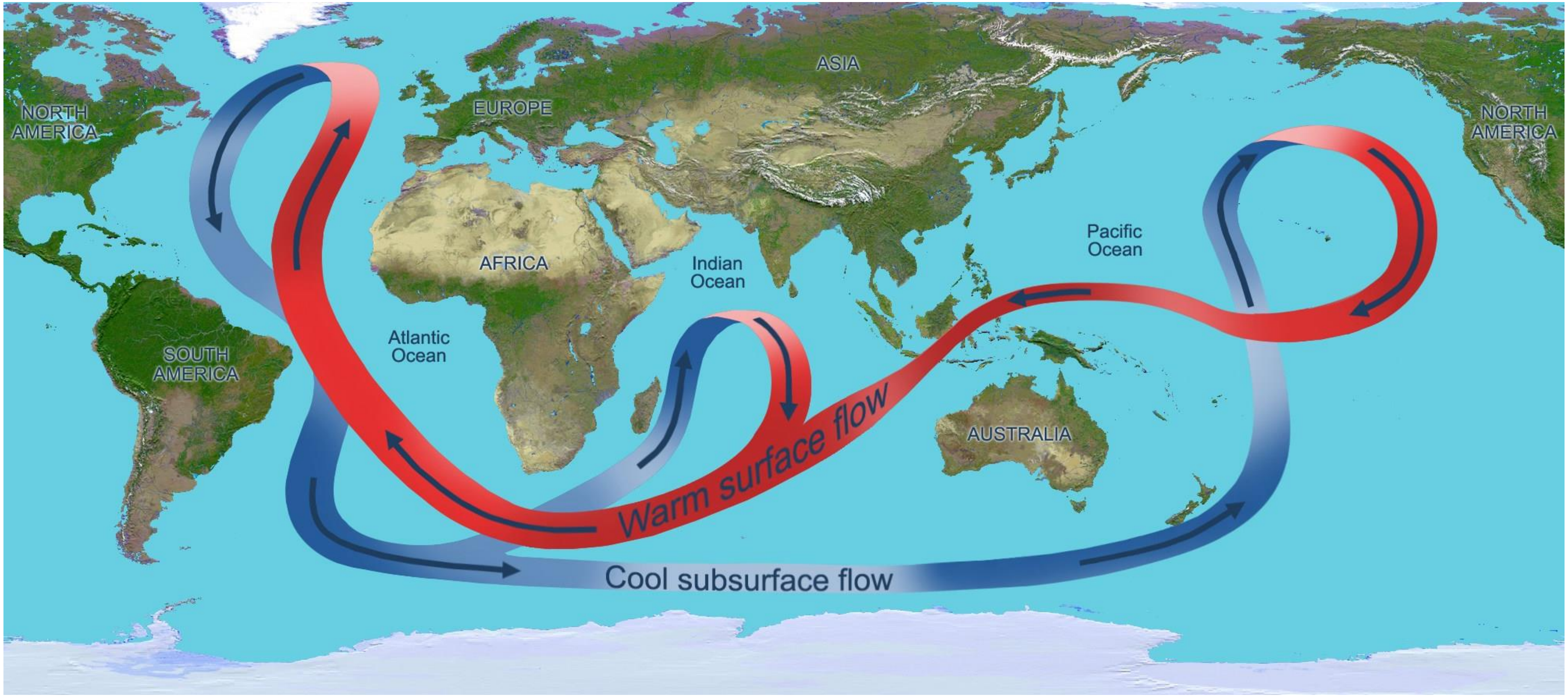
Wind-driven gyres motion





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The Overturning Circulation – Where and How Water Sinks

Where and How does Water Sink?

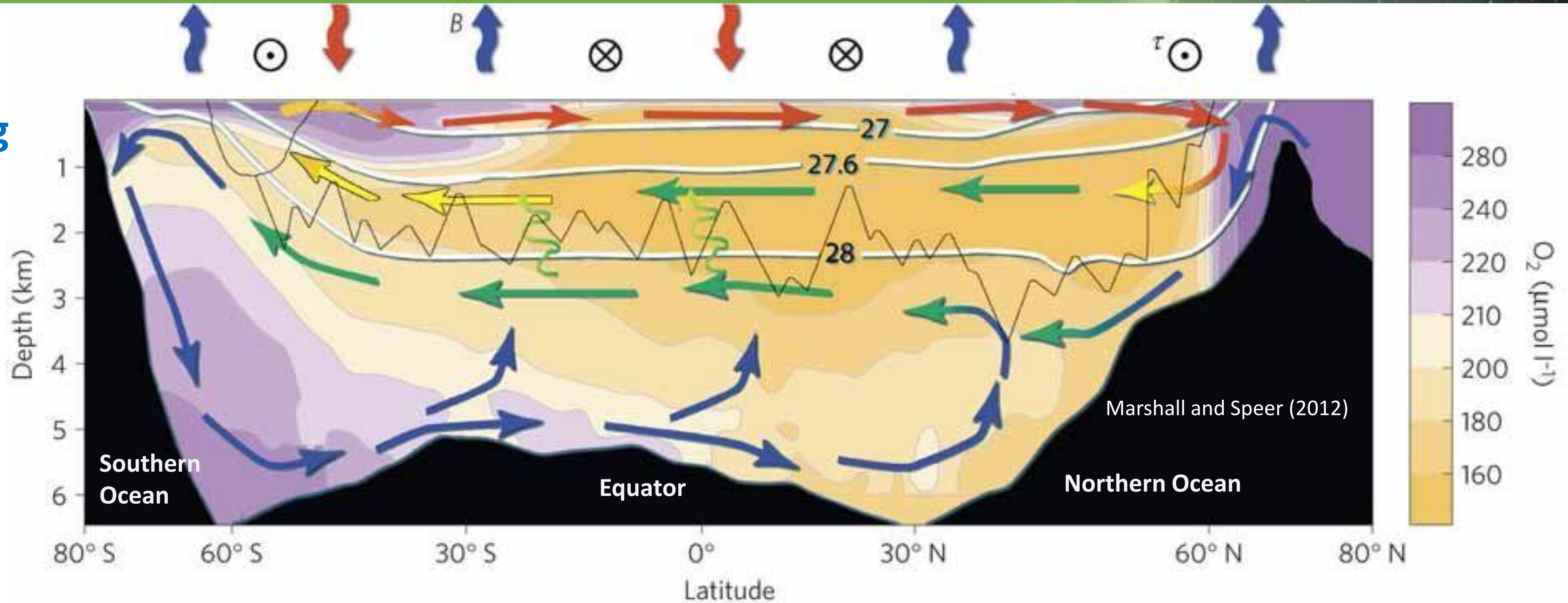
- What is **Overturning Circulation**?
- Where does water **sink**?
- Formation of the **North Atlantic Deep Water**
- Formation of the **Antarctic Bottom Water**

Wind-Driven Circulation vs Overturning Circulation

Wind-driven Circulation	Overturning Circulation
Upper Ocean	**Surface and Deeper Ocean**
More horizontal – Confined by upper density surfaces up to 2,000 m	**More vertical** – Penetrates and connects upper surface ocean to deep ocean bottom (4,000 m depth)
Driven by **wind**	Driven by **air-sea heat exchange** and by **salt input** via ice formation
Transports **warm/cold water** towards colder/warmer parts of the Earth	Transports **water, heat, salt, carbon dioxide, nutrients** to deep sea

The Overturning – Another Way of Subduction

Global Overturning (2D)

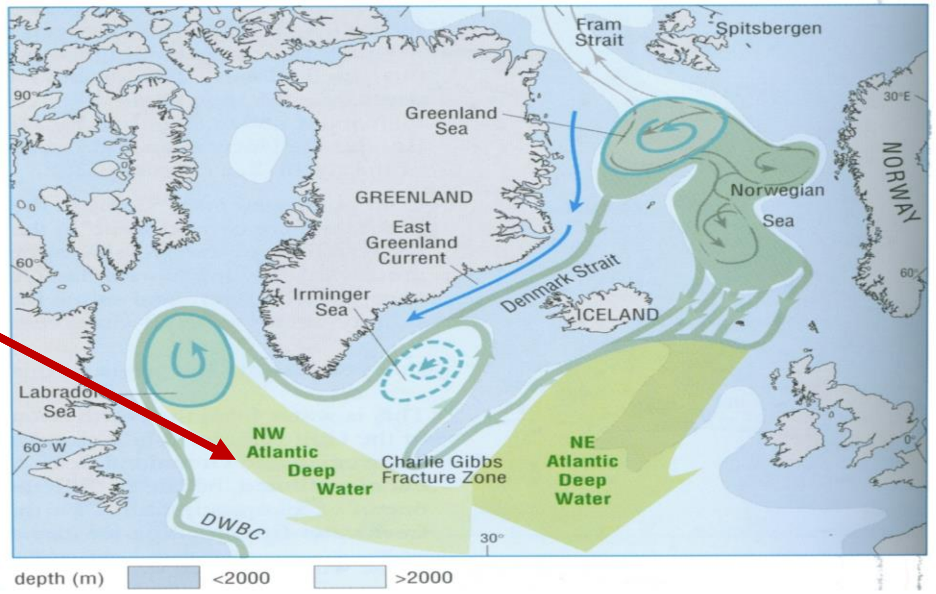


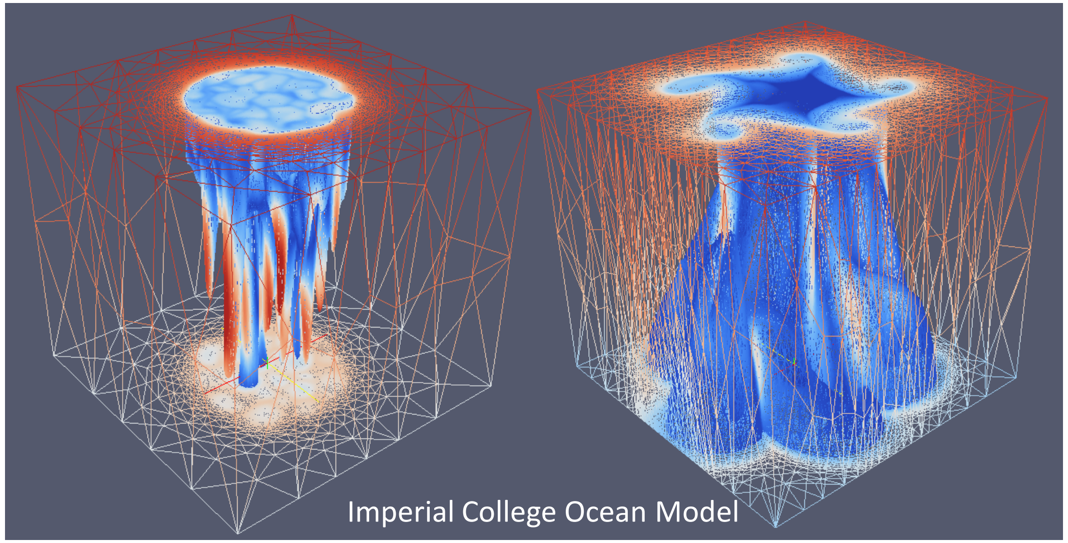
The existence of a global scale overturning circulation has been well established by scientists, and adopted in Hollywood movies (e.g. *The Day After Tomorrow*). It differs from the ocean gyres in that **surface wind is not always a deterministic factor driving the motion**.

Formation of the North Atlantic Deep Water

North Atlantic Deep Water formation

- Mainly driven by **cold air**
- Mainly occurs **away from the coast**
- Cold water **sinks** to deeper level because it is **denser** (higher in salinity)





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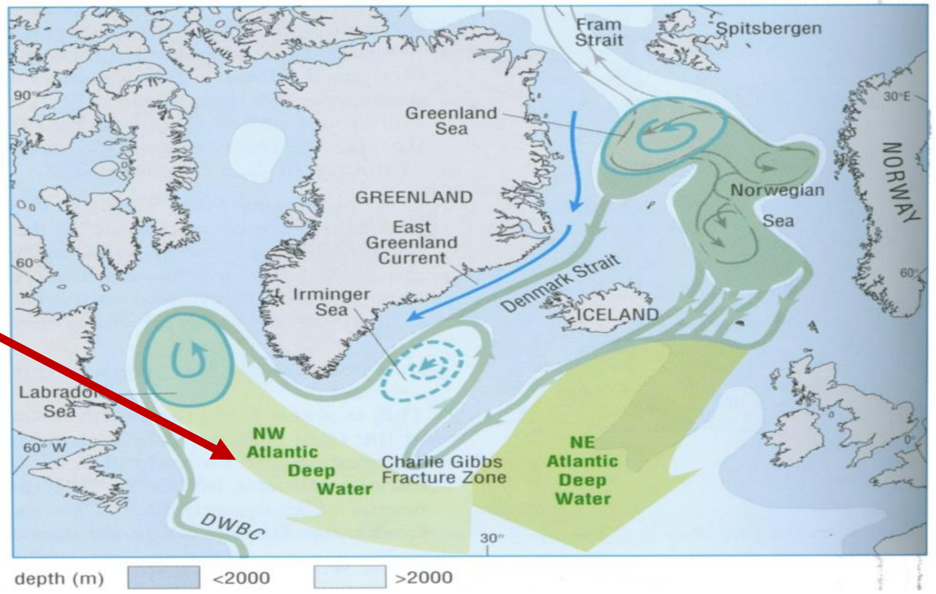

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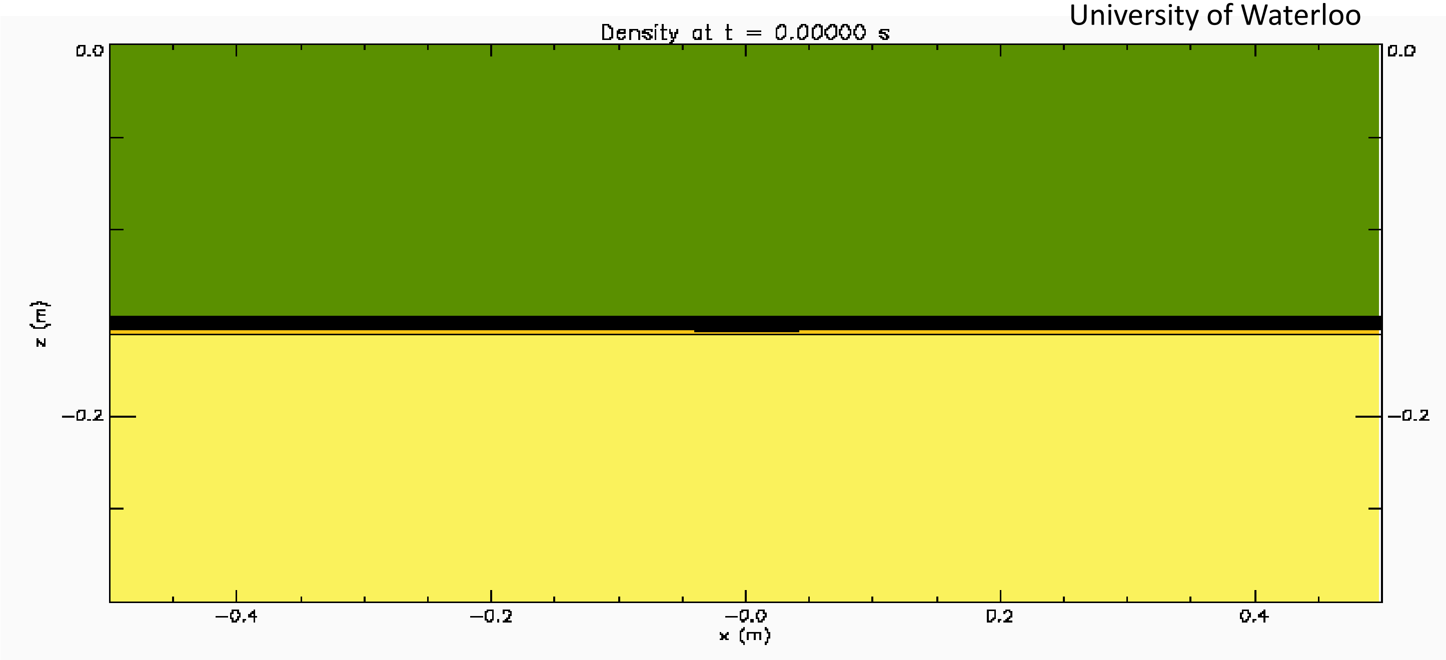
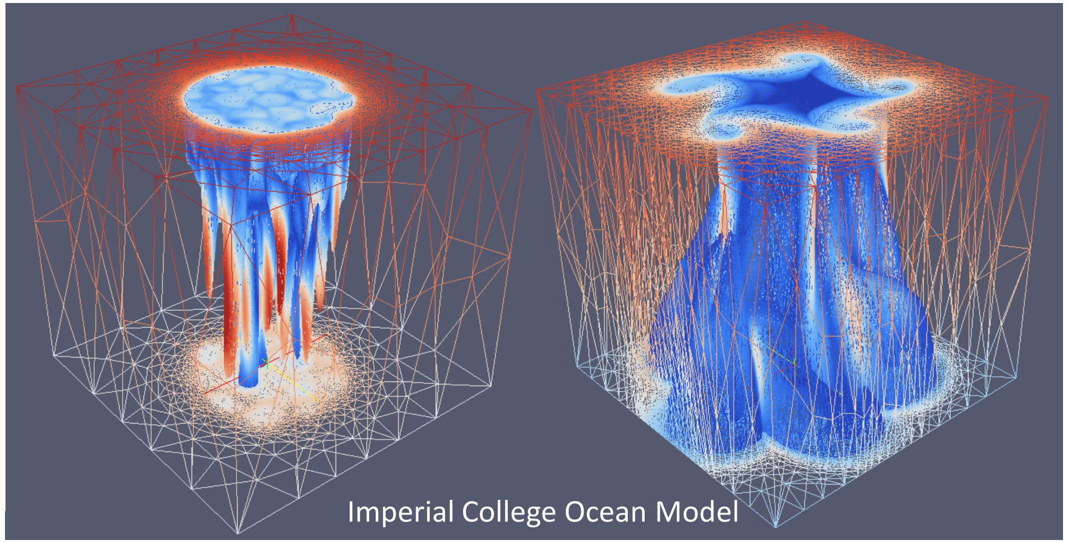


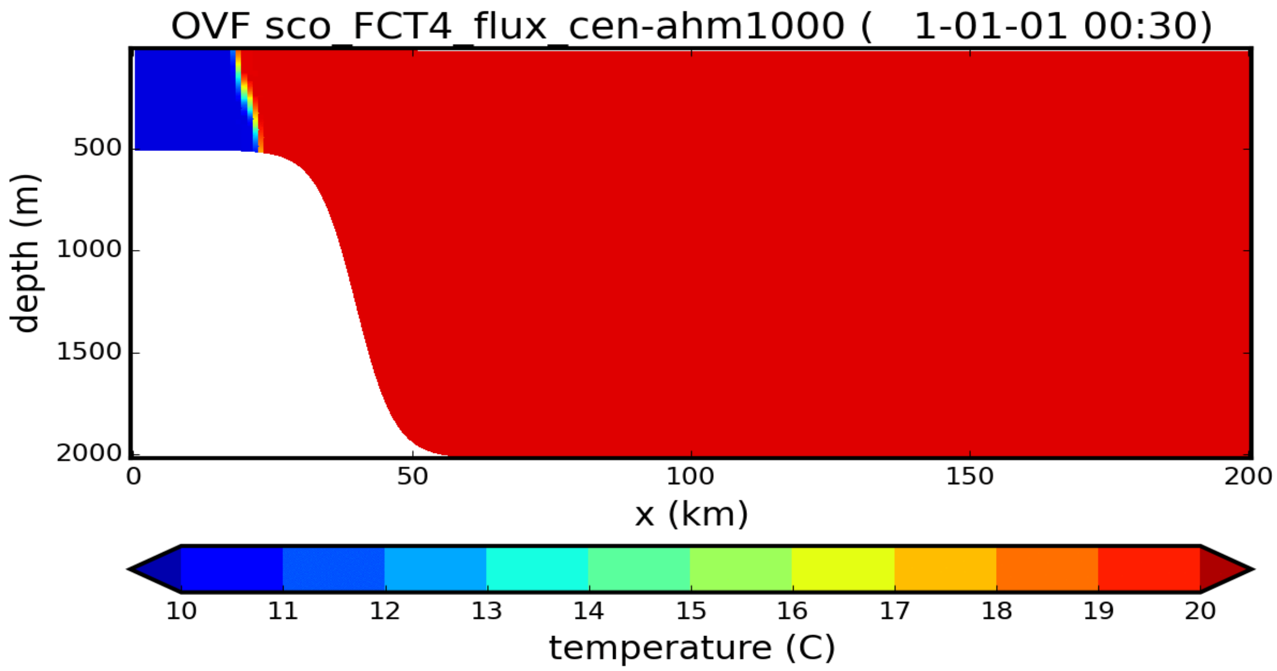


Imperial College Ocean Model

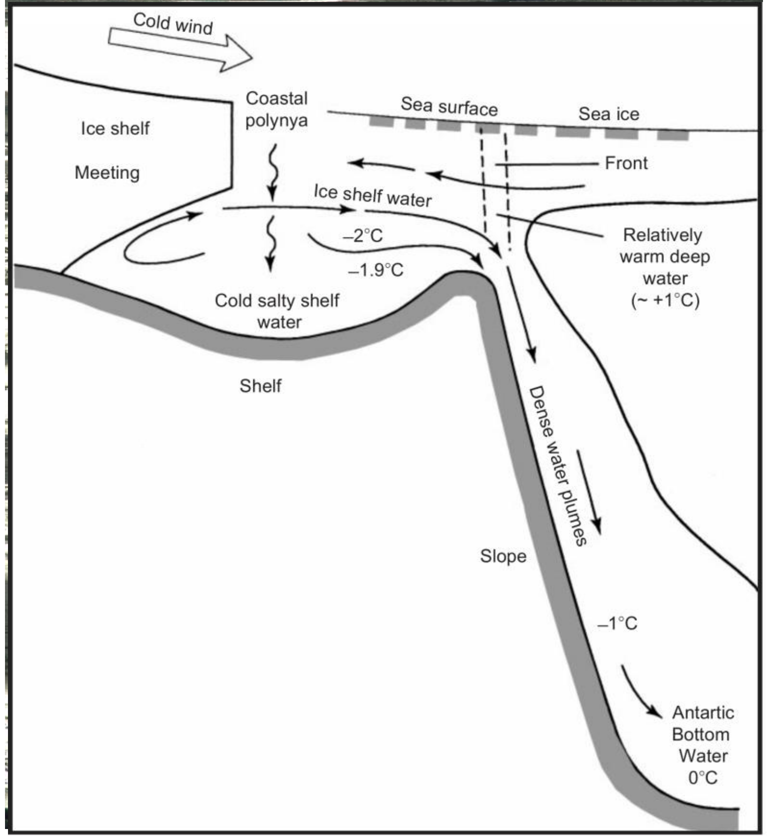
Formation of the Antarctic Bottom Water

Antarctic Bottom Water formation

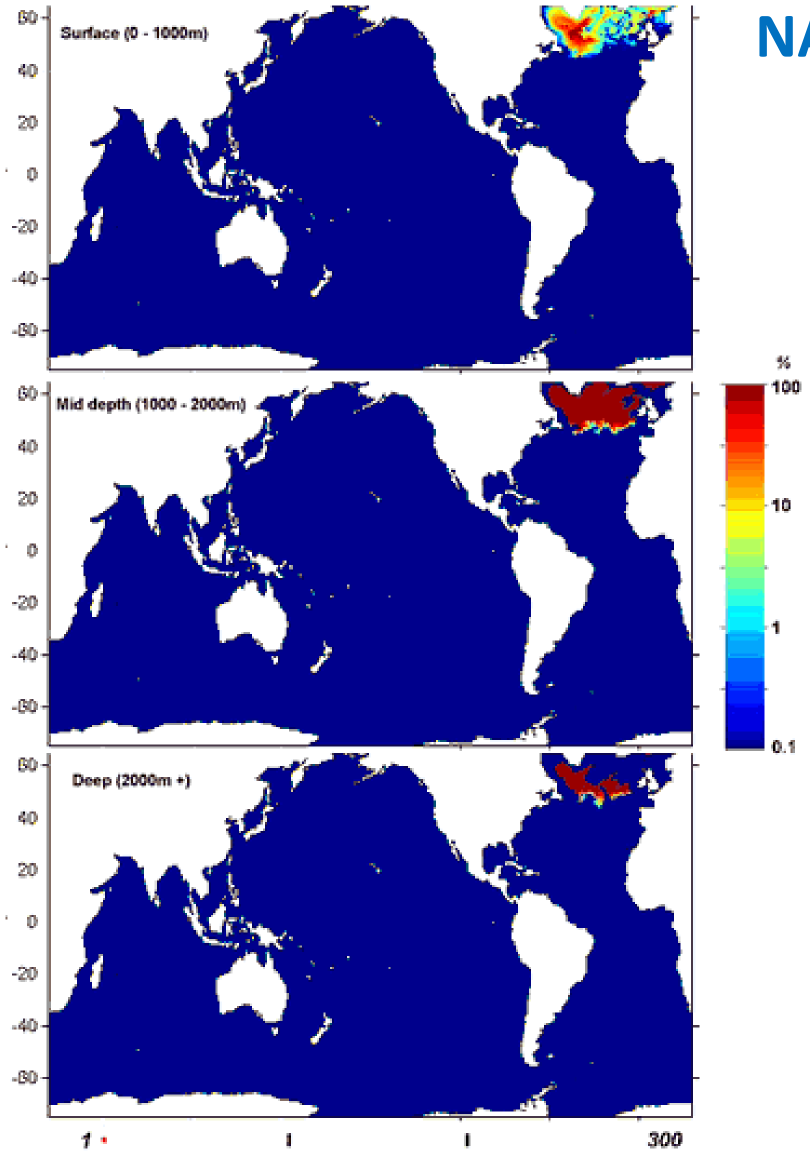
- **Similar to that of the North Atlantic Deep Water**
- Mainly occurs **along the coast**
- Cold water **moves along the coast** and stays at the **bottom**



Animation: NEMO docs



Spreading of NADW (left) and AABW (right)



NADW

0-1 km

1-2 km

> 2 km

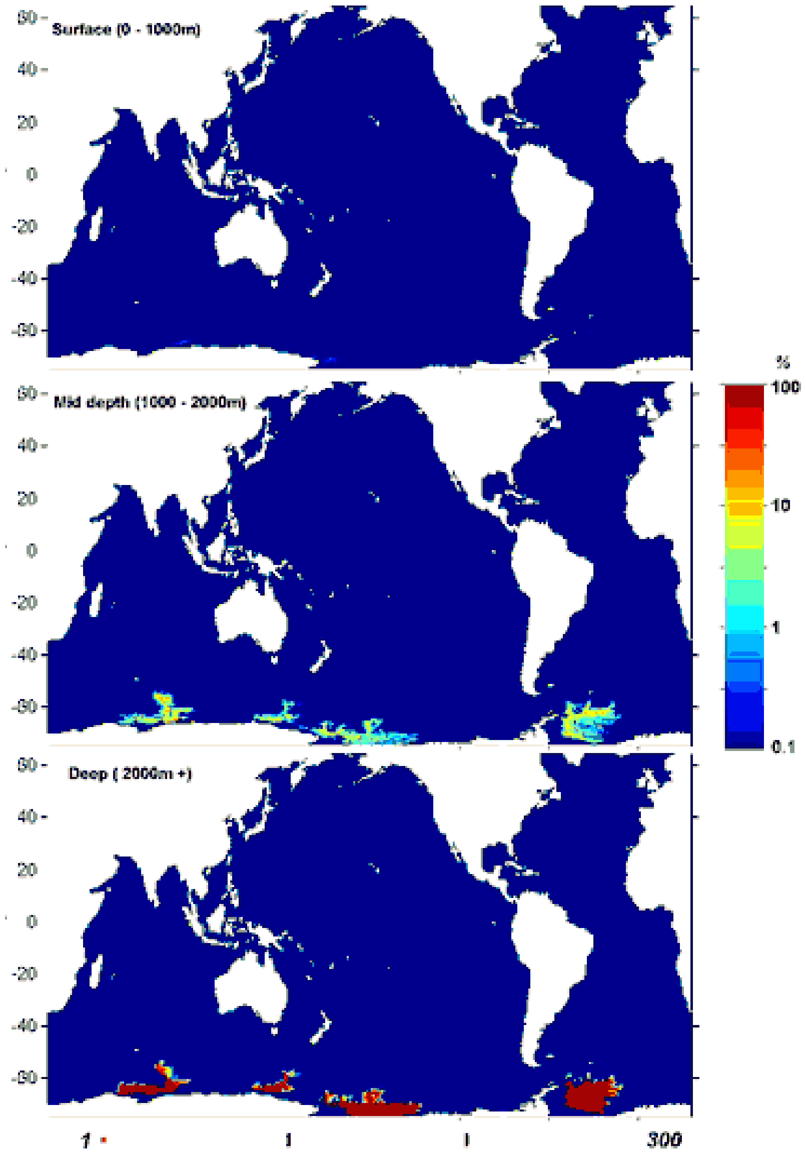
AABW

0-1 km

1-2 km

> 2 km

From A. S. Gupta (UNSW)



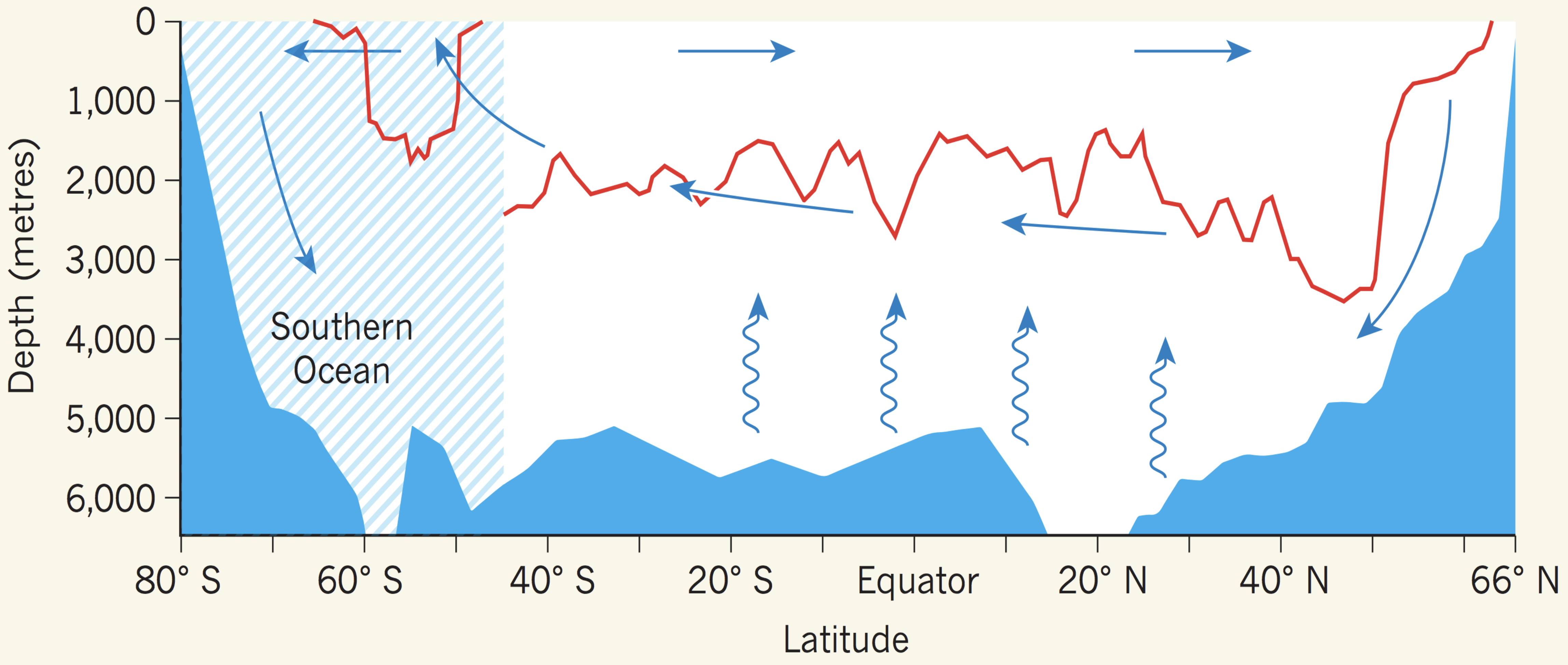
Questions – Where and How does Water Sink in the Ocean?

1) **Where does dense water sink in the global ocean?** Polar regions.

2) **How does water sink?** **The overturning circulation** – Driven by heat, salinity and fresh water with more vertical penetration of water from surface ocean to deep ocean.

3) **Where is the North Atlantic Deep Water formed?** Away from the coast.

4) **Where is the Antarctic Bottom Water formed?** Along the coast.



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The Overturning Circulation – Where and How Water Rises

Where and How does Water Rise?

KEY TERMS

Internal Waves

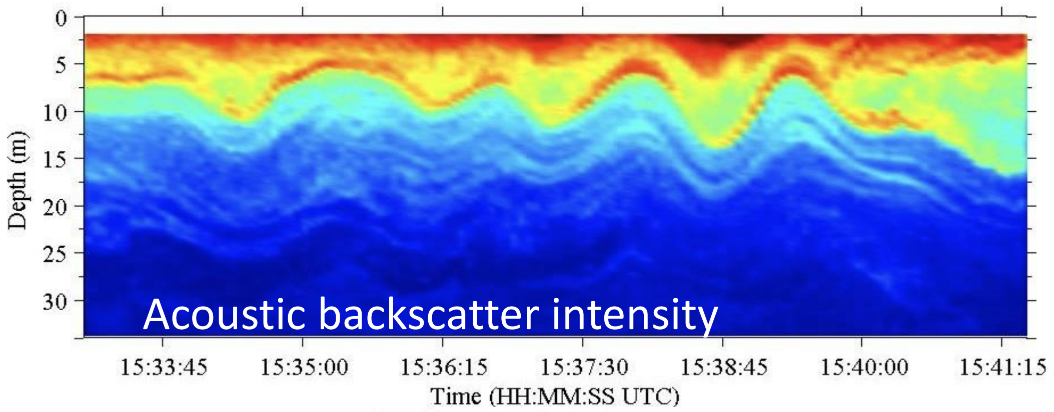
Internal waves and transportation

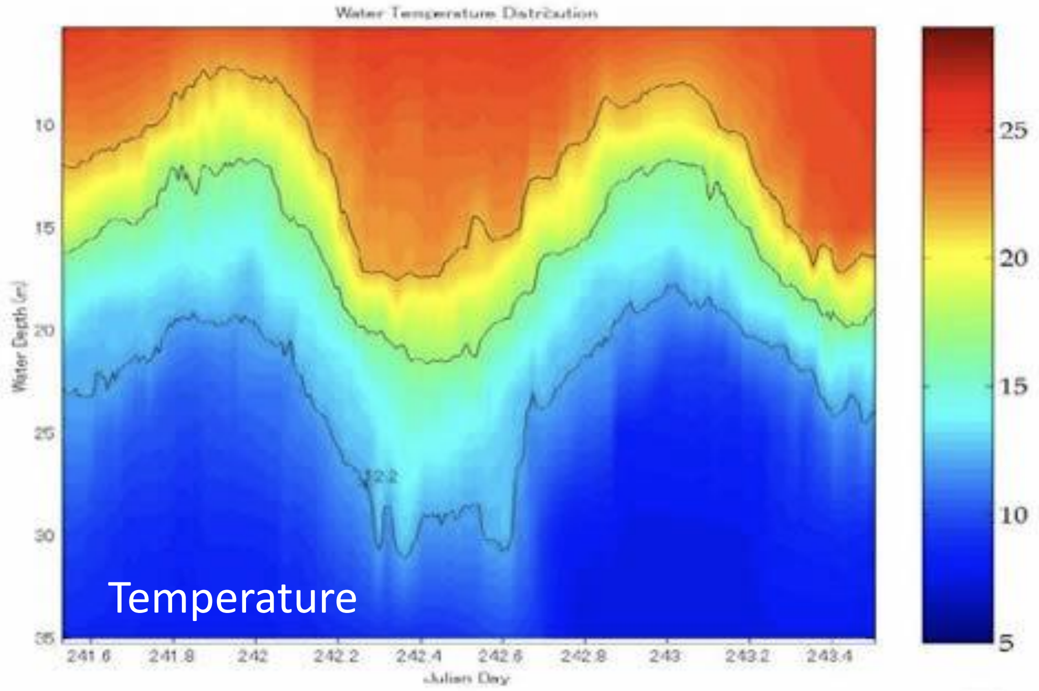
Internal Wave Breaking

Internal Waves – Observation

- **Sensor measurements** of the water column capture **large variations in the depths of density surface** over time.
- Can also be visualized using acoustic backscatter intensity, which indicates the presence of **biological material**.
- **Wave amplitudes** are typically tens of meters, but can reach hundreds of meters.

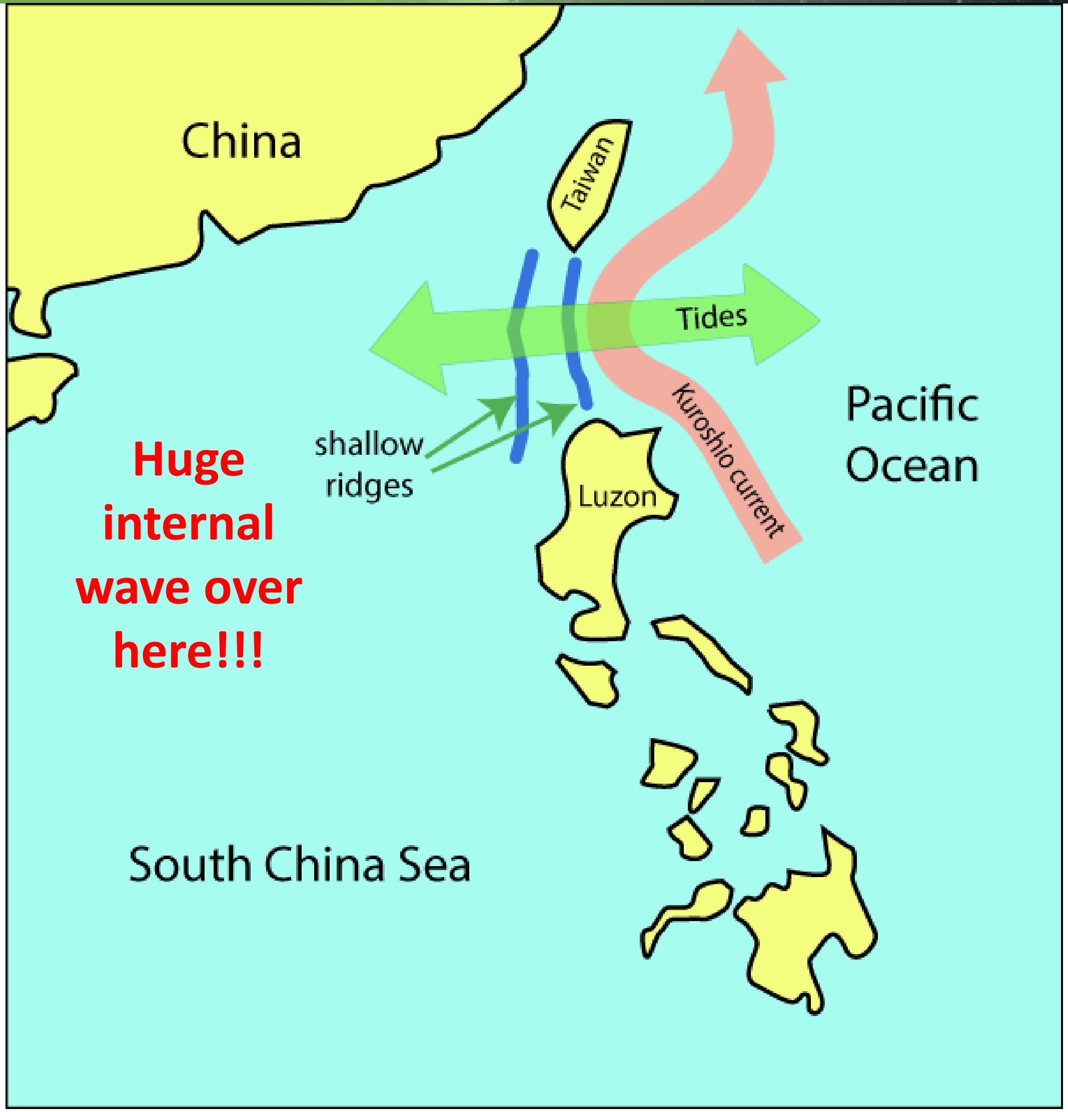
(Much larger than surface waves we observe in Clear Water Bay)





Internal Waves – Propagation

Just as disturbances to the ocean surface can generate surface waves, **daily disturbances to the ocean's density surfaces (e.g. tides)** can generate internal waves.



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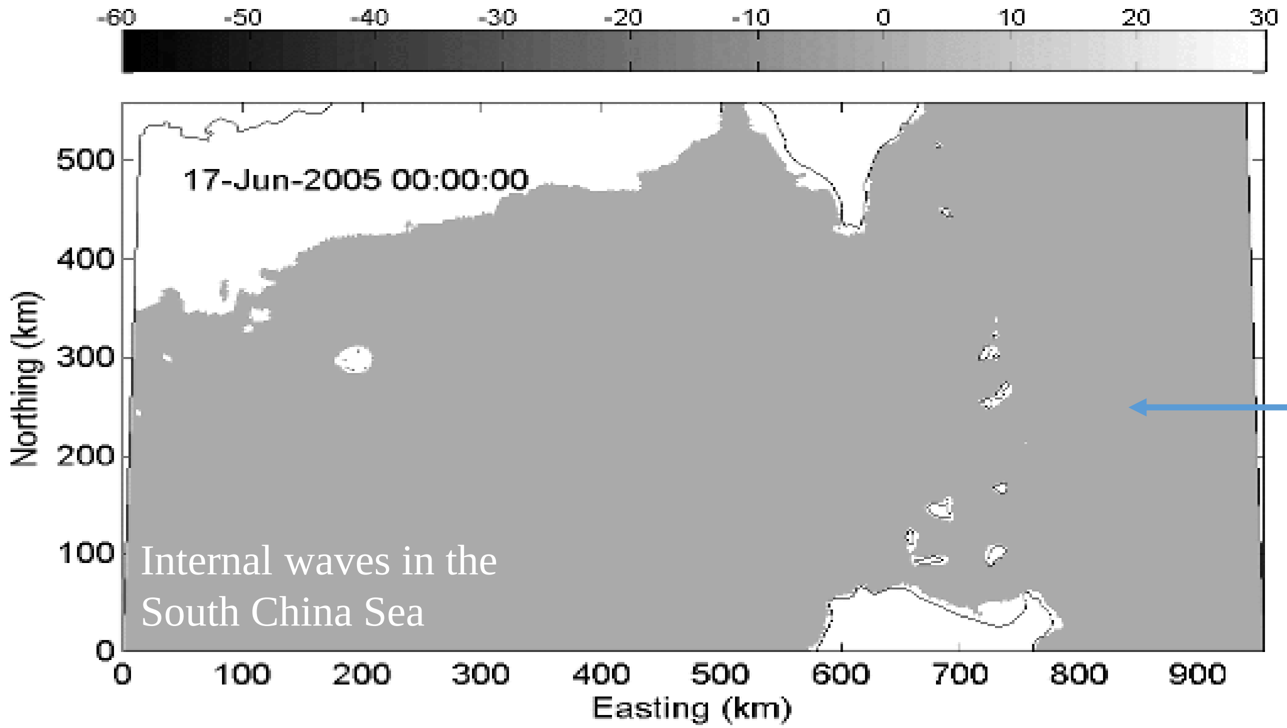
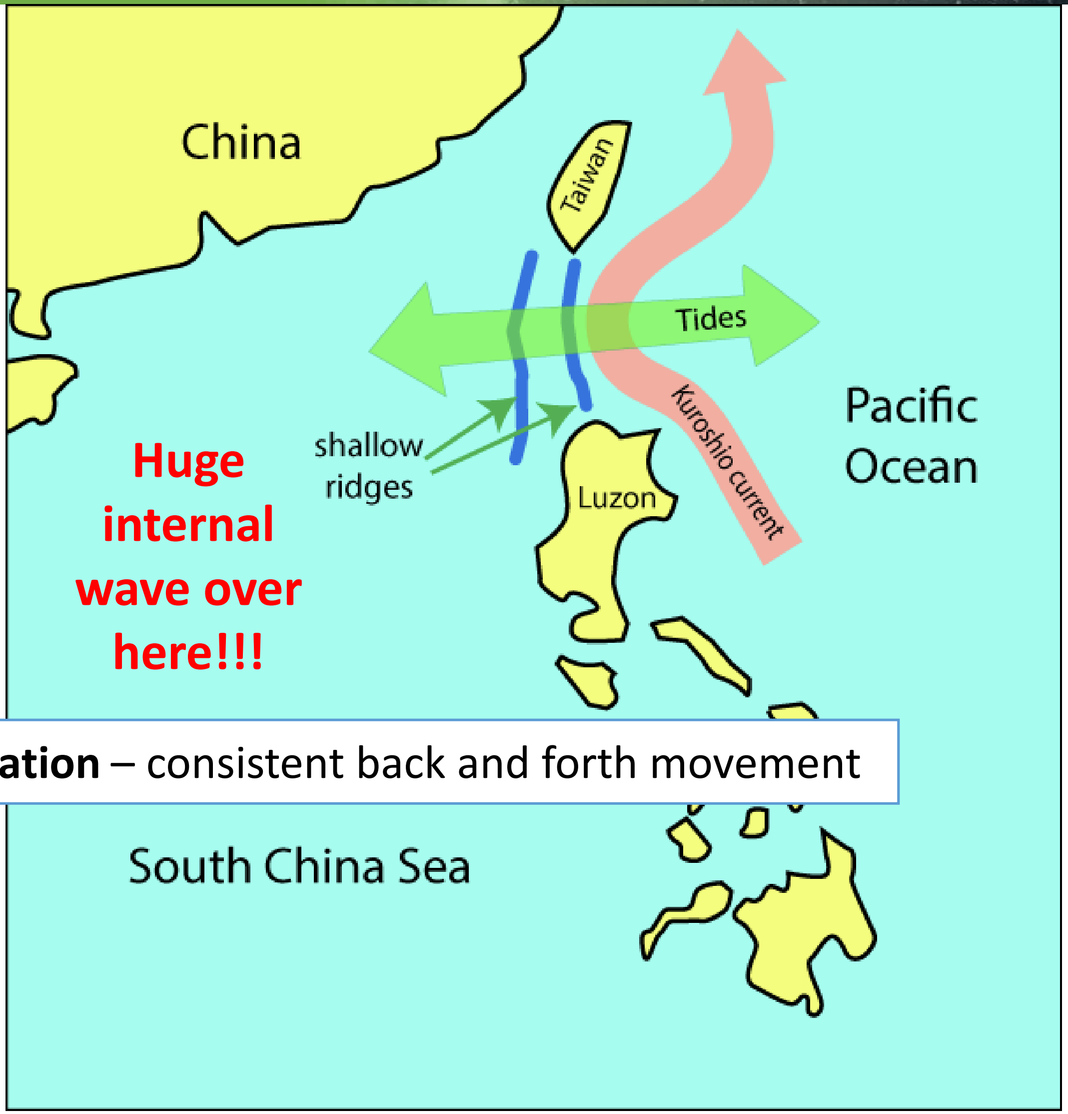
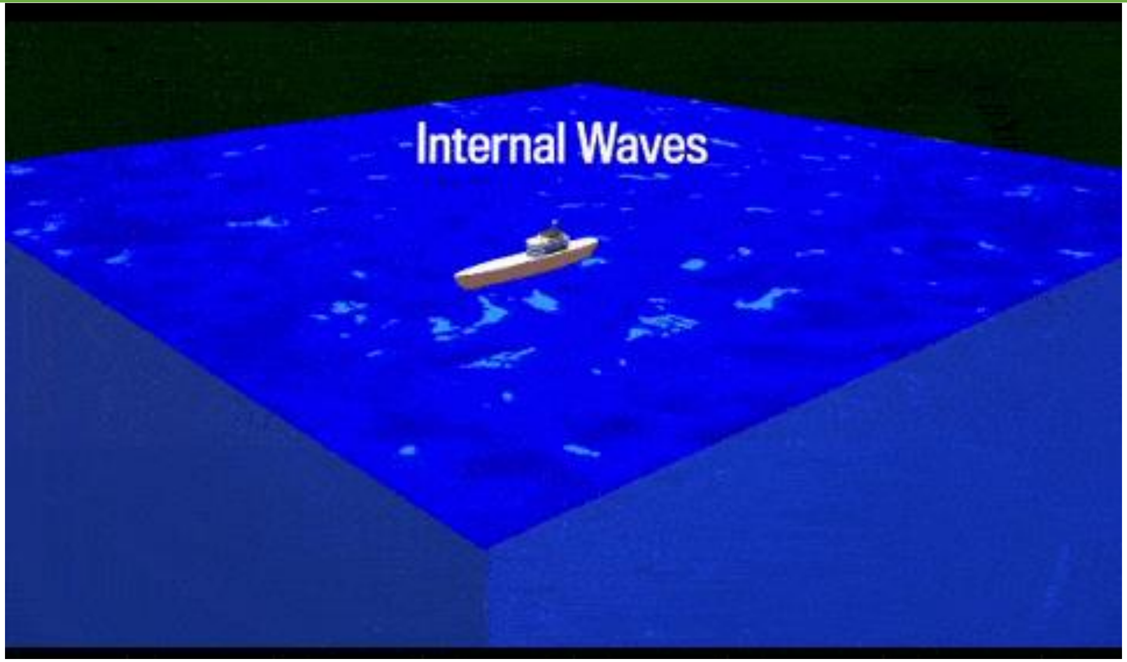


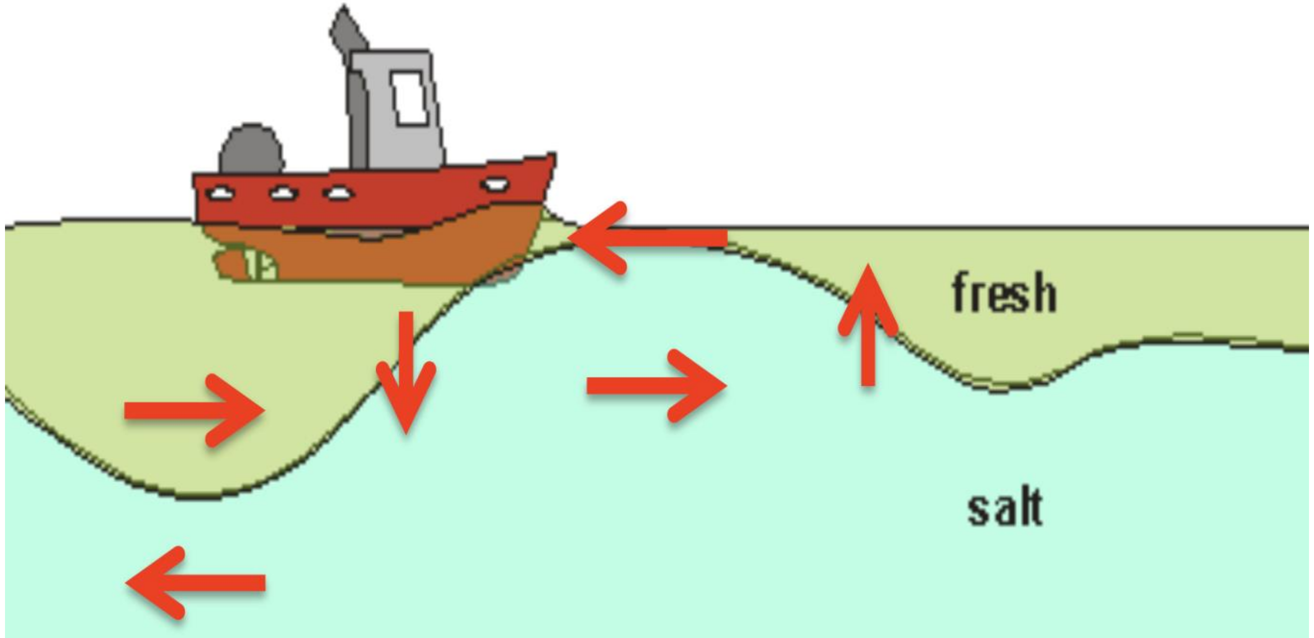
(Animation: Internal waves across the South China Sea)



Oscillation – consistent back and forth movement

Internal Waves can Cause "Dead Zone"

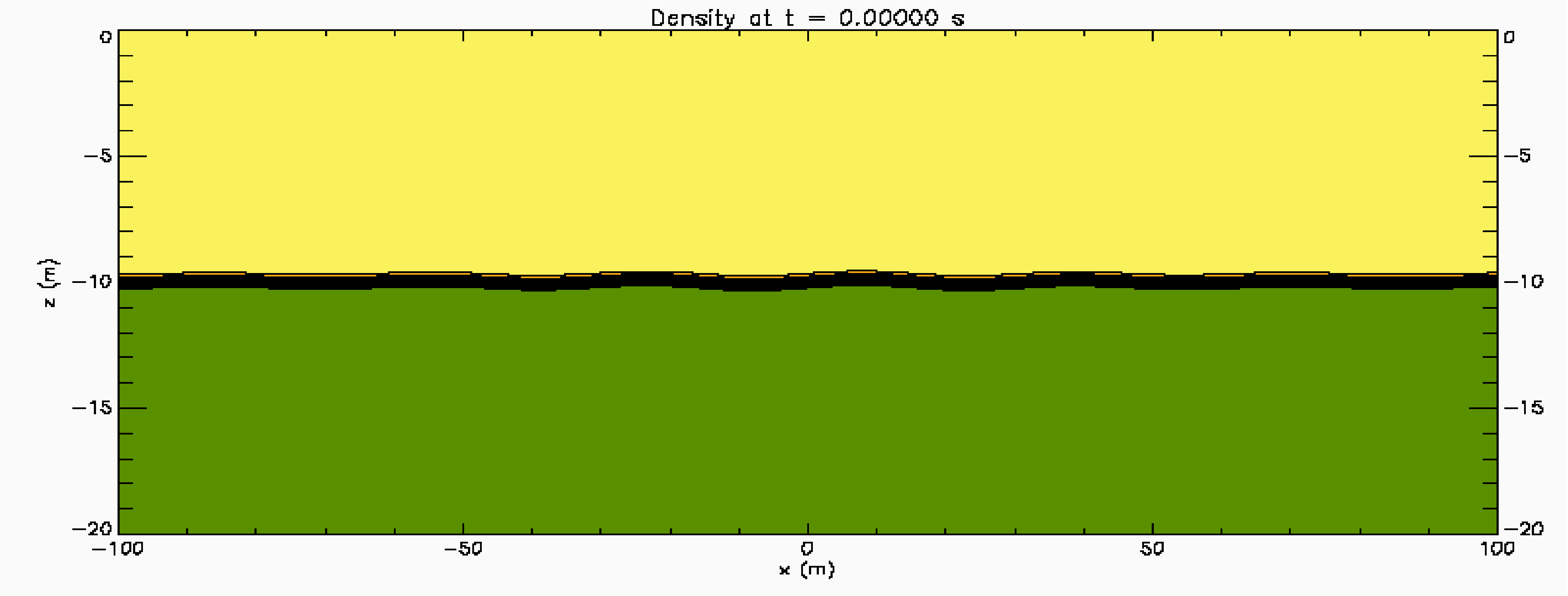




Prior to establishing the knowledge of internal waves, **people at sea sometimes found their vessels unmovable no matter how they fire the engines**.

This is because **internal waves can move *opposite* to the vessels, and will push the vessels *backward*** — **the dead zone.**

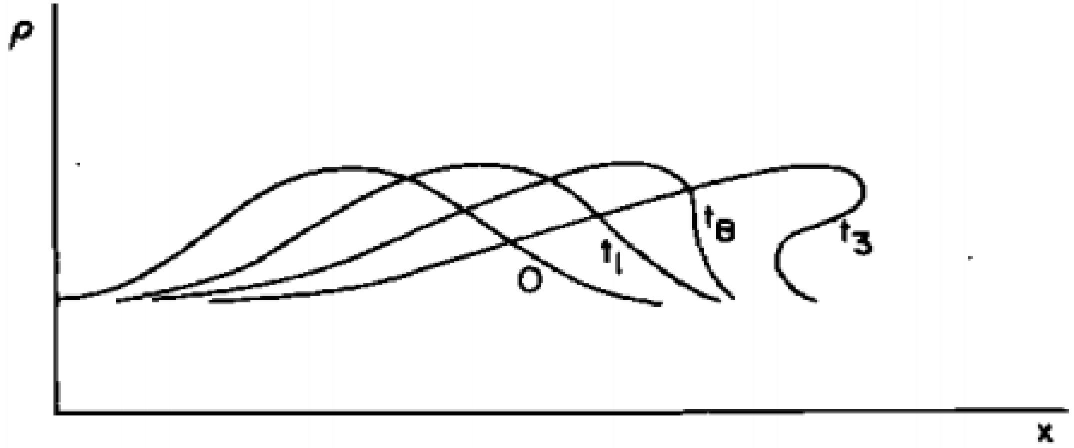
Internal Wave Breaking



University of Waterloo

- Decreasing the waves' propagation speed and wavelength steepens the waves, and induces **Wave Breaking.**

- This can occur due to a **decrease in the ocean depth** or **interaction of waves with bottom topography.**



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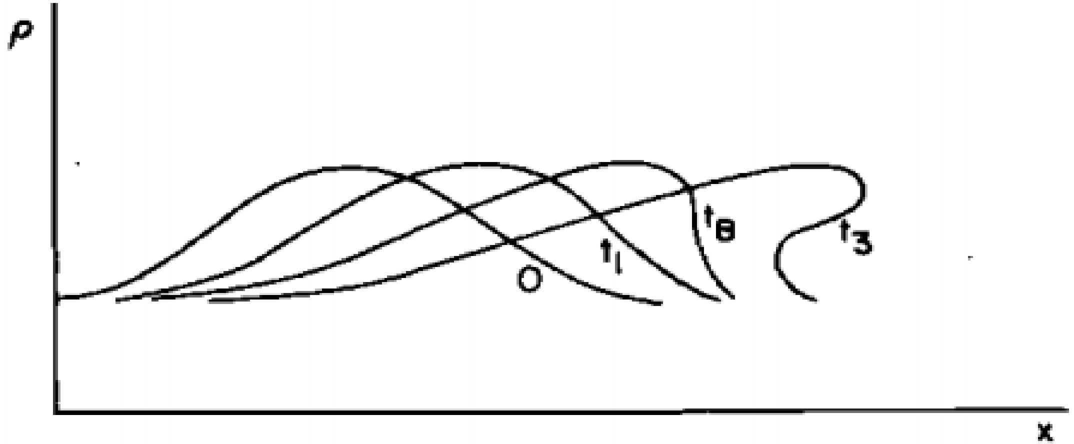

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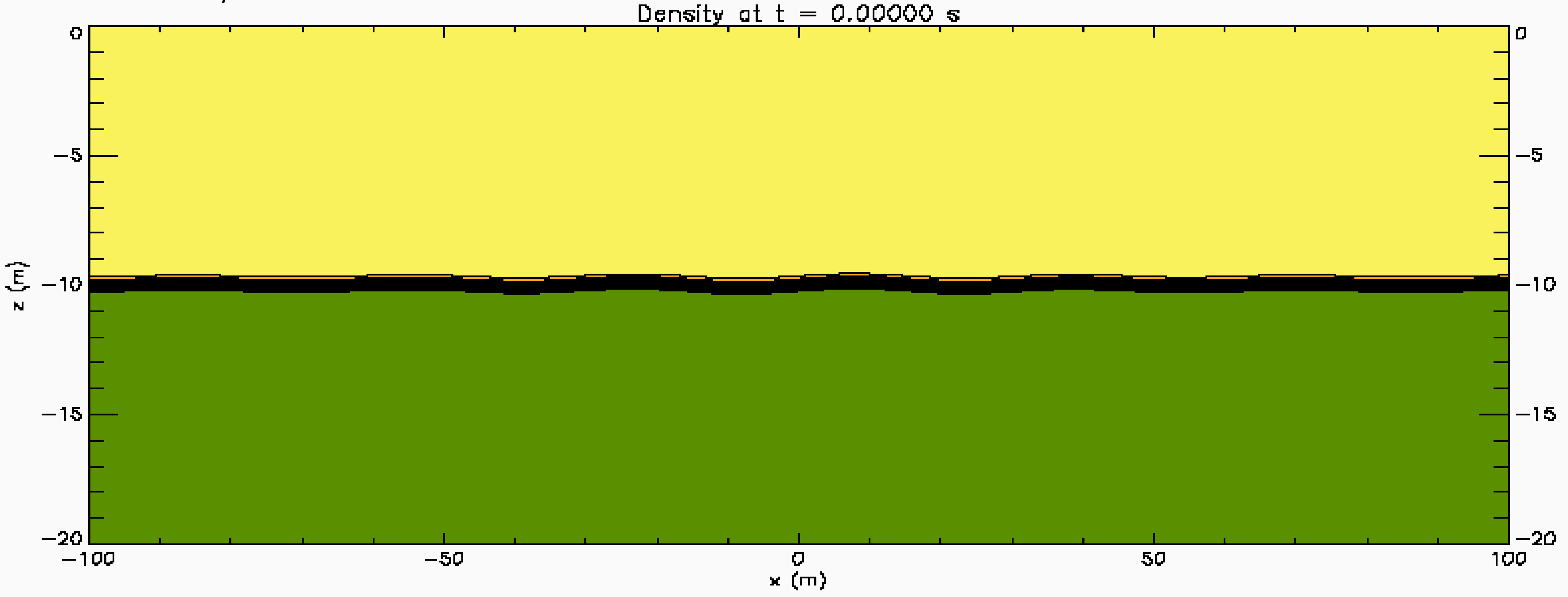
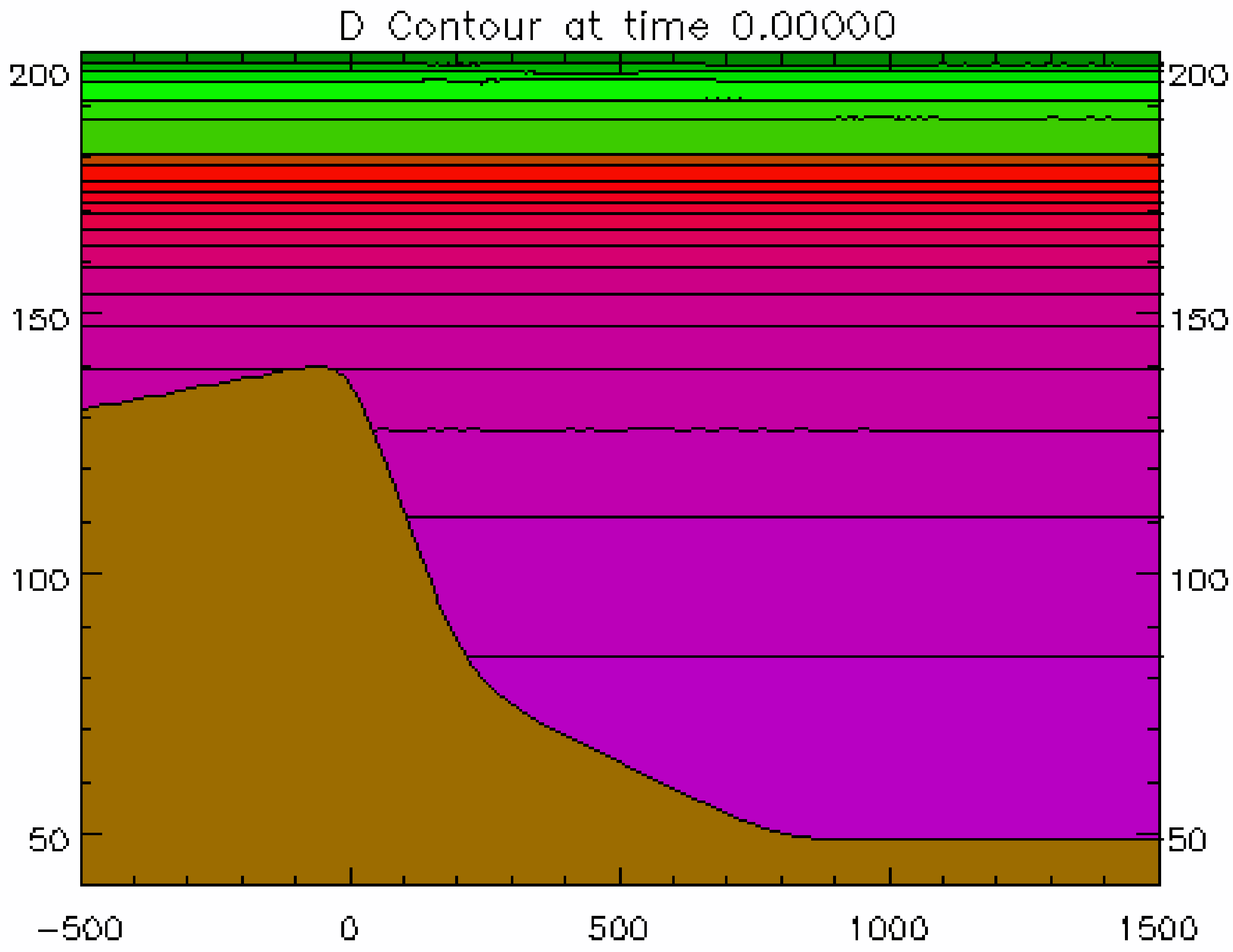


Internal Wave Breaking Closes Overturning Circulation

- Breaking of internal waves induces “mixing” that make water masses lighter and rise, and therefore **close the global overturning circulation**.

- Over the globe, this mixing transforms 25 million cubit meters of Antarctic Bottom Water into other water mass types.



Questions – Where & How Water Rises in the Ocean?

1) **Where do Internal Waves rise?**

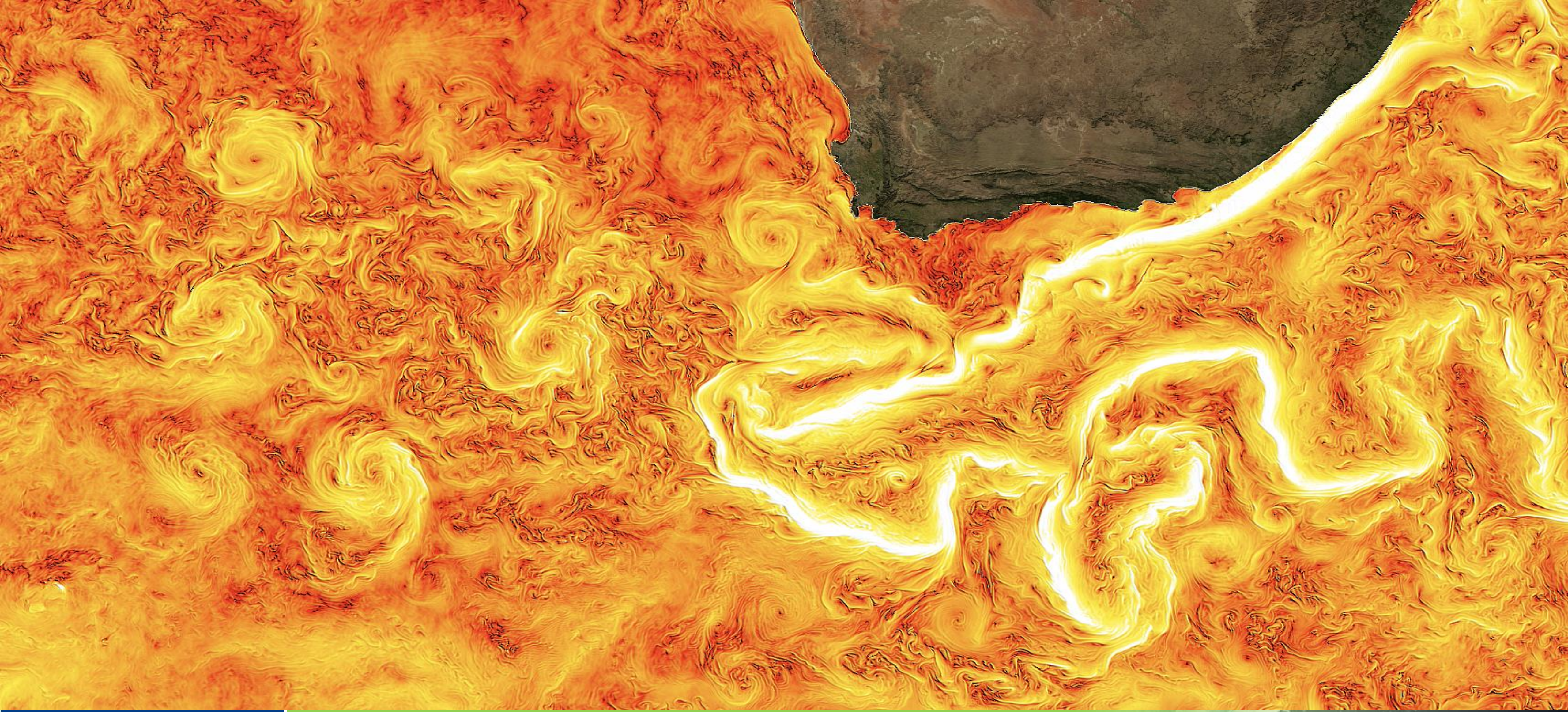
   In the ocean interior.

2) **How do Internal Waves drive the bottom water upwards across density surfaces?**

   Via wave breaking.

3) **How do internal waves effect transportation?**

   Creates a dead zone because Internal waves move opposite to the vessel pushing it backwards instead of forward.



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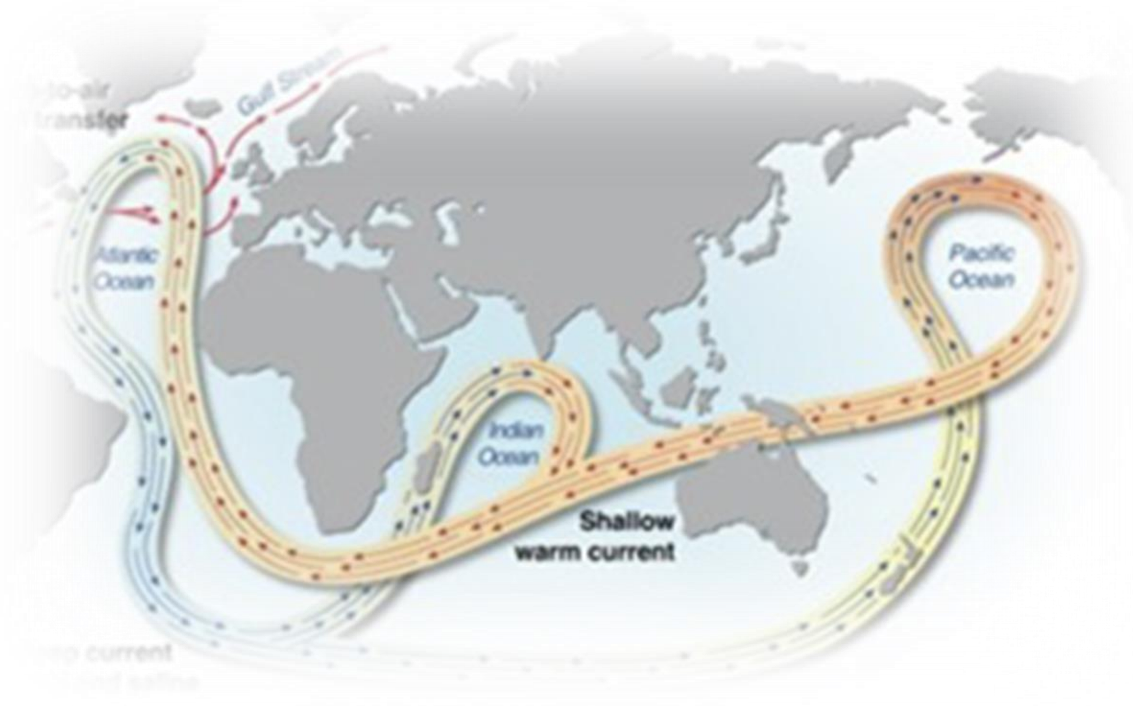
Mesoscale Eddies

Mesoscale Eddies

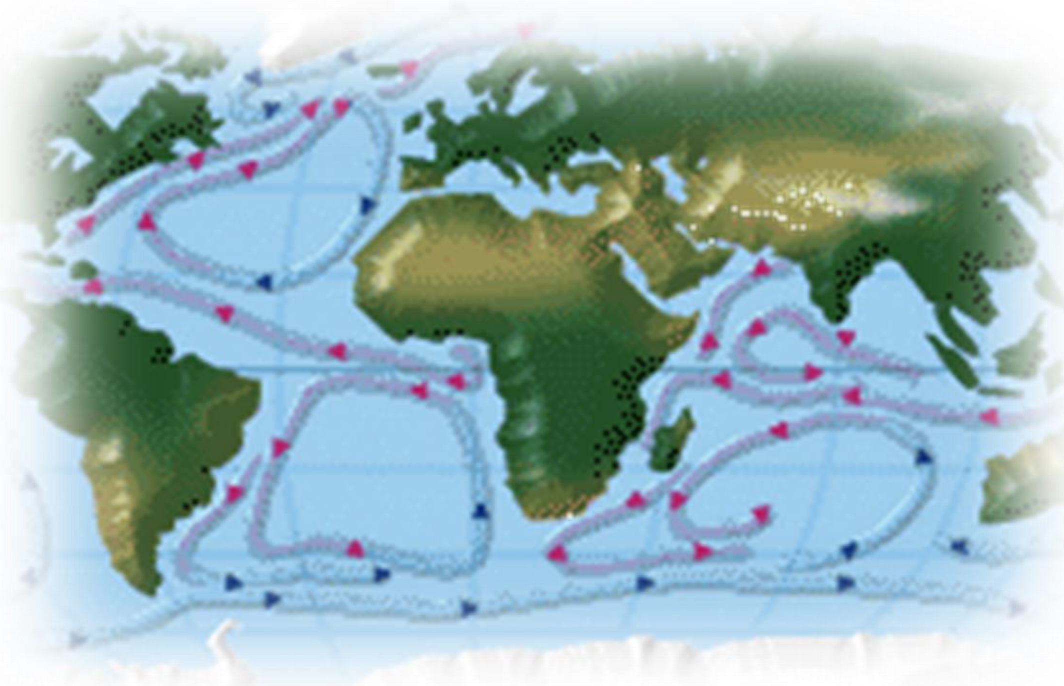
- **The flow of ocean currents**
- Mesoscale Eddies in **satellite and 3D models**
- **What is a Mesoscale Eddy?**
- **Impacts**
  - Marine ecosystems
  - Inter-basin exchange
  - Ocean mixing

The Flow of Ocean Currents

- The canonical view of the ocean circulation is just of a series of **sluggish and steady ocean currents flowing around the globe.**

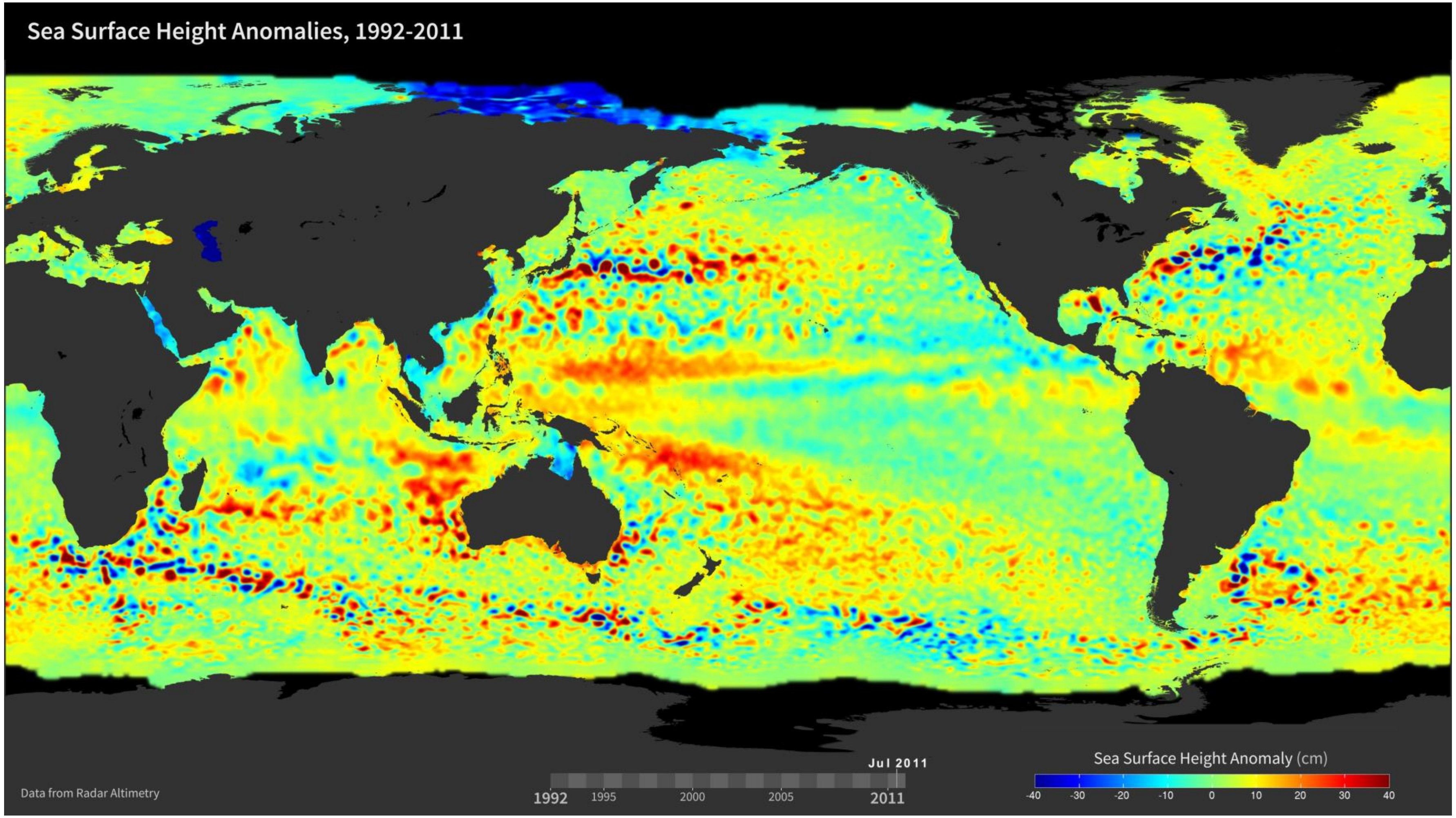


- In the past couple of decades, it has become clear that this picture is **much too simple**.



Emergence of Mesoscale Eddies in Satellite Record

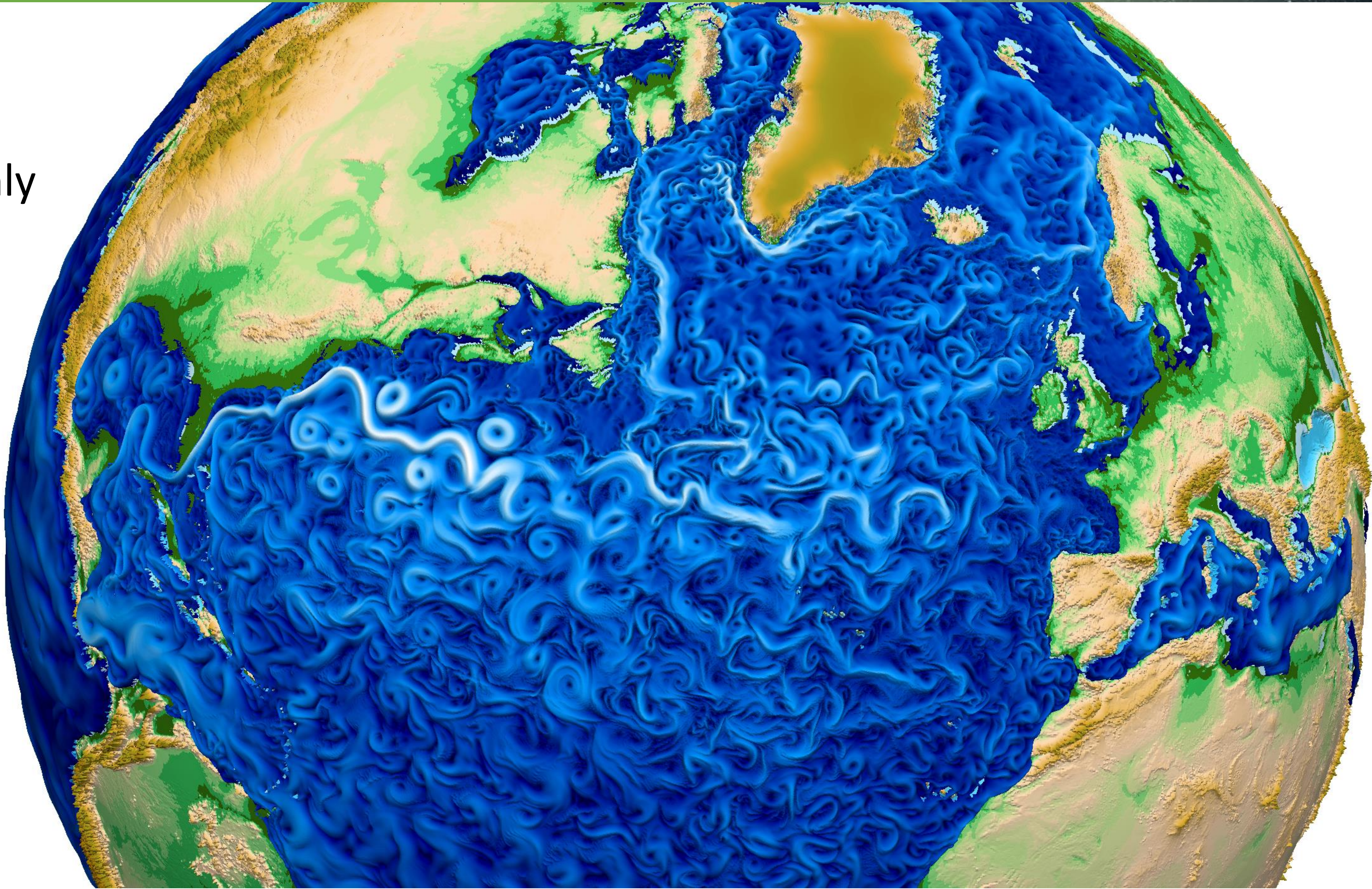
Sea surface height anomalies measured by satellite suggest that **the ocean is full of smaller, "baby" currents** (i.e. Mesoscale Eddies).



From NASA

Mesoscale Eddies in Models

When the resolution of ocean models is refined, **Mesoscale Eddies** suddenly appear **everywhere**.

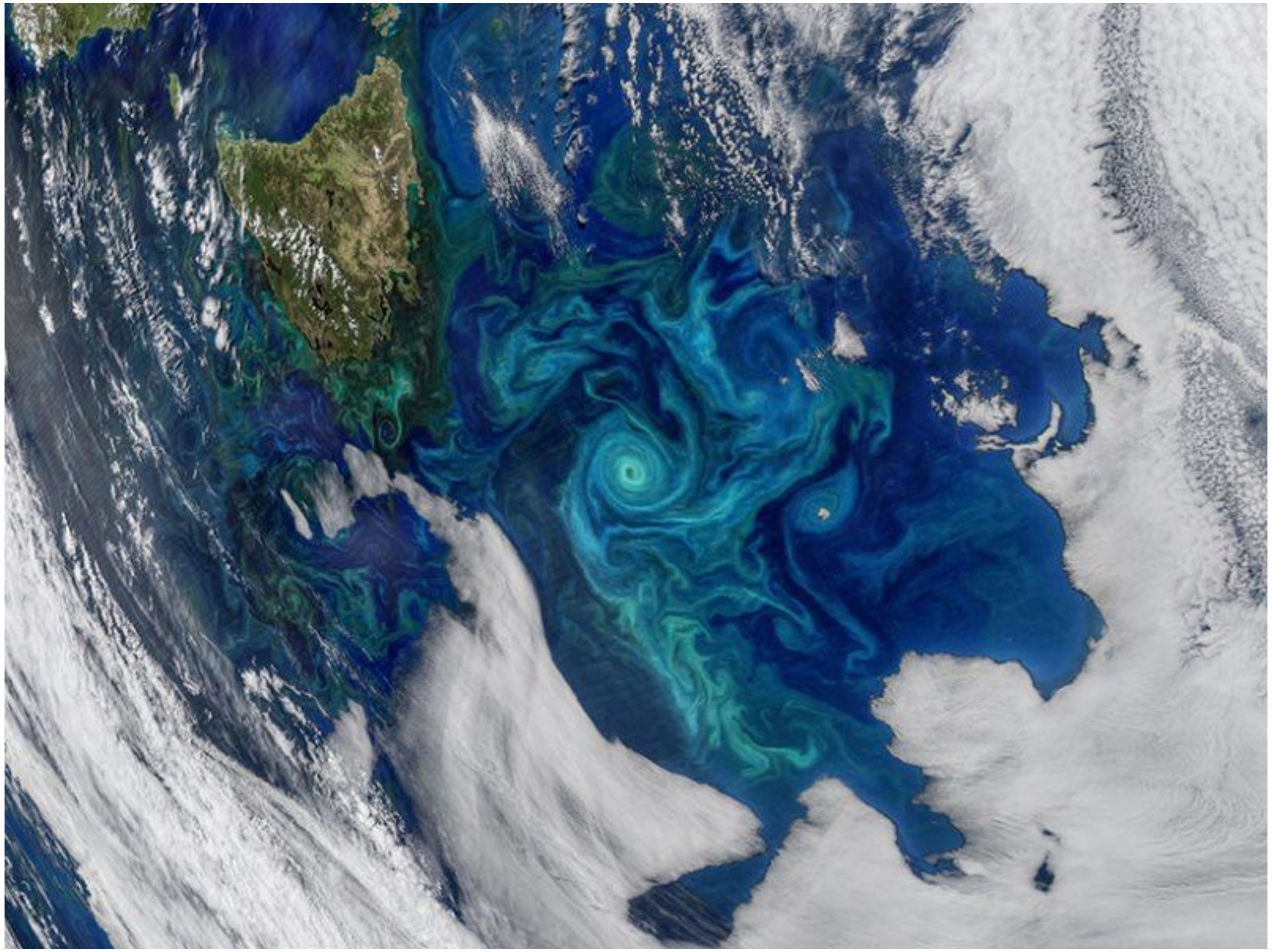


Sea surface current speed in a global ocean model.

(From T. Ringler)

What is a Mesoscale Eddy?

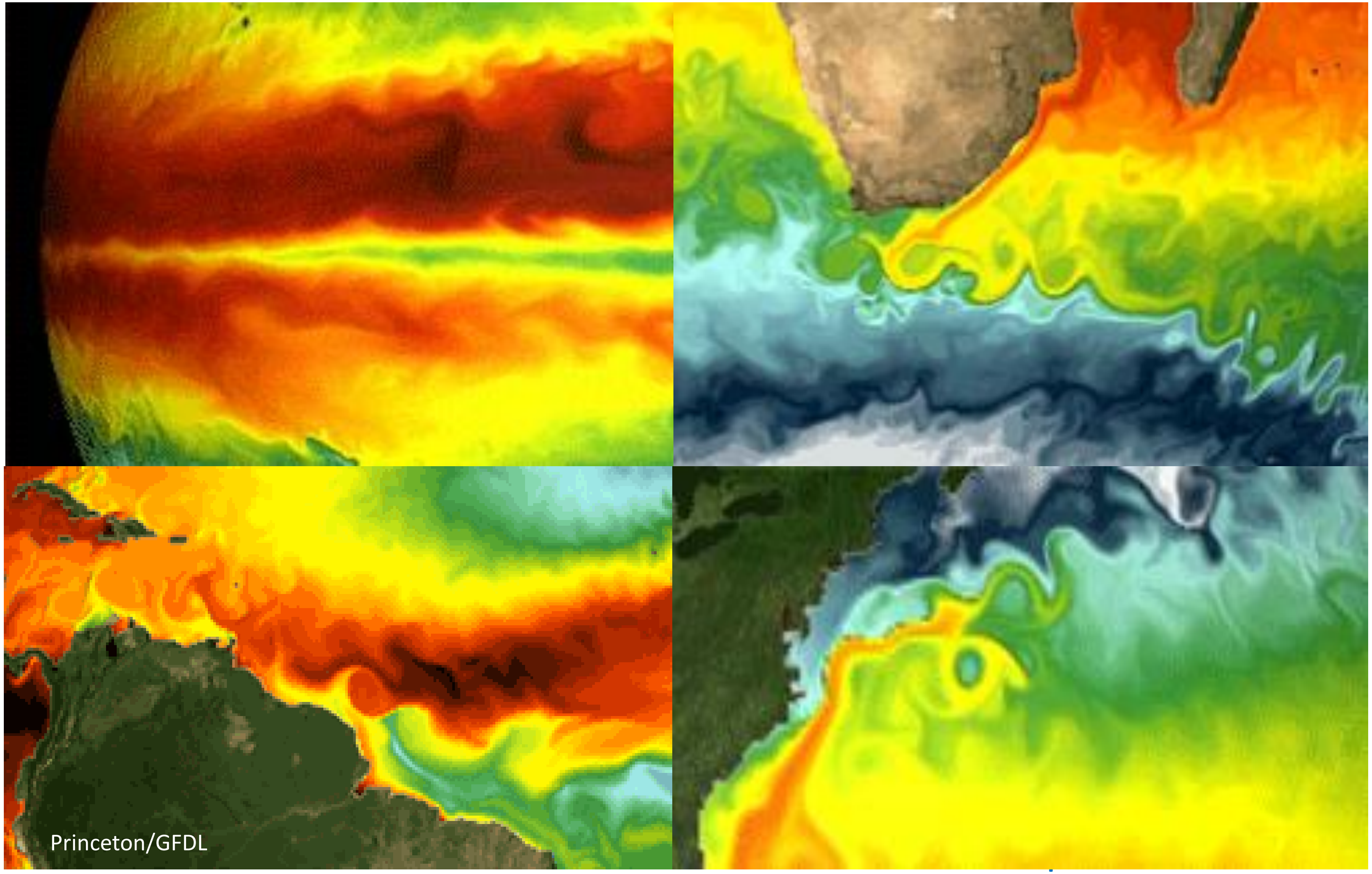
- One definition for an eddy is as a **vortex**: a horizontal, rotating body of fluid
- Typical size: 100 - 200 km
- Velocities of rotation may reach 1 m/s or higher
- It typically takes a mesoscale eddy **several weeks to months to rotate once**



Mesoscale Eddies – Heat Transport

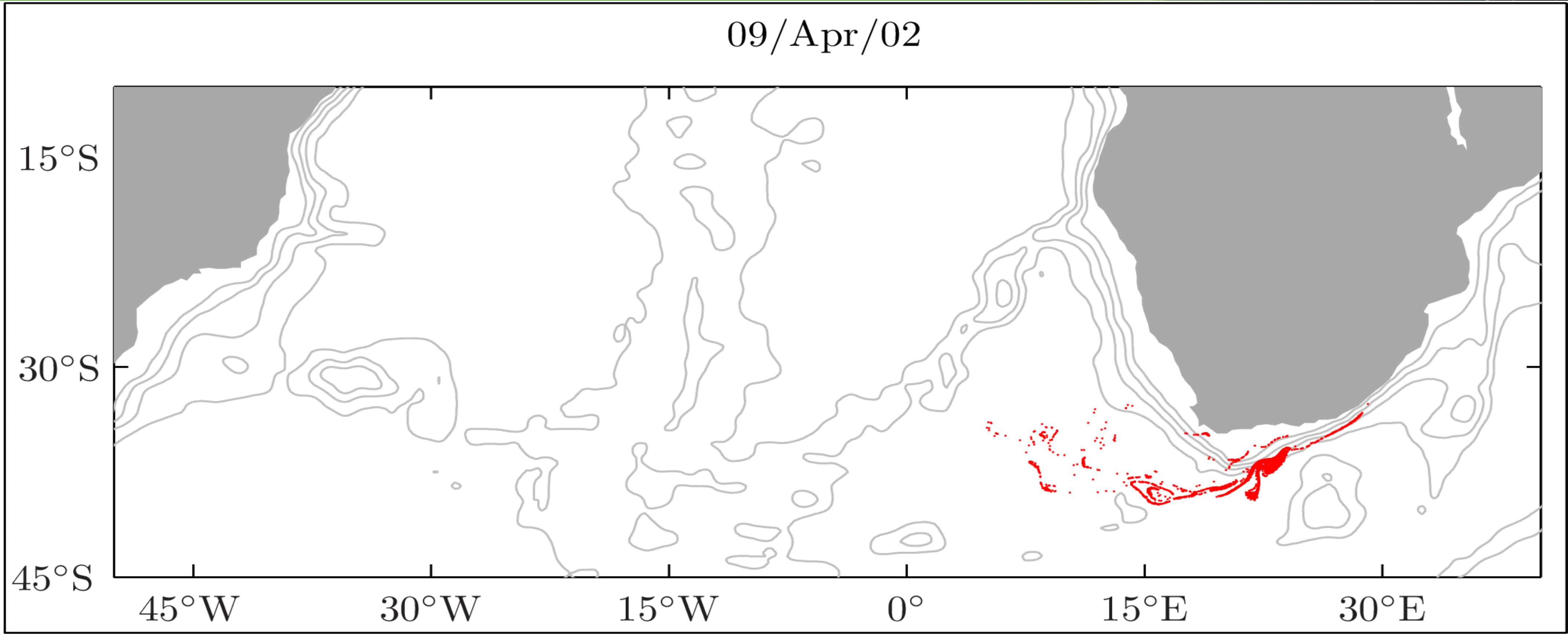
- Mesoscale Eddies can **trap cold/warm water** over long distances

- Mesoscale eddies impact the ocean temperature **bringing heat from one place to another**



Mesoscale Eddies – Impact to Inter-Basin Exchange

An eddy carrying Indian Ocean water into the Atlantic.



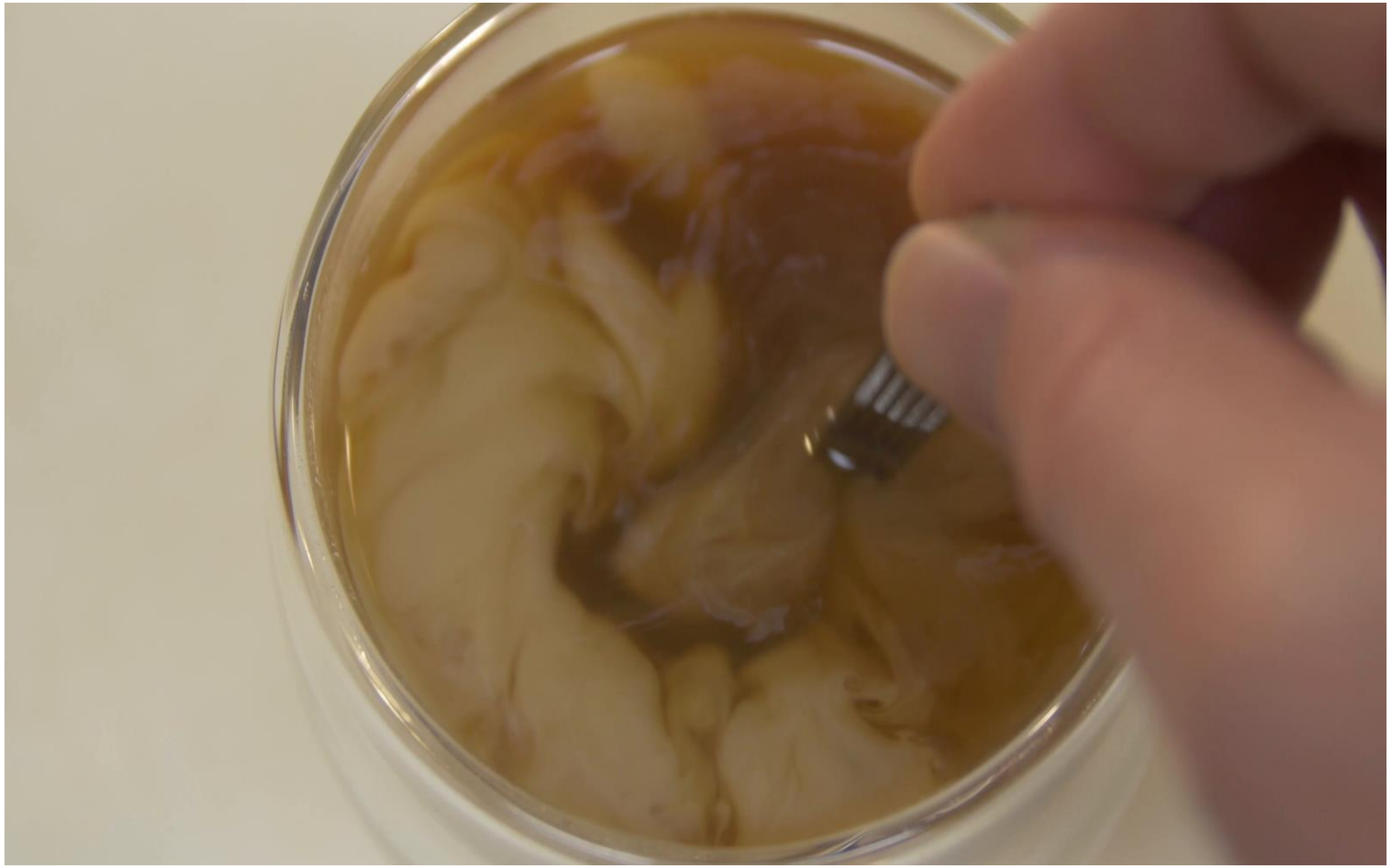
(From Wang *et al.*, 2015)

Some Mesoscale Eddies are **fairly long-lived (up to 3 years)** while travelling, carrying water mass from one place to another.

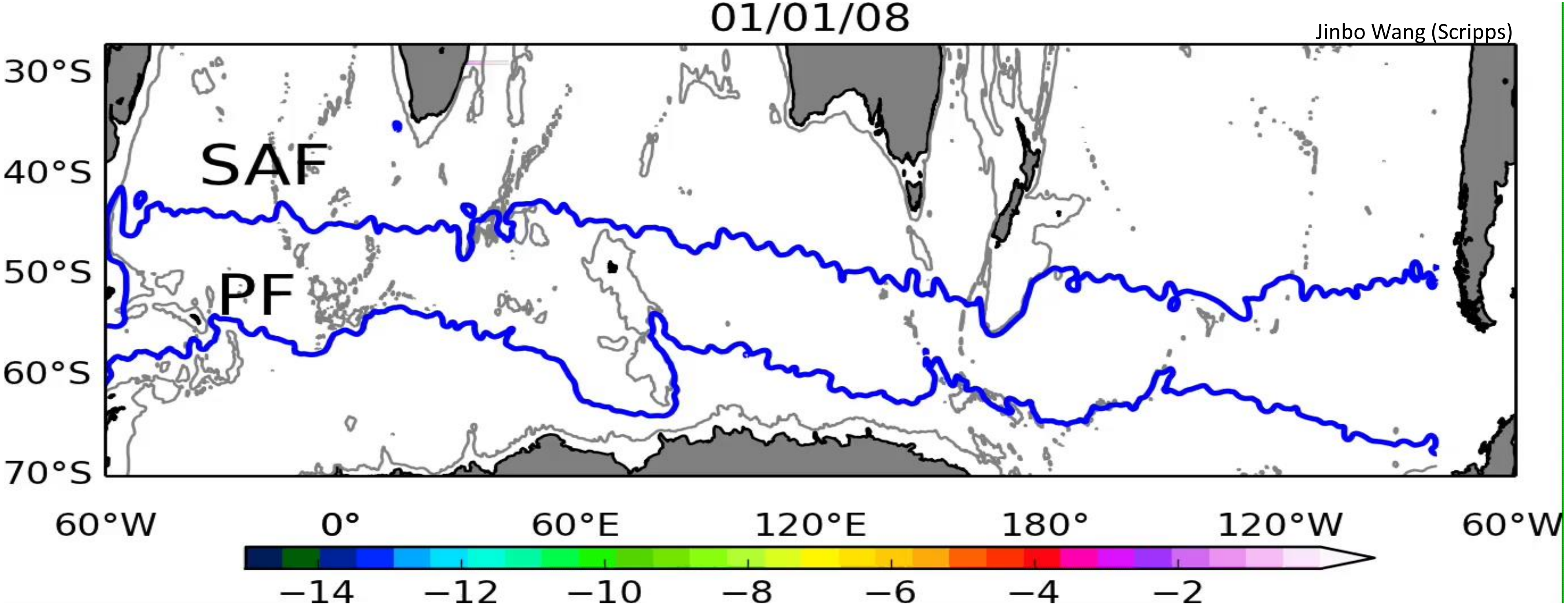
Mesoscale Eddies – Impact to Ocean Mixing

Eddies tend to **stir and spread properties**.

Comparable to stirring milk into coffee.



Mesoscale Eddies – Impact to Ocean Mixing



Tracers (warmer waters) introduced into the ACC are carried rapidly eastward by the current, but also spread meridionally from north to south because of eddy mixing. This is the major mechanism via which **heat is transported southward across the ACC, towards the Antarctic**.

Mesoscale Eddies

- **The flow of ocean currents**
- Mesoscale Eddies in **satellite and 3D models**
- **What is a Mesoscale Eddy?**
- **Impacts**
  - Marine ecosystems
  - Inter-basin exchange
  - Ocean mixing

Questions – What are Mesoscale Eddies?

1) **What are mesoscale eddies?**

   Like baby currents

2) **What are the typical spatial and time scales of Mesoscale Eddies?**

   100 km / Weeks to Months

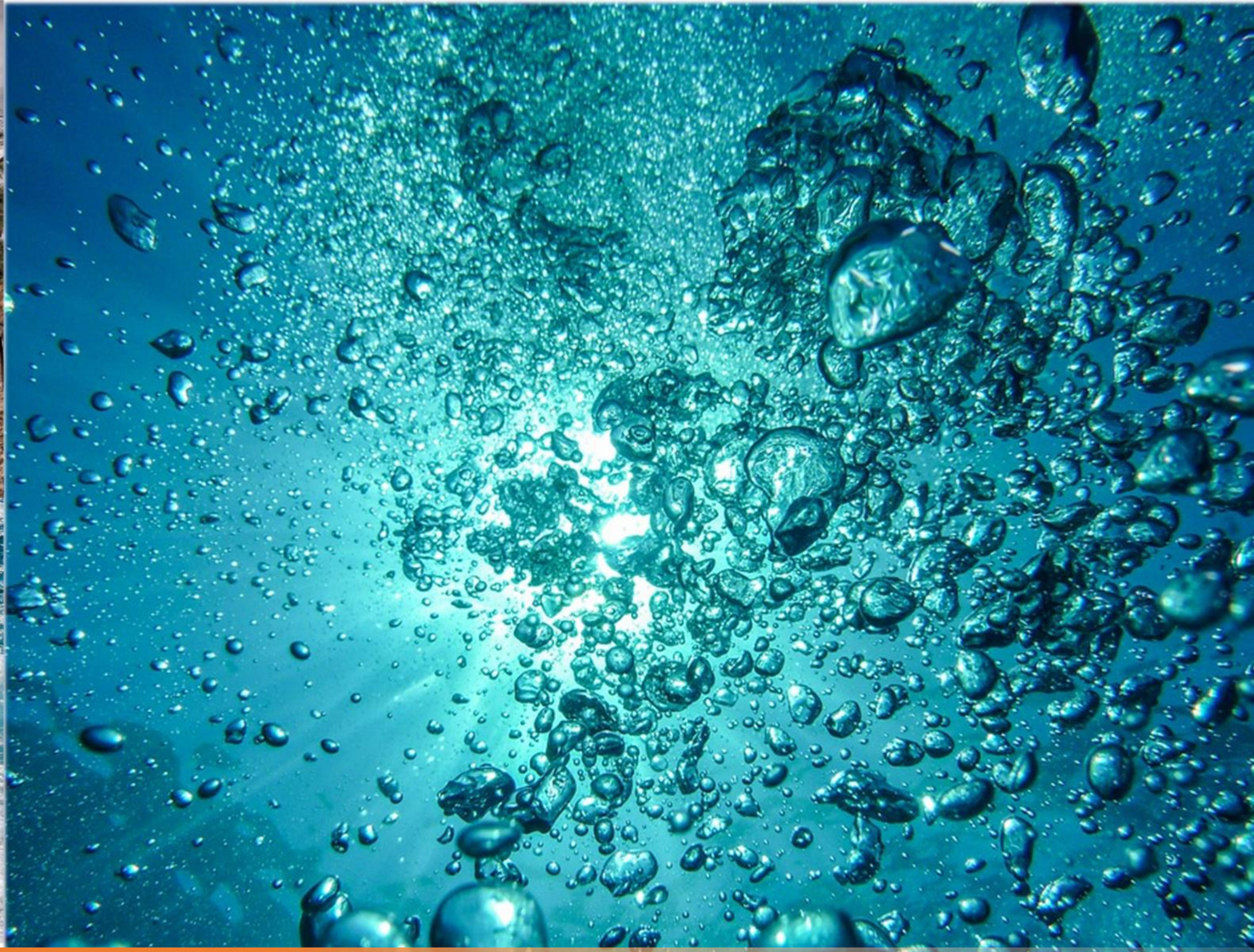
3) **Where can we find Mesoscale Eddies in the ocean?**

   Everywhere!

4) **What do Mesoscale Eddies do in the ocean?**

   Transport and mix up ocean properties





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Overall Summary:

Physical Characteristics of the Ocean

Module Goal

- Recall the oceanic processes
- Explain how the ocean functions in relation to the climate system;
- Describe certain oceanic parameters such as those about hydrography

Summary

- The ocean is an almost two-dimensional body of water covering the Earth surface.
- Surface winds drives the **Ocean Gyres** and **Circumpolar Currents**.
- The global **Overturning Circulation** is driven by heat and fresh water exchange with air at sea surface of polar regions, and **Internal Wave Breaking** at the ocean bottom.
- **Mesoscale Eddies** are ubiquitous in the world ocean and able to enhance the transport of oceanic properties from one place to another.

Summary of Key Terms

- **Oceanic Flows (upper ocean)**
  - Wind-driven Currents
  - Ocean Gyres
  - Circumpolar Currents

- **Temperature, Salinity & Stratification – Layers of the ocean**

- **Overturning Circulation (deeper ocean):**
  - Water sinks: Polar regions
  - Water rises: Near bottom
  - Internal wave breaking: Closes the overturning circulation

- **Mesoscale Eddies:** Everywhere, from surface to deep ocean

The Ocean – Far Richer than What is Covered in this Module

The **Oceanic Motions** span a wide range in space and time. **All these processes are coupled with each other, transferring energy from one type of motion to another**.

Understanding the Ocean requires understanding these multiple scale motions and their interactions.