OCES1001 - Course Map

Physical Characteristics of the Ocean → Focus on Open Ocean

A Glimpse of Marine Life → Focus on marine organisms relationship
Focus on relationship & interaction of organisms

Marine Ecosystems → **Coastal, Intertidal, Subtidal**

Humans & the Sea

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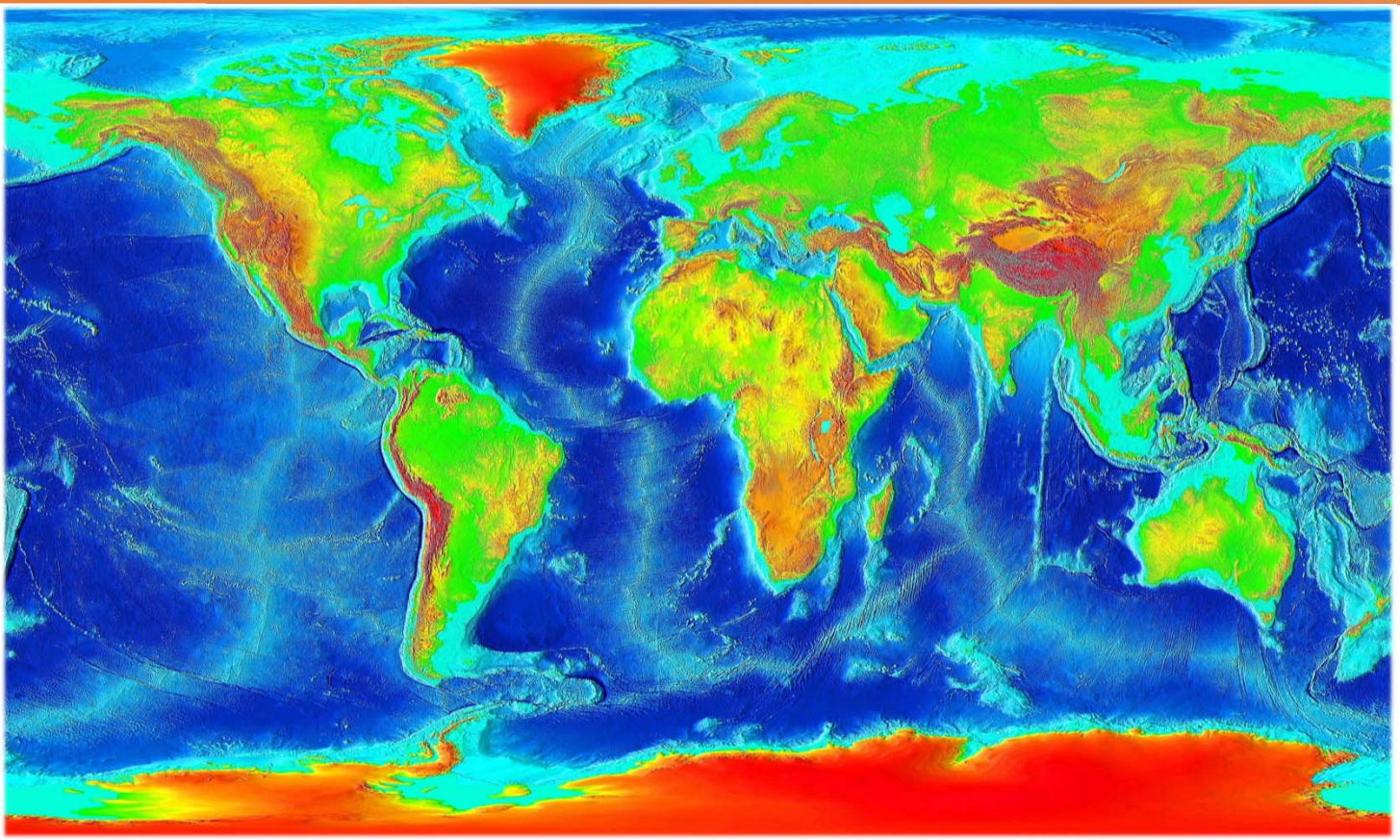
Overview:
Marine Ecosystems – The Coastal, Intertidal & Subtidal

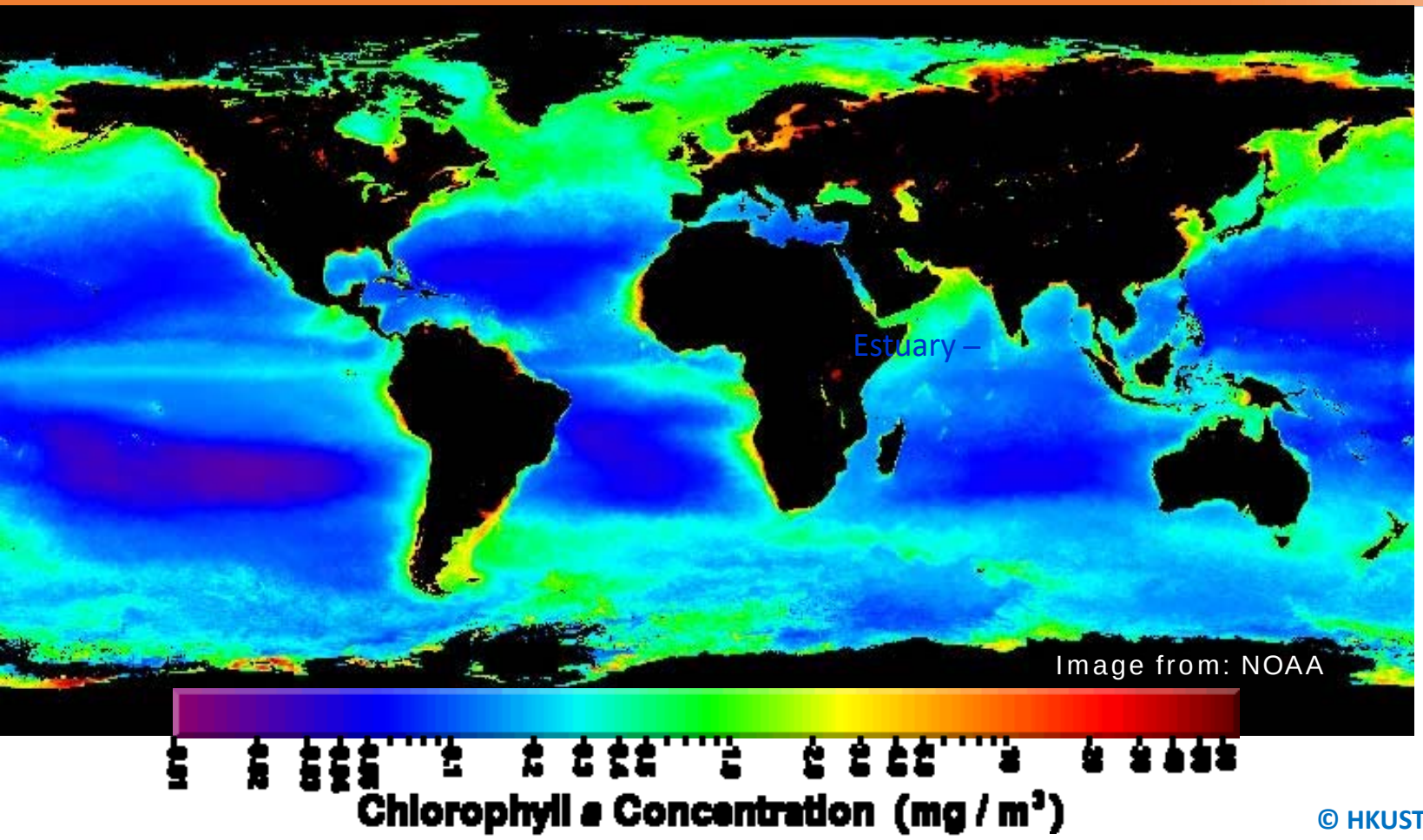
Global Shelf & Coastal Sea



The global continental shelf (highlighted in cyan)

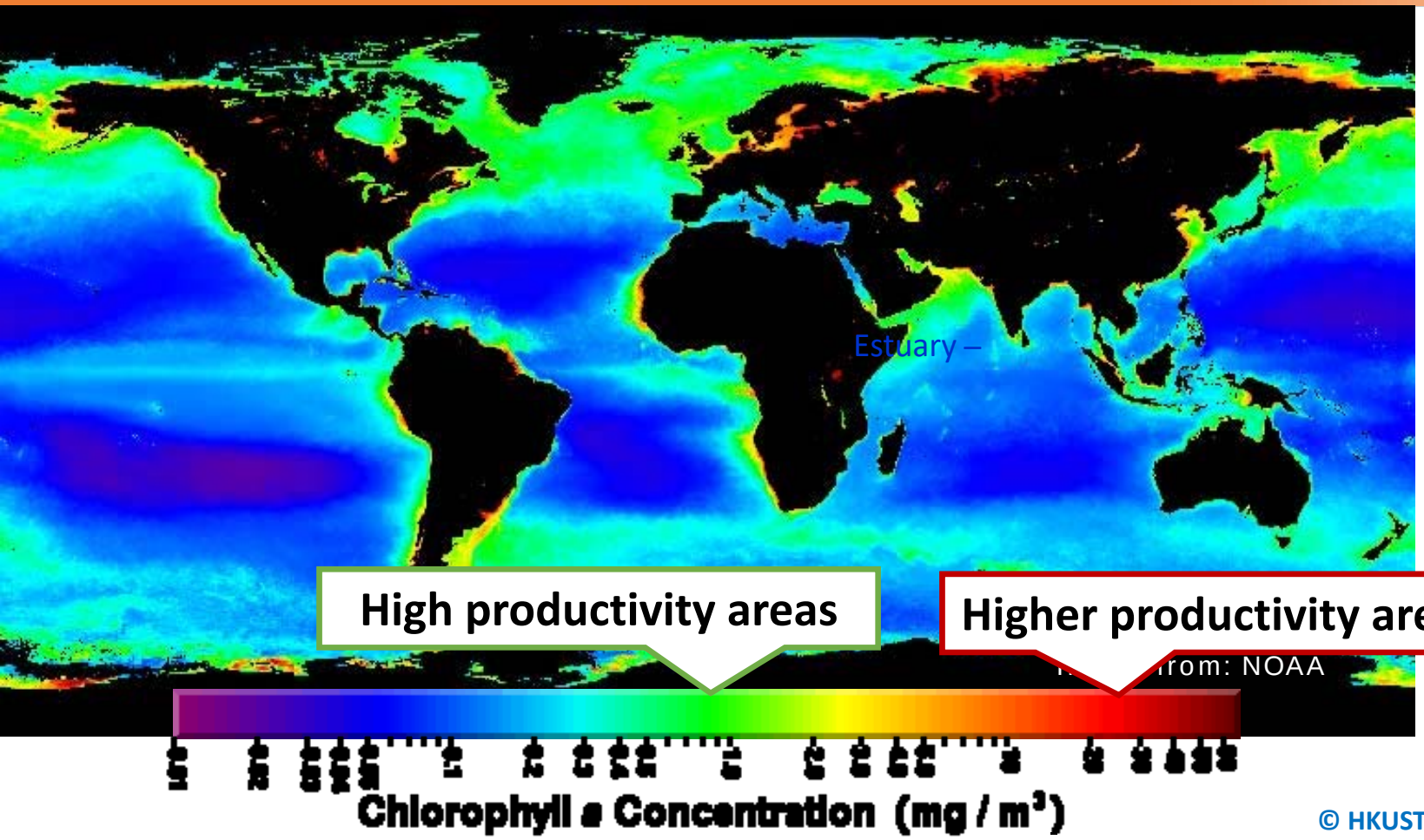
- **Coastal areas** comprise **20% of the Earth's surface** yet contain **>50% of the entire human population**;
- **70% of the world's megacities** are located in coastal areas;

High Biological Productivity



Although it only occupies **7% of the surface area** of the oceans, **shelf sea has high biological productivity.**

High Biological Productivity



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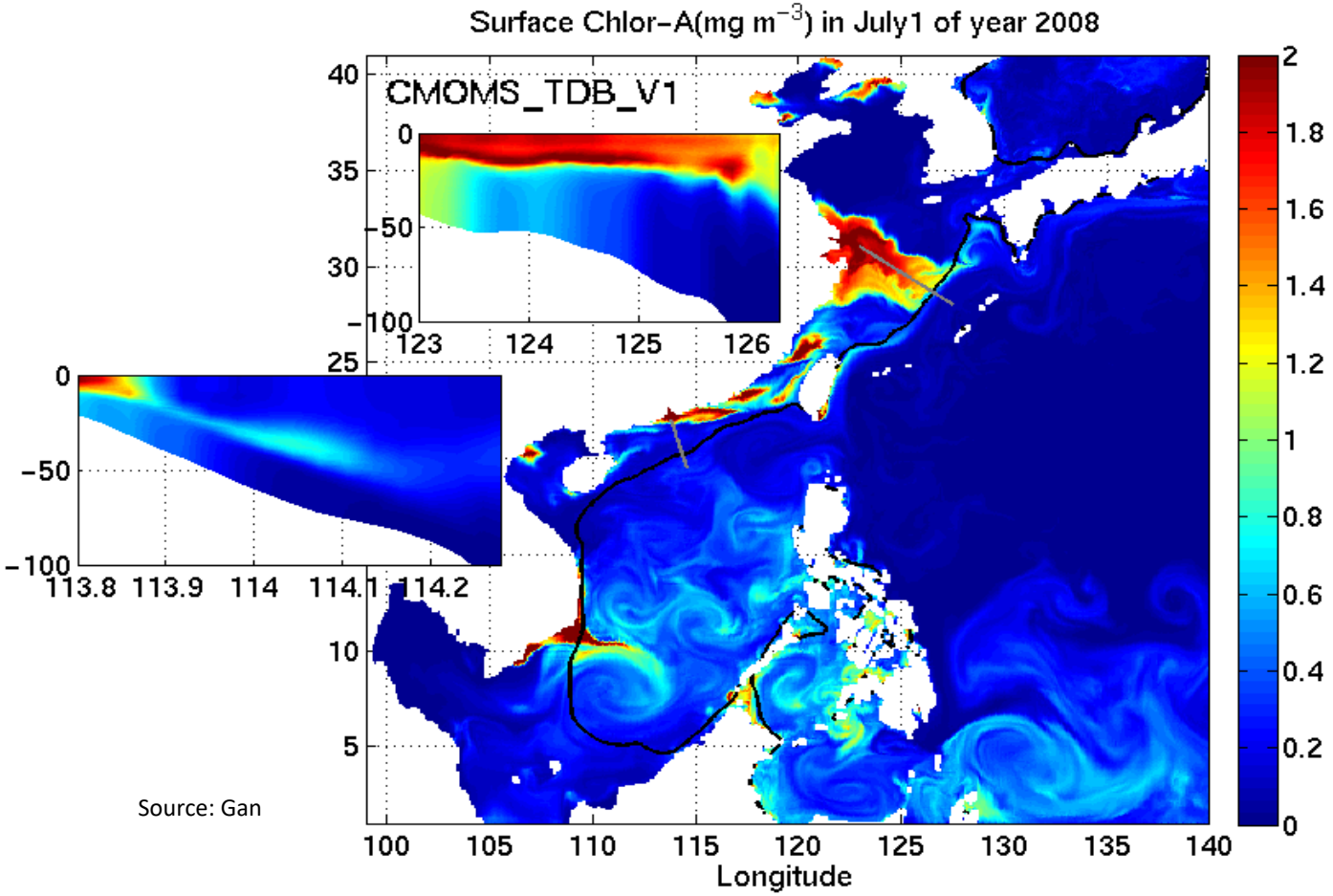
Active Hydrodynamics & High Bio-Productivity



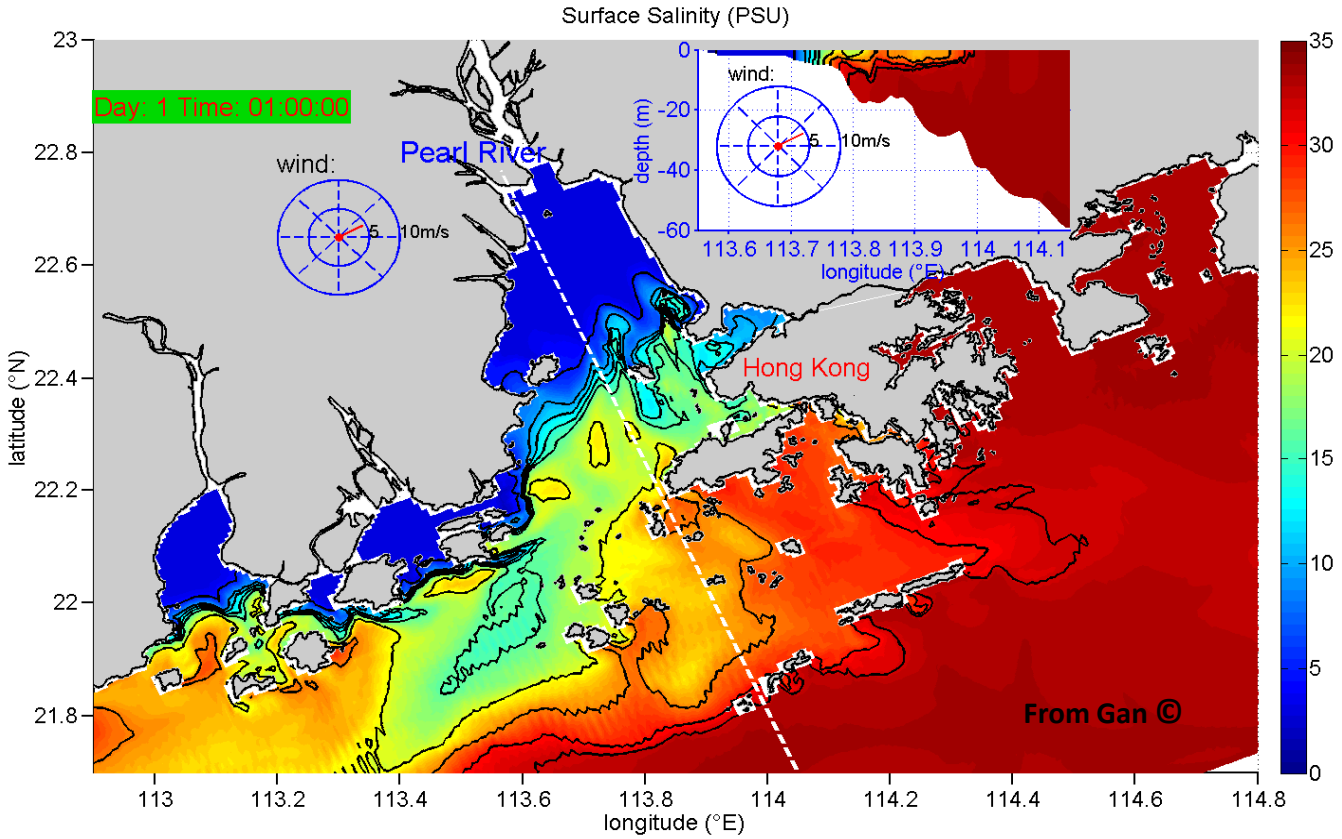
Source: Gan

Coastal waters **move swiftly** and have generally **high bio-productivity.**

Left: Surface chlorophyll in China Seas

Active Hydrodynamics

Land-Sea Interface: The Great Bay Area



The coastal waters are **biophysically-active zones** where **land-source fresh and nutrient-rich waters** meet the **salty and nutrient-depleted oceanic waters**.

Marine Ecosystems: The Coastal, Intertidal & Subtidal

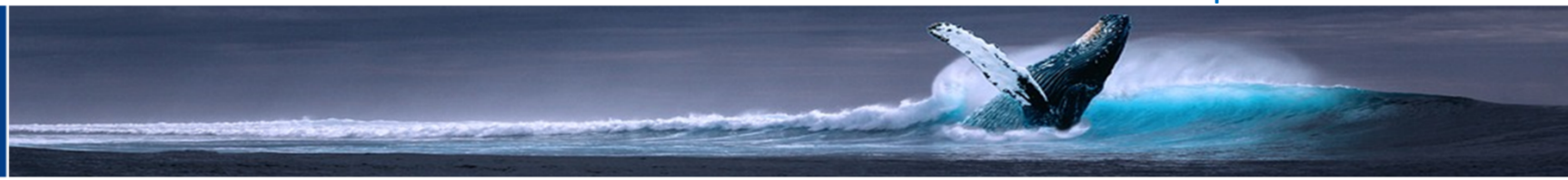
- Characteristics of Coastal & Shelf Sea
- Ekman Transport
- Wind-driven Current
- Coastal Upwelling
- Coastal Downwelling
- Estuary & Estuarine Circulation
- Classification of Estuaries
- Tides
- Waves

Module Goals

- **What will I gain after studying this Module?**
  - Fundamental **physical process (water motion)** that regulates biogeochemical response in the Marine Ecosystem.

- **Why should I choose to study Marine Ecosystems?**
  - It is an **interdisciplinary science** with broad training and application.

- **Why is it important and how is it connected to the bigger picture?**
  - It is one of the most critical elements about the **environment**, **life**, **climate** and **sustainability** on over 72% of Earth's surface.



The Coastal and Shelf Sea

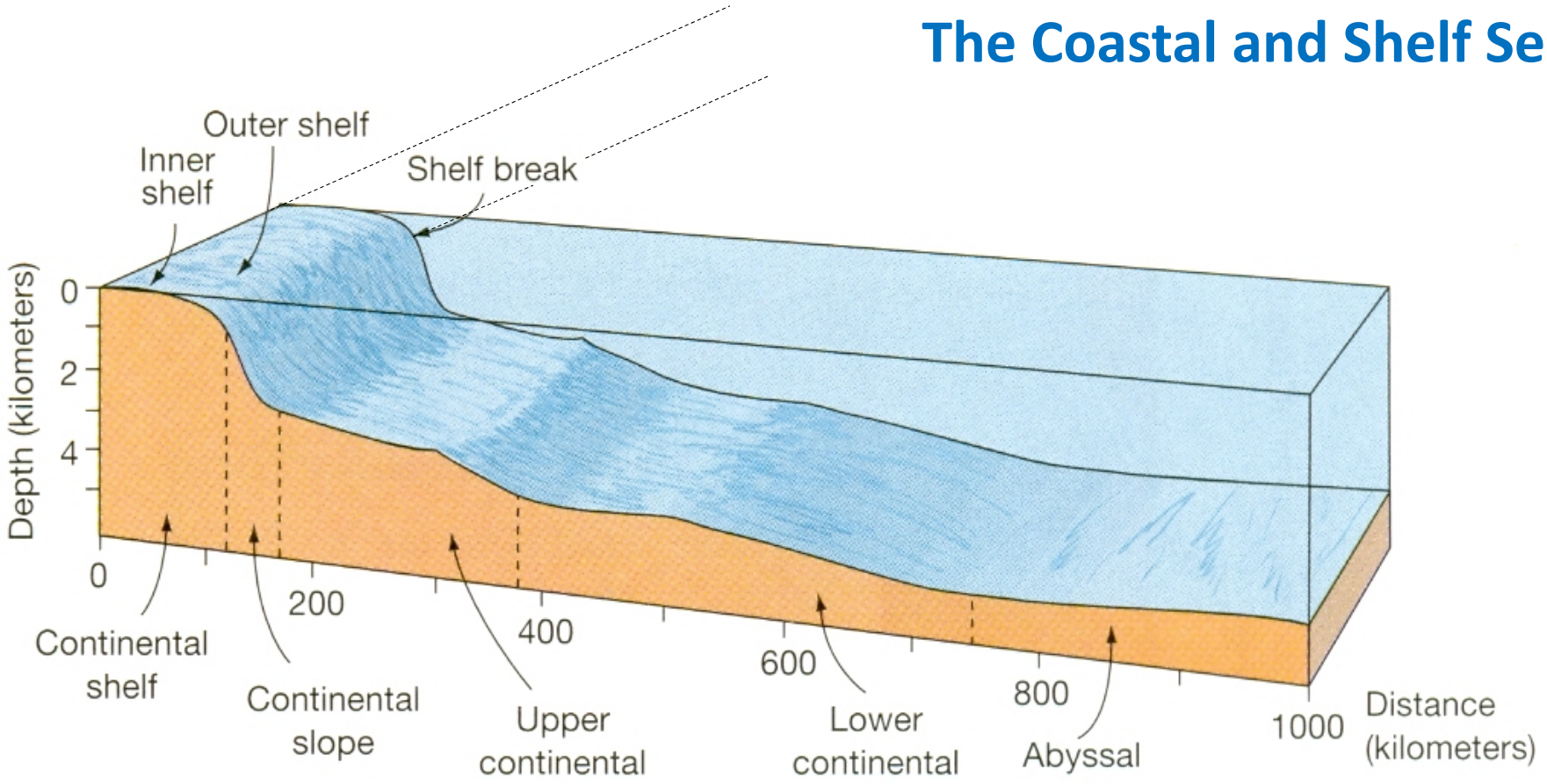


Image: Gross

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Characteristics of Coastal & Shelf Sea

The Coastal & Shelf Sea

- **Shelf Sea:** A sea area between a continental shelf break with a water depth of about 200 m and the land shore.

- **Shelf Break:** The location where the continental shelf joins the flanks of the continents near the 200 m depth.

- **Coastal Ocean:** Those shelf sea regions that display the dynamics of the deep ocean, modified by shallow water depth and the presence of the coast.

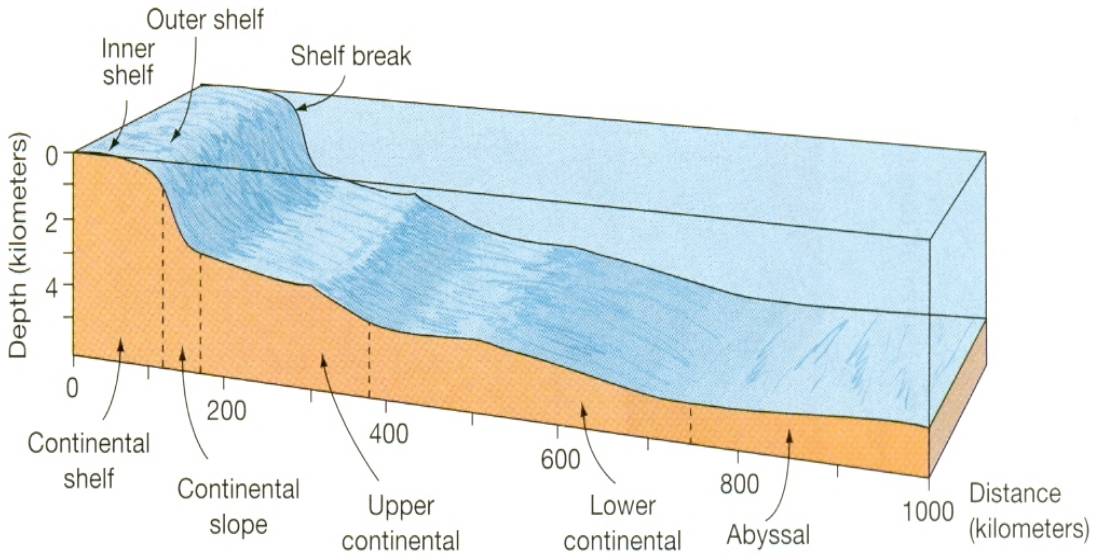


Image: Gross

Why do We Care about the Coastal and Shelf Sea?

Key points:

1. The Coastal and Shelf Sea affects us directly and is the **buffer between us and the open ocean**;
2. It has **unique physical and bio-geochemical characteristics** that are drastically different from the open ocean;
3. About **70% of global fish resources spend part of their life cycle** in the coastal seas;
4. Accounts for **90% of marine biomass yield**; and **almost 80 % of known species of marine fish**;
5. Great influence of **freshwater and nutrients from the land**;
6. **Chemical reactions occur rapidly** between substances from the land and those from the ocean;
7. Boundary layer of **energy and substance exchange with the open ocean**.

Overview – Characteristics of Coastal & Shelf Sea

1) Shallow water depth

2) Presence of coastline

3) Terrestrial influences

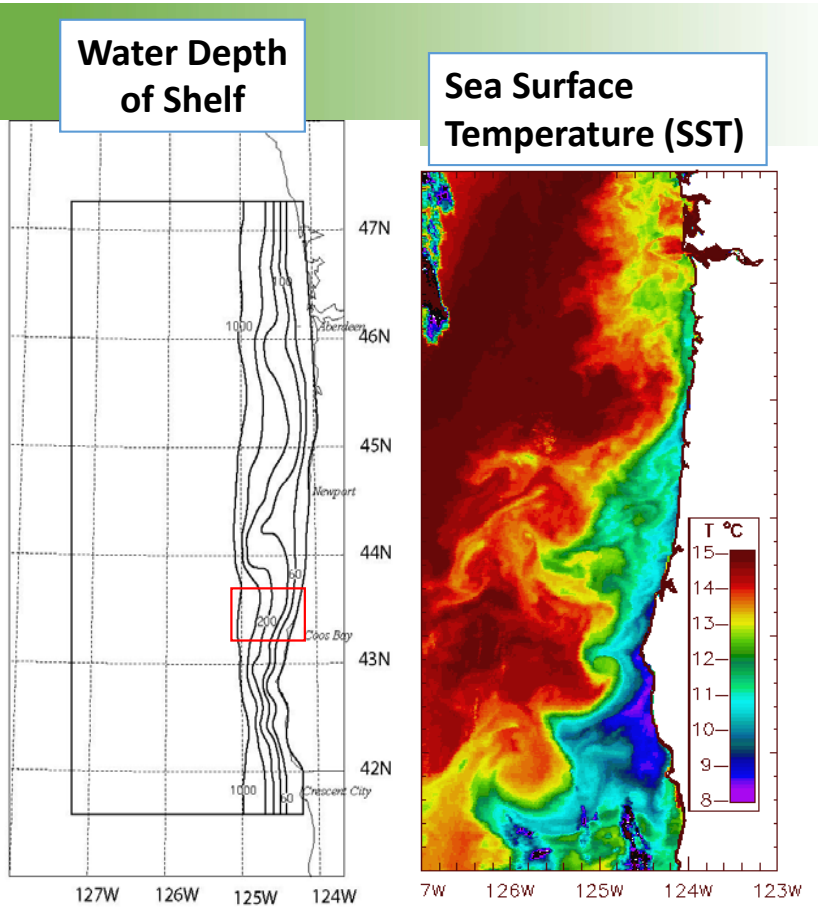
4) Open ocean influences

1) Shallow Water Depth

- **Wind Effect** – wind impact on the water column is ***inversely proportional*** **to water depth** and ***amplified*** **in the shallow coastal water**

- **Friction Effect** – **bottom friction** can be readily felt by water through the water column

- **Amplification of Tide and Tidal Current** – due to constraint on the volume capacity and intensified tidal mixing, i.e. **same amount of the water mass from *deep* open ocean has to 'squeeze' in the *shallow* water**

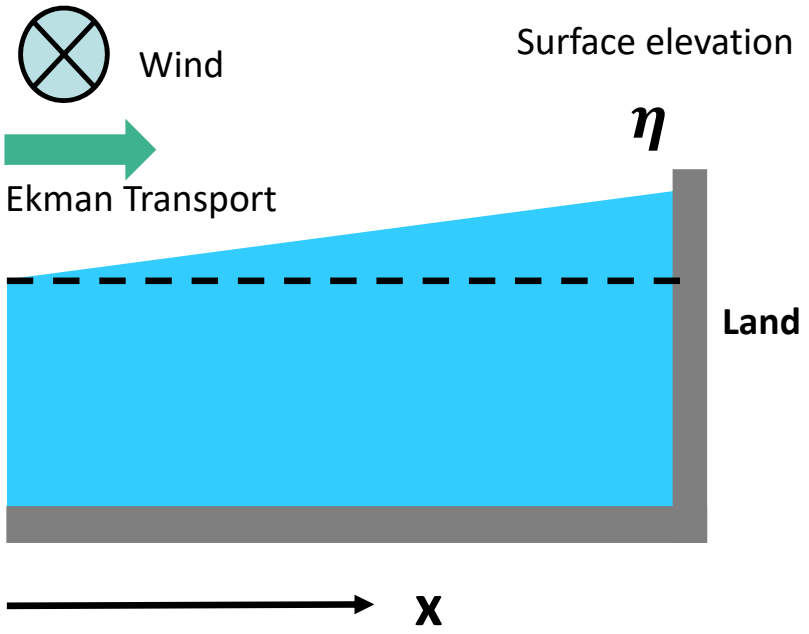


Location of cold temperature matches with topographic feature off the west coast of U.S. (Gan *at al*., 2002), indicating the control of water depth.

2) Presence of Coastline

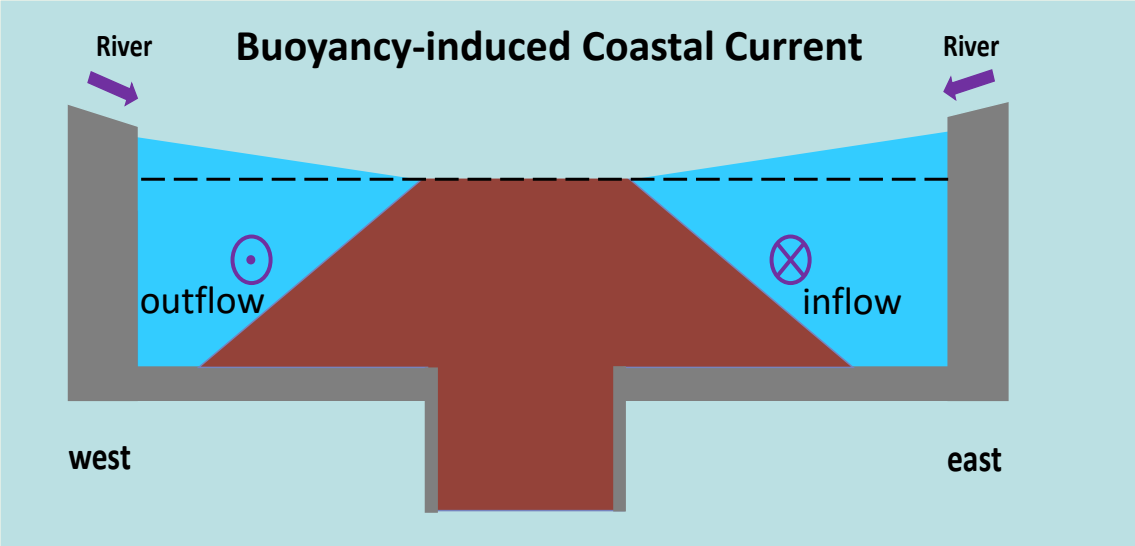
- **Block the water on landside**, resulting **convergence** or **divergence** when flow arrives at or departs the coast *(figure shows convergence case)*;
- **Sea-level increases/decreases**, and leads **surge** *(or storm surge when sea level increases, as shown in the figure)*.

Mass accumulation (convergence) and pressure-gradient set up at coast



3) Terrestrial Influences

- **Freshwater discharge** from land forms **higher sea level**
- Change **buoyancy** and **direction of the current**
- Bring rich **inorganic nutrients and organic matter** to enhance **biological productivity**

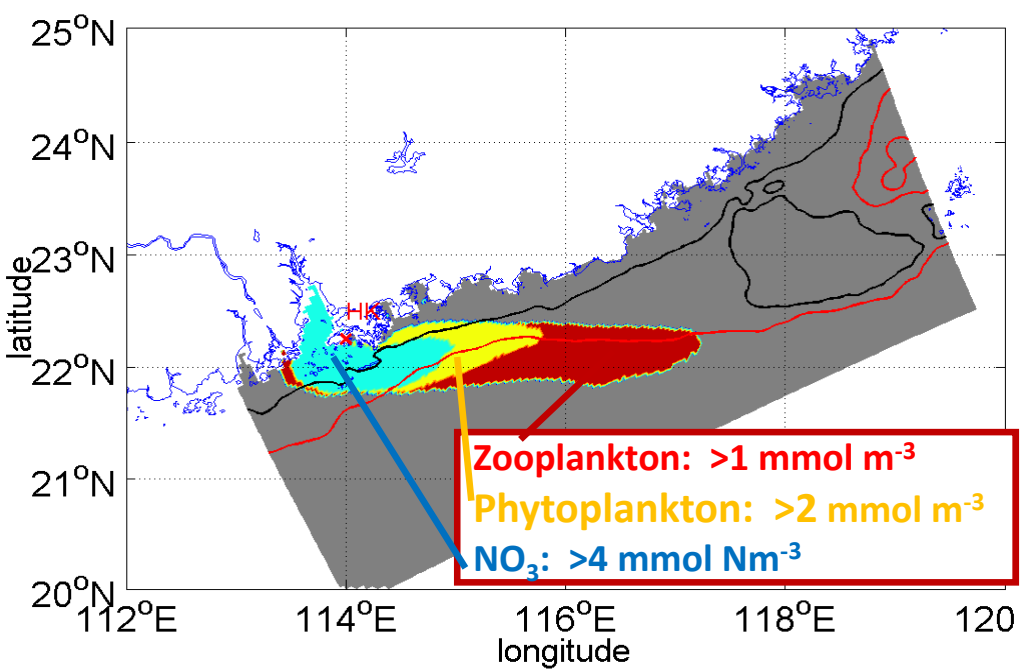


A sketch of the circulation on the shelf produced by freshwater input into the coastal zone.

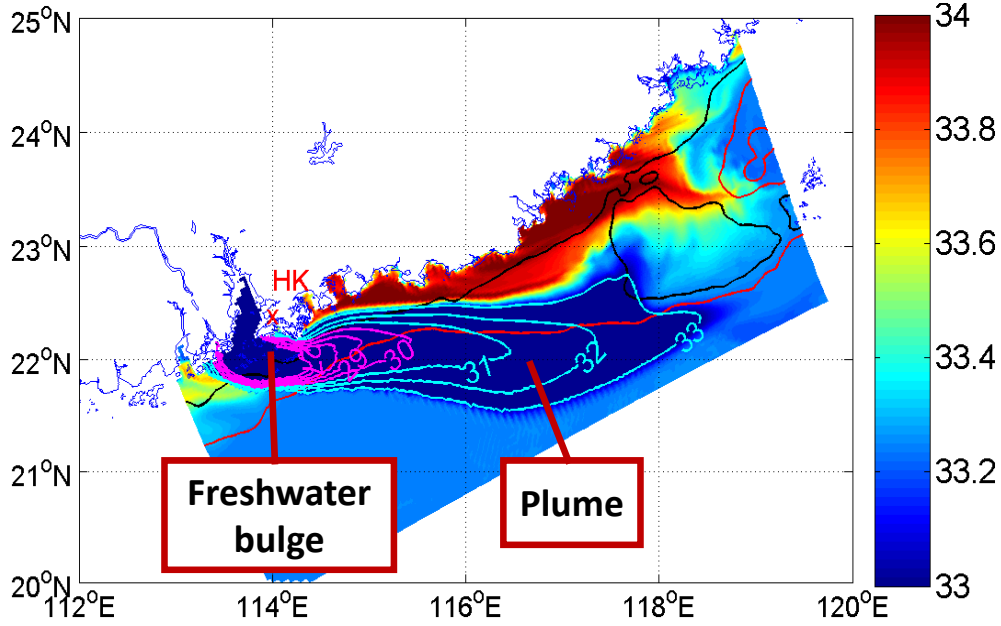
(An ***x in a circle*** indicates a current going ***into*** the page; a ***dot in a circle*** indicates a current coming ***out of*** the page. The reasons for current direction is to be explained.)

3) Terrestrial Influences – Example

Enhanced biological productivity in the bulge due to Pearl River discharge



Freshwater plume



Gan *et al.* (2008, 2010)

4) Open Ocean Influences (Intrusion of Waters from Open Ocean)

- **Large-scale circulation**
  (e.g. Current from South China Sea)
- **Eddies**
- **Internal waves**

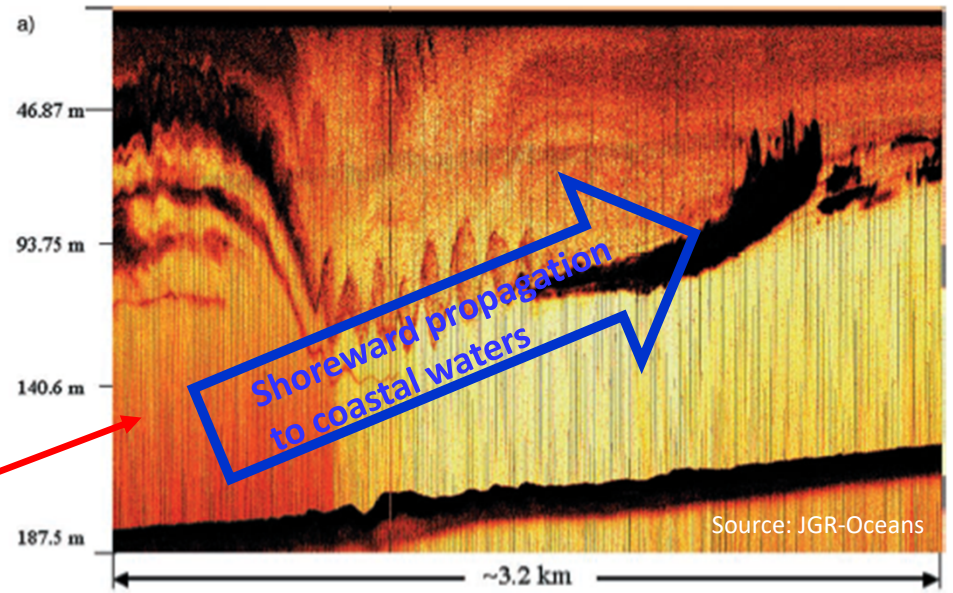
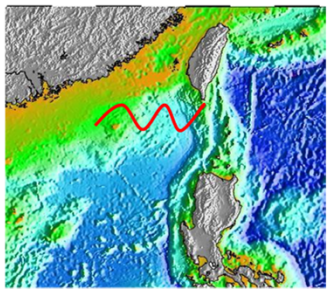


Figure 9. May 7th Internal Wave crossings. (a) Upslope ship track crossing the leading soliton that is in conversion from a depression to an elevation internal wave. Note the large shear instabilities. (b) An expanded section of the shear instabilities at the base of the mixed layer with evidence of mixing in shallower water. (c) A front to rear transect of the upslope propagating internal wave packet showing the depression to elevation conversion zone, elevation waves and a following series of depression solitons.

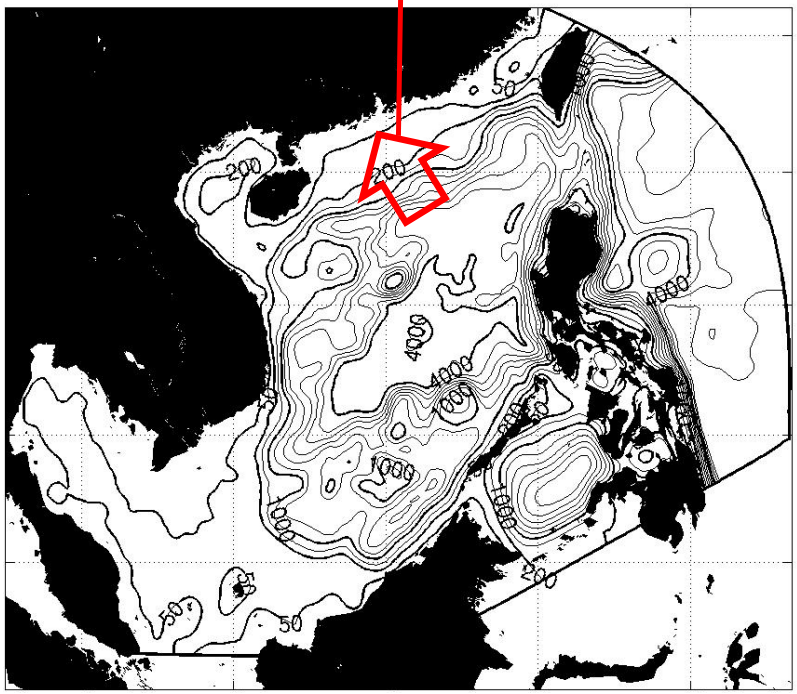


Shoreward propagation of solitary waves, showing the influence of open ocean disturbances on coastal waters. The wave breaking enhances **mixing** and brings **nutrients** to upper layer for **biological bloom**.

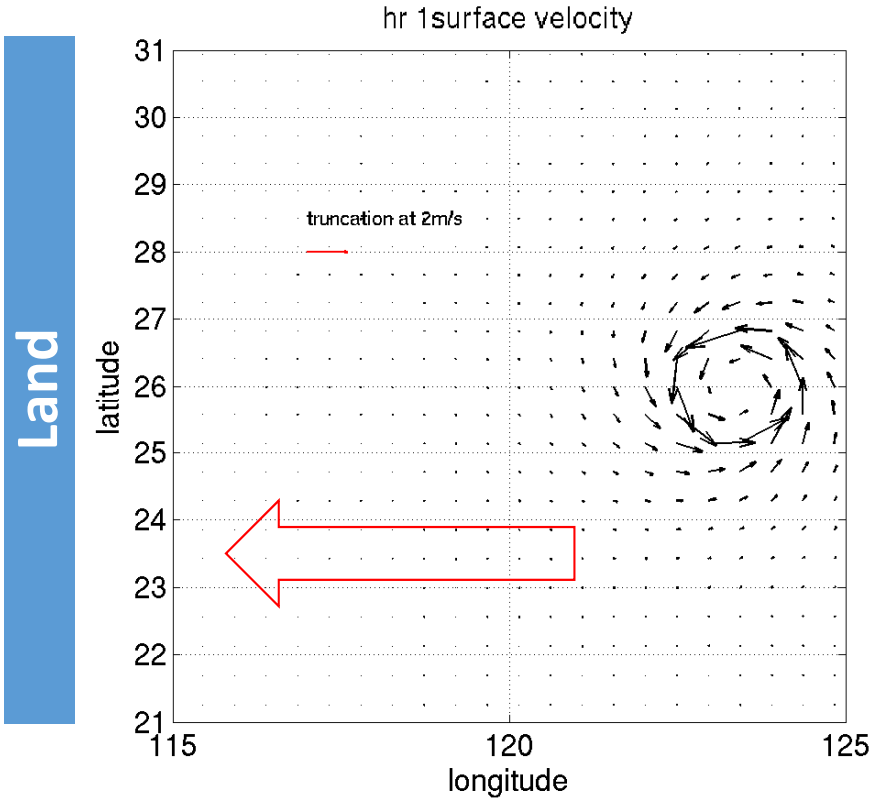
4) Open Ocean Influences

Shoreward Intrusion

Current intruding towards the coastal ocean from South China Sea basin

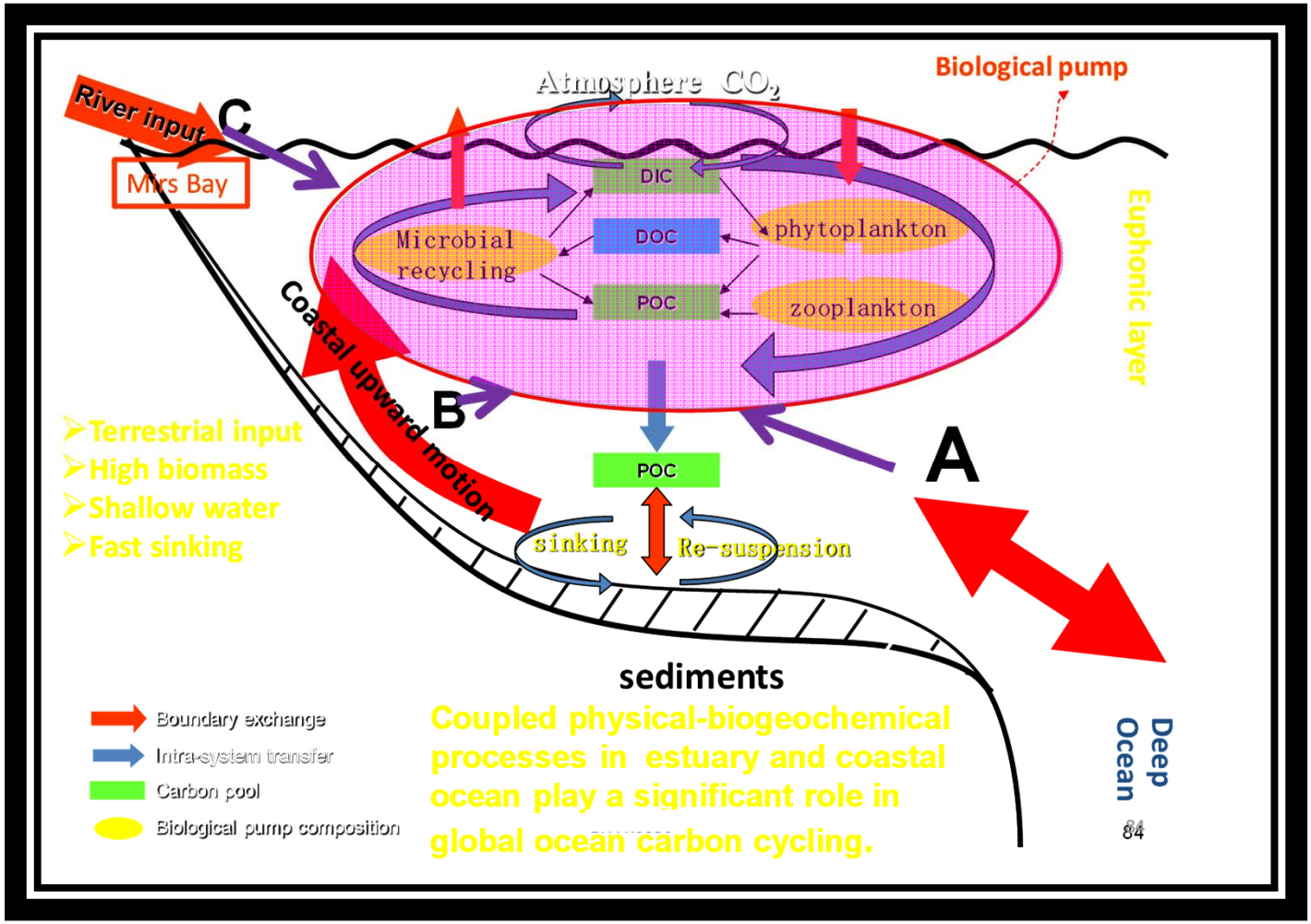


Shoreward Propagation of Eddy



Source: Gan

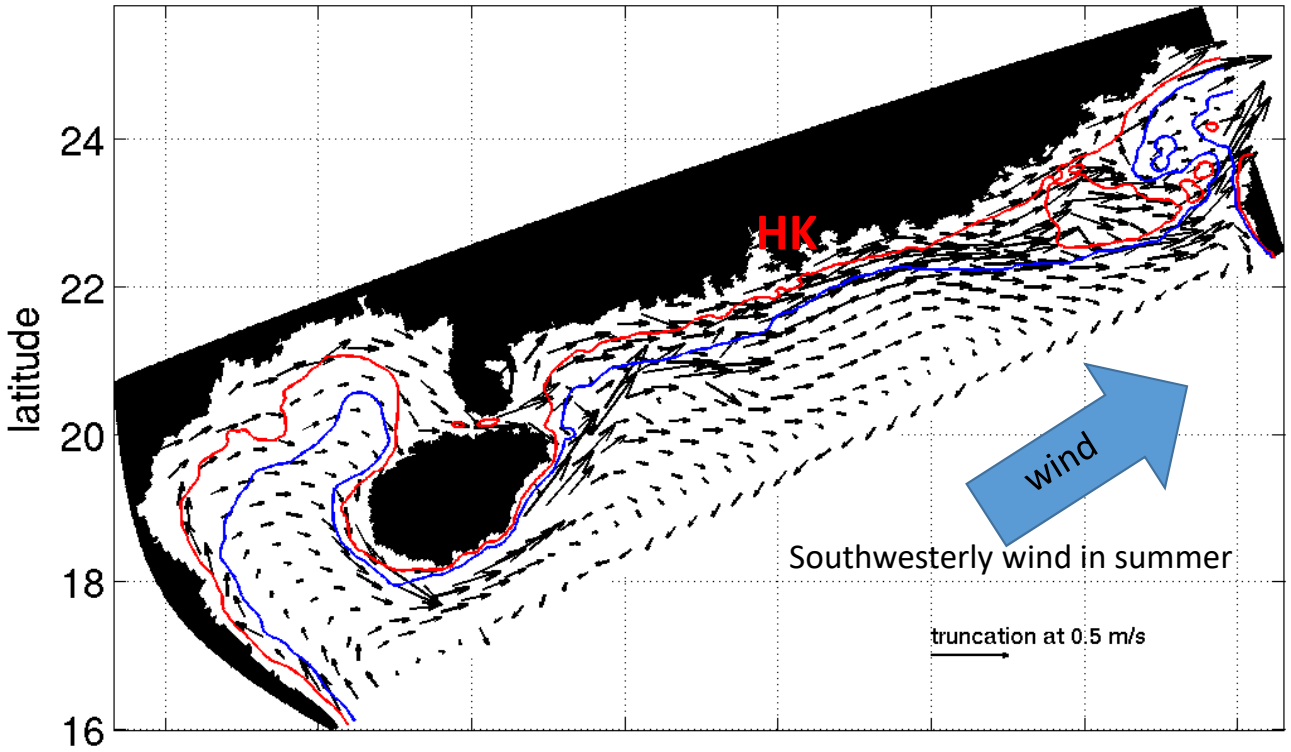
Summary – Biophysical Processes over Coastal and Shelf Sea



- Physically driven water motion and **transport of biogeochemical substances**
- Unique physical characteristics over the shallow water and **linking terrestrial and open ocean waters**
- Active hydrodynamics and thus relatively **high biological productivity**

Source: Dai & Gan

Example of Wind-driven Current in the Northern South China Sea



What Drives the Motion of Water in the Ocean?

Key points:

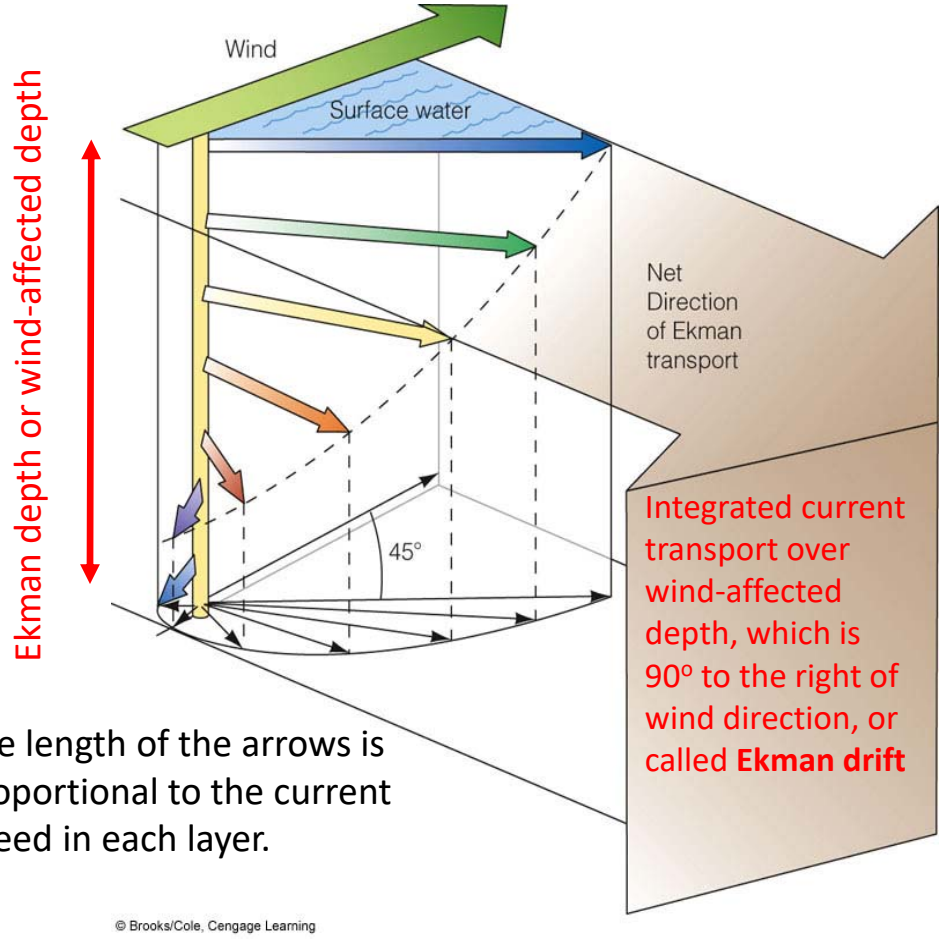
1. The **wind** drags the surface ocean motion, then drags the motion below, and it goes on until the depth where wind energy cannot reach

2. The combined effect of **wind forcing** and **Earth rotation** leads to **Ekman Transport (Drift)**

Ekman Transport (Drift)

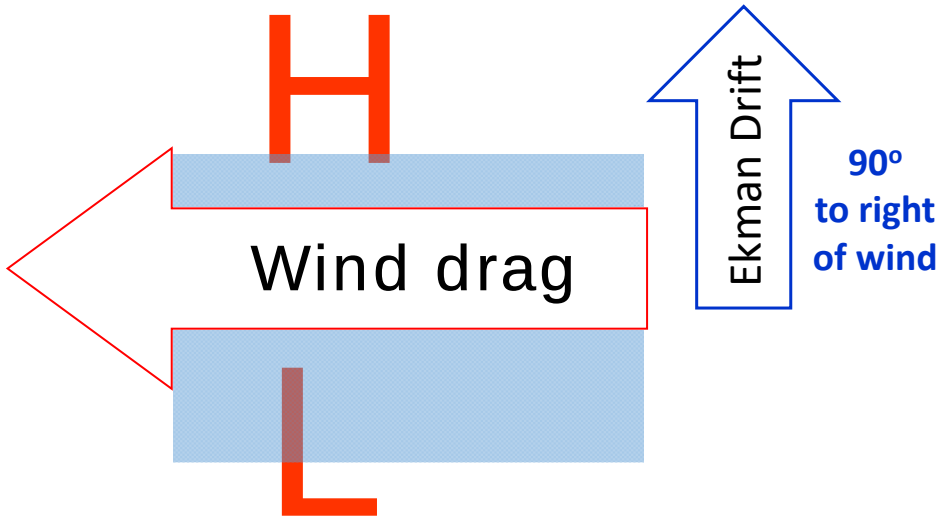
The Ocean is mainly driven by wind stress, via Ekman Spiral and the mechanism by which it operates.

- The **surface current deviates 45° to the right of the wind direction.**
- The direction of current **deviates further to the right** relative to the current above and forms a **spiral pattern** in the water column.
- The **Ekman Spiral** is the result of the ***balance* between the wind-induced forcing and Earth rotation** in the water column.
- **Ekman Transport** is the **average current** within the Ekman spiral.



Formation of Sea-Level Difference (Sea Level Gradient)

Pile-up water mass and form a higher surface elevation or higher pressure



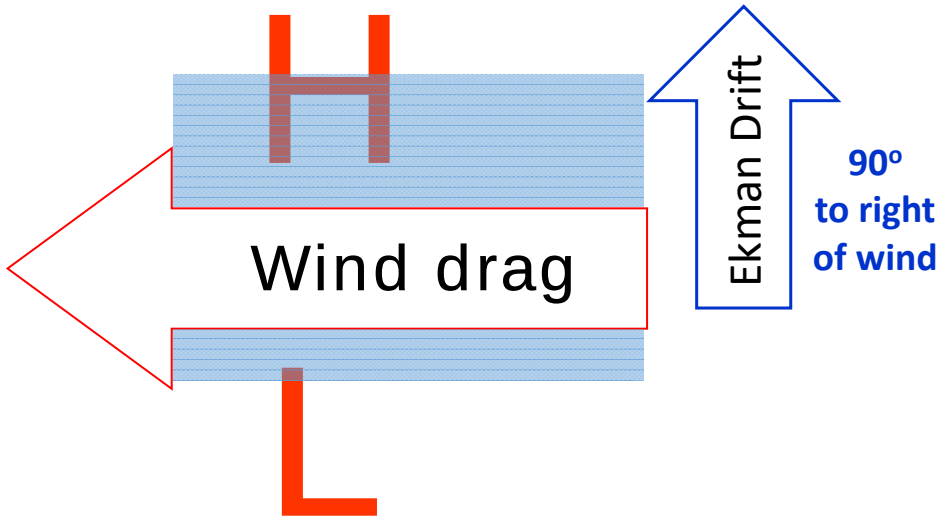
Lower surface elevation or lower pressure

The ***net*** **movement of the wind-driven flow or Ekman Drift**, after averaging over the Ekman layer, is **90º to the *right* of the wind.**

Ekman Drift forms sea-level difference.

Formation of Sea-Level Difference (Sea Level Gradient)

Pile-up water mass and form a higher surface elevation or higher pressure



Lower surface elevation or lower pressure

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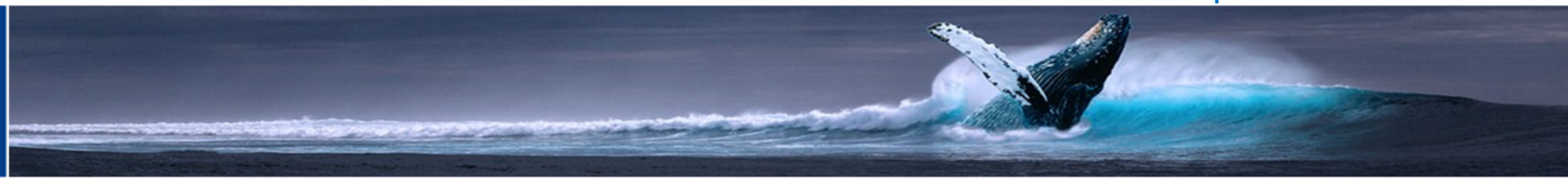
Ekman Drift forms sea-level difference.

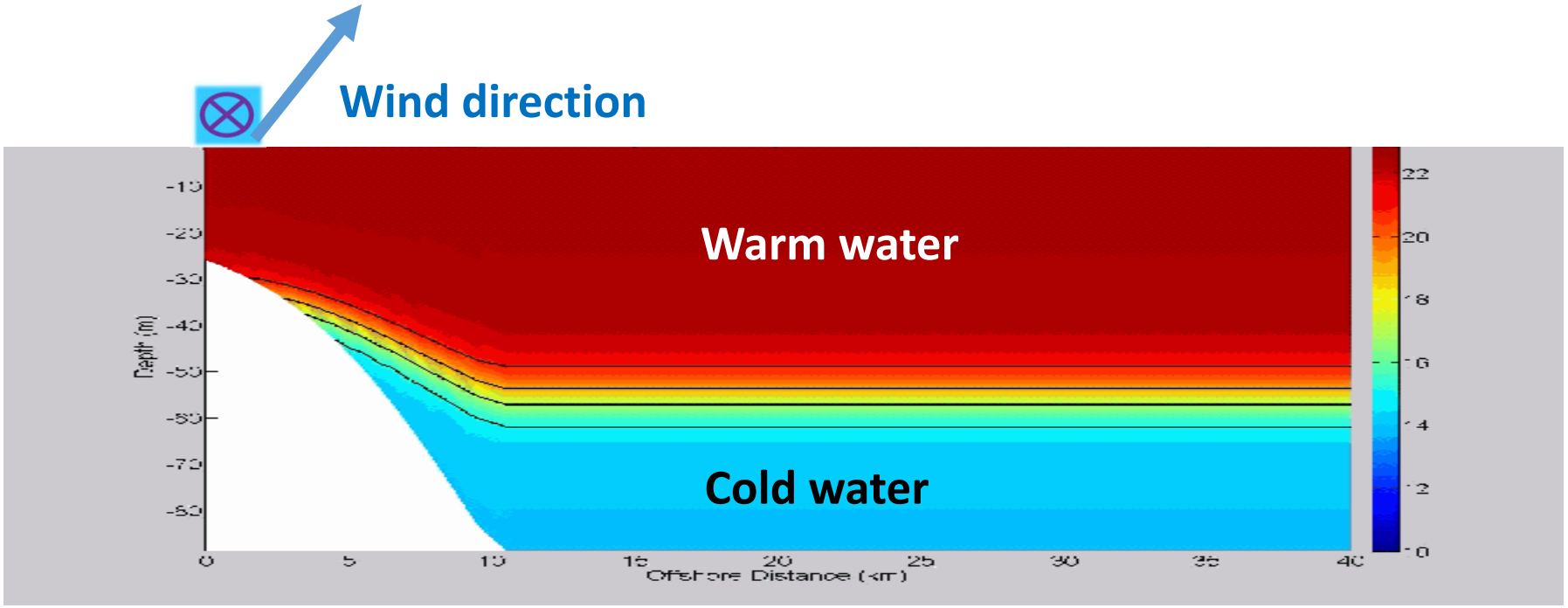
Summary – Wind-Driven Coastal Circulation

- **What powers the upper ocean motion?**
  - The movement of **upper ocean is powered mainly by winds via the Ekman Transport.**

- **How does Ekman Transport lead to the motion in the ocean ?**
  - The **wind drags ocean motion** through **Ekman Spiral** and **Ekman Transport**.
  - The **Ekman Transport forms sea-level difference**.
  - The **wind-driven Ekman Transport is the fundamental physics** that provides the transports in the coastal and shelf sea.



Upwelling Process



Source: Gan

Vertical Temperature Profile

Overview – Coastal Upwelling & Downwelling

- **Why coastal ocean has a high biological productivity?**
- **How is the biogeochemical substance in the coastal ocean transported effectively offshore?**

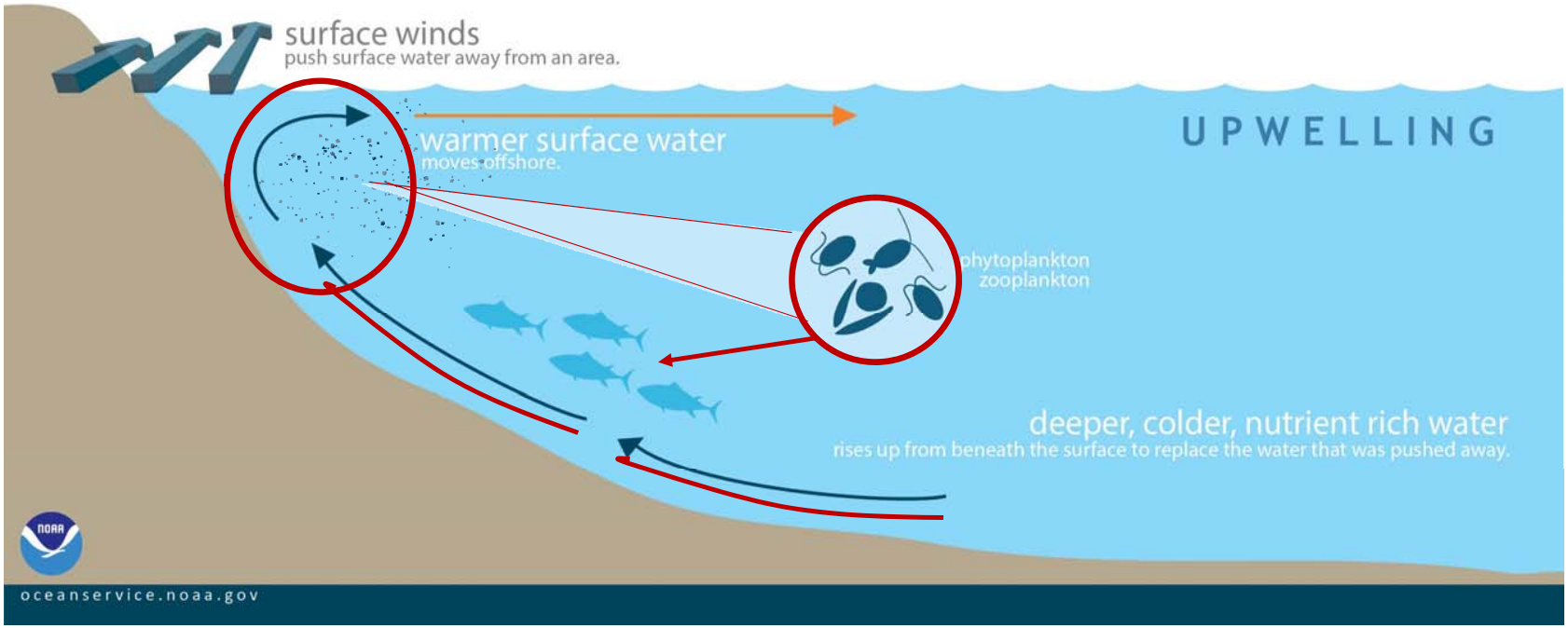
Key points:

- As a result of the **characteristics of coastal and shelf sea** (outlined before) and **Ekman transport**, **coastal upwelling or downwelling** are formed
- Coastal upwelling and downwelling processes are the prominent phenomena that govern the **transport of nutrients** for the formation of **biological blooms** and **rich fishing grounds** in many of the coastal and shelf seas around the world

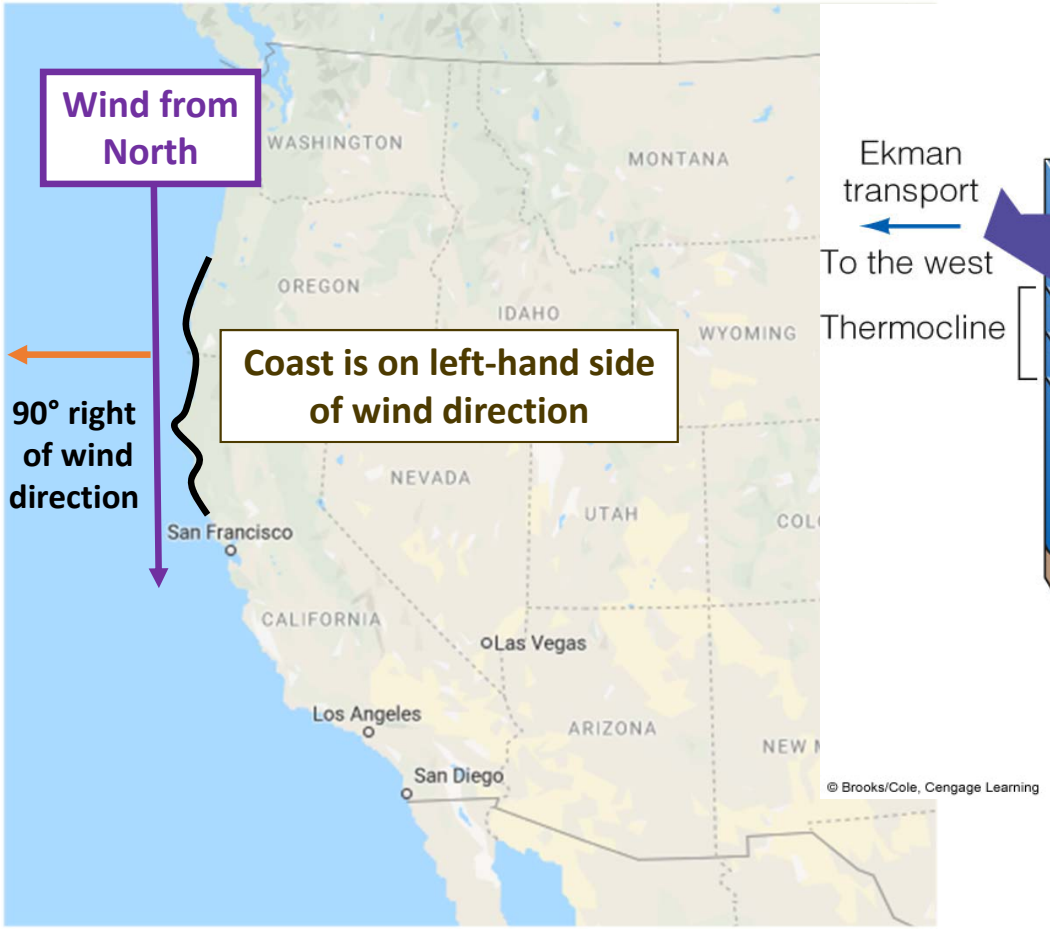
What is Coastal Upwelling?

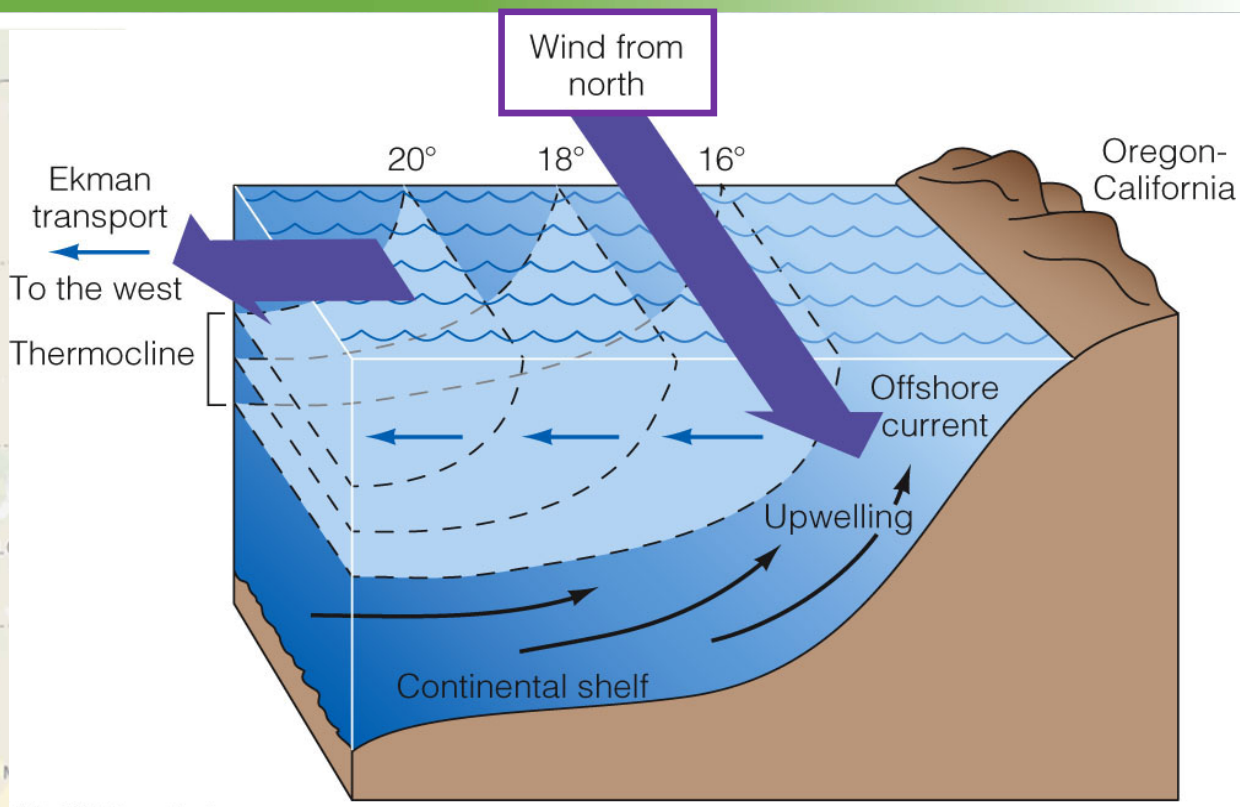
Wind can induce Coastal Upwelling:

- Where Ekman transport moves surface water **away from** the coast (land), surface waters are **replaced by water that wells up from below**.



Wind can induce Upwelling near Coasts

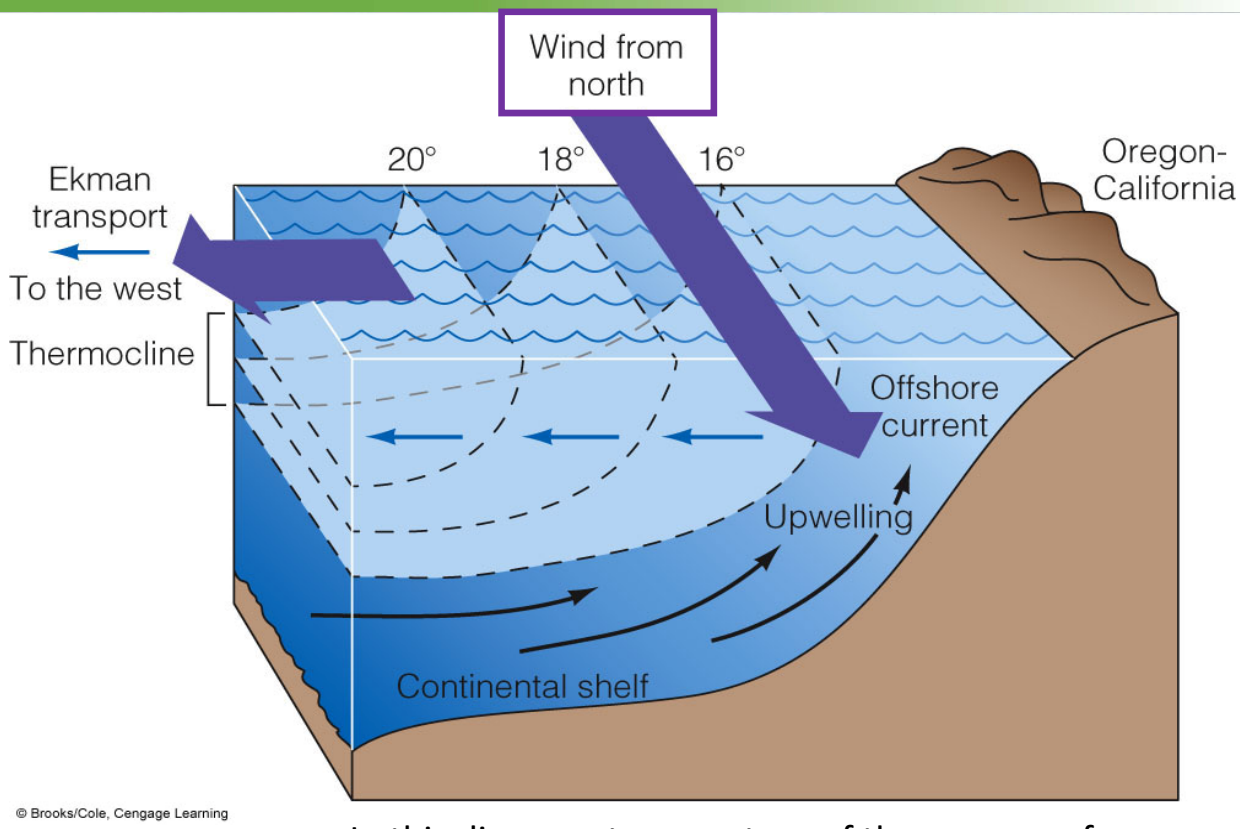




In this diagram, temperature of the ocean surface is shown in degrees Celsius.

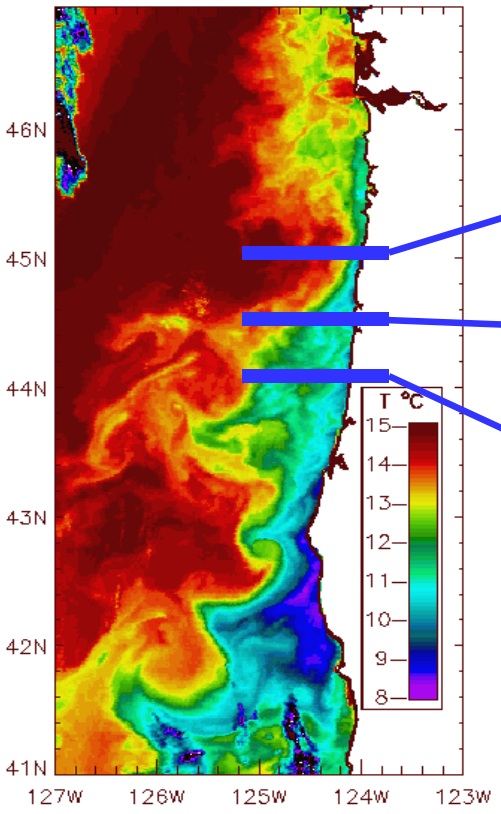
Wind can induce Upwelling near Coasts

- In the **Northern Hemisphere**, coastal **upwelling** can be caused by **winds from the north** blowing along the west coast of a continent.
- Water moved offshore by Ekman transport in the surface layer is **replaced by the upwelled cold, deep, nutrient-laden water**.

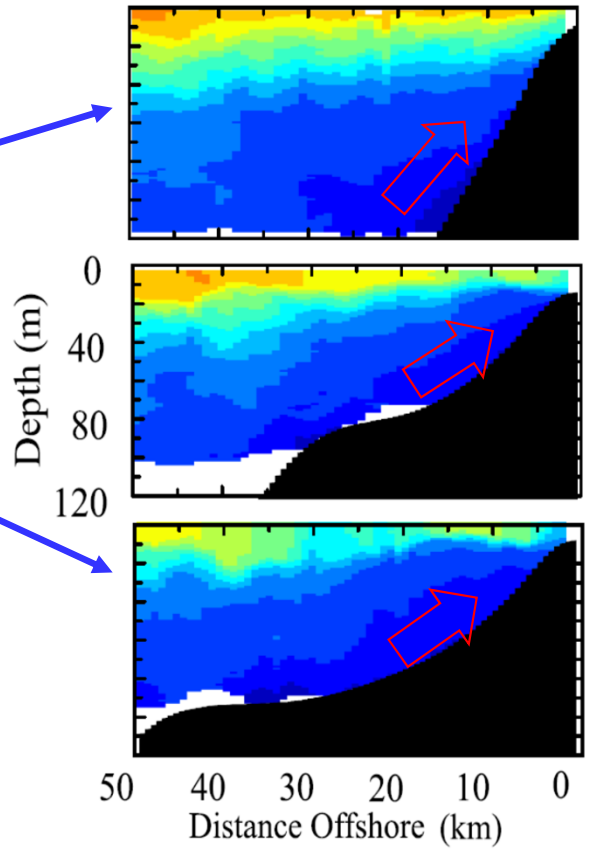


In this diagram, temperature of the ocean surface is shown in degrees Celsius.

Formations of Upwelling of Cold Coastal Waters



Gan & Allen (2005)



Barth *et al.* (2003)

Upwelling of **cold deep water** off Western Coast, U.S.

Processes in Coastal Upwelling

When winds blow parallel to the coast, **Ekman transport is directed 90° to the right** and results in **sea-level difference**.

↓

Upwelling: Offshore surface **Ekman transport moves near-shore water offshore**, and the **water below moves upward** (upslope) to compensate the loss of near-shore waters or upwelling.

↓

High in Nutrients: **Colder nutrient-rich waters from deep ocean** are uplifted onto the shelf.

↓

Rich Biological Productivity: >50% of the world's annual **commercial fishing** occurs in the upwelling zone.

Upwelling zones around the world

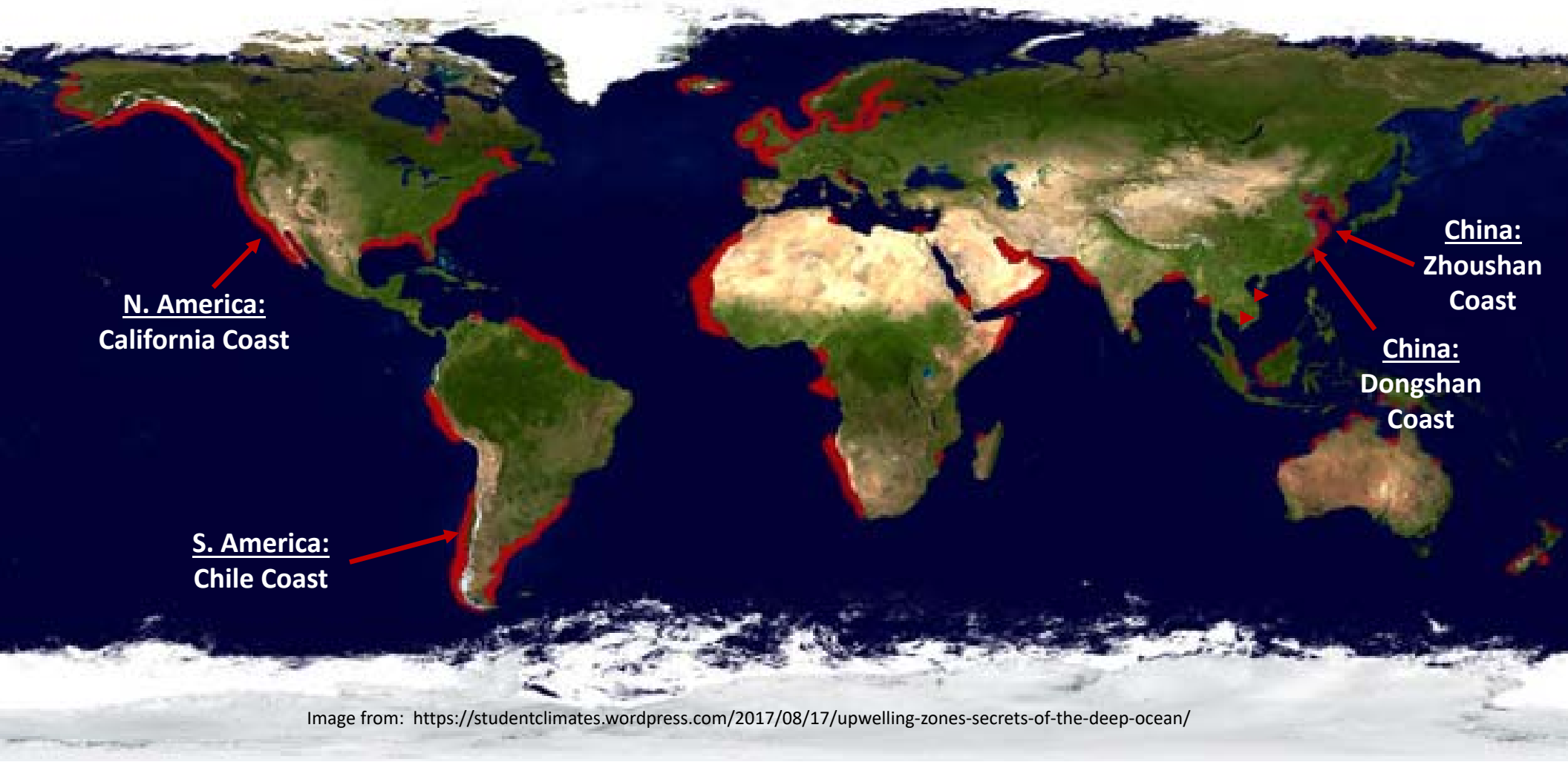
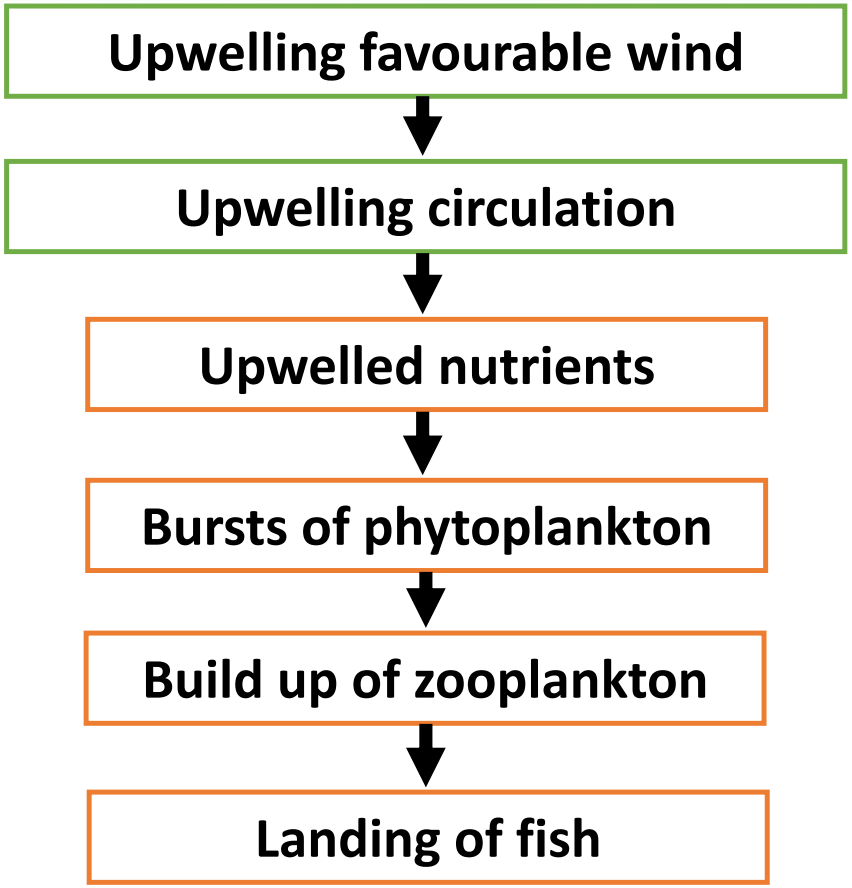
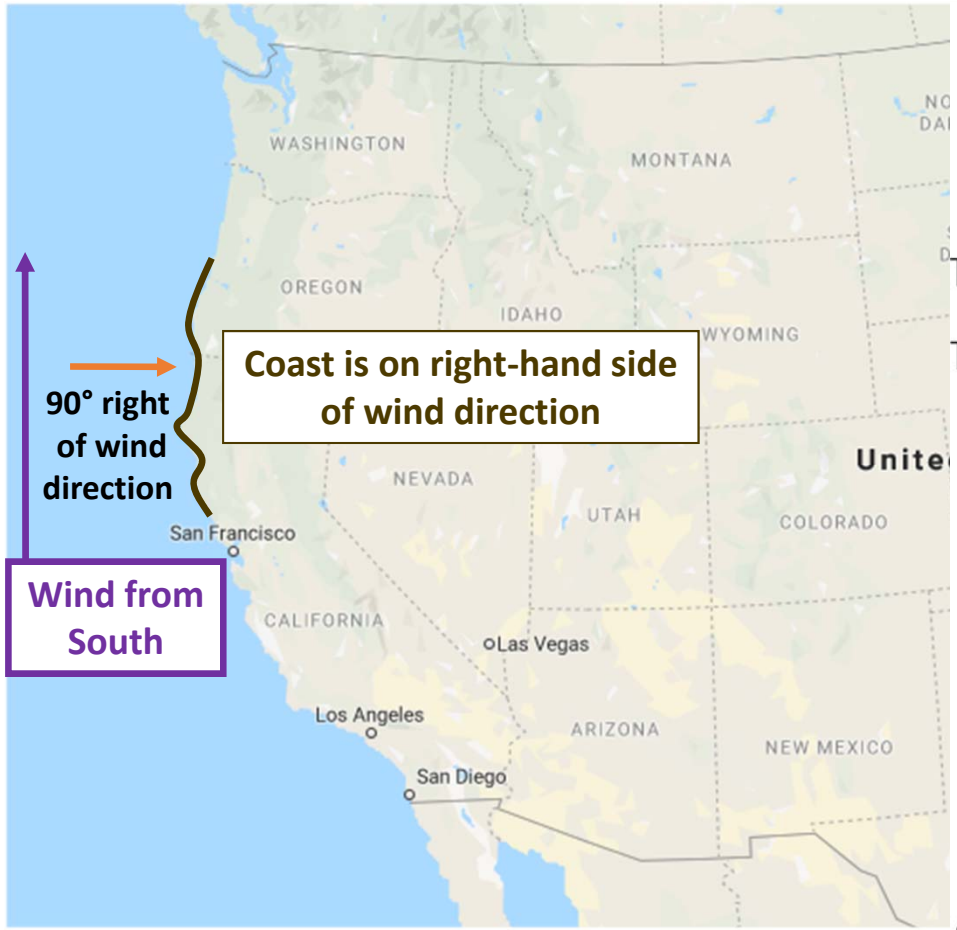


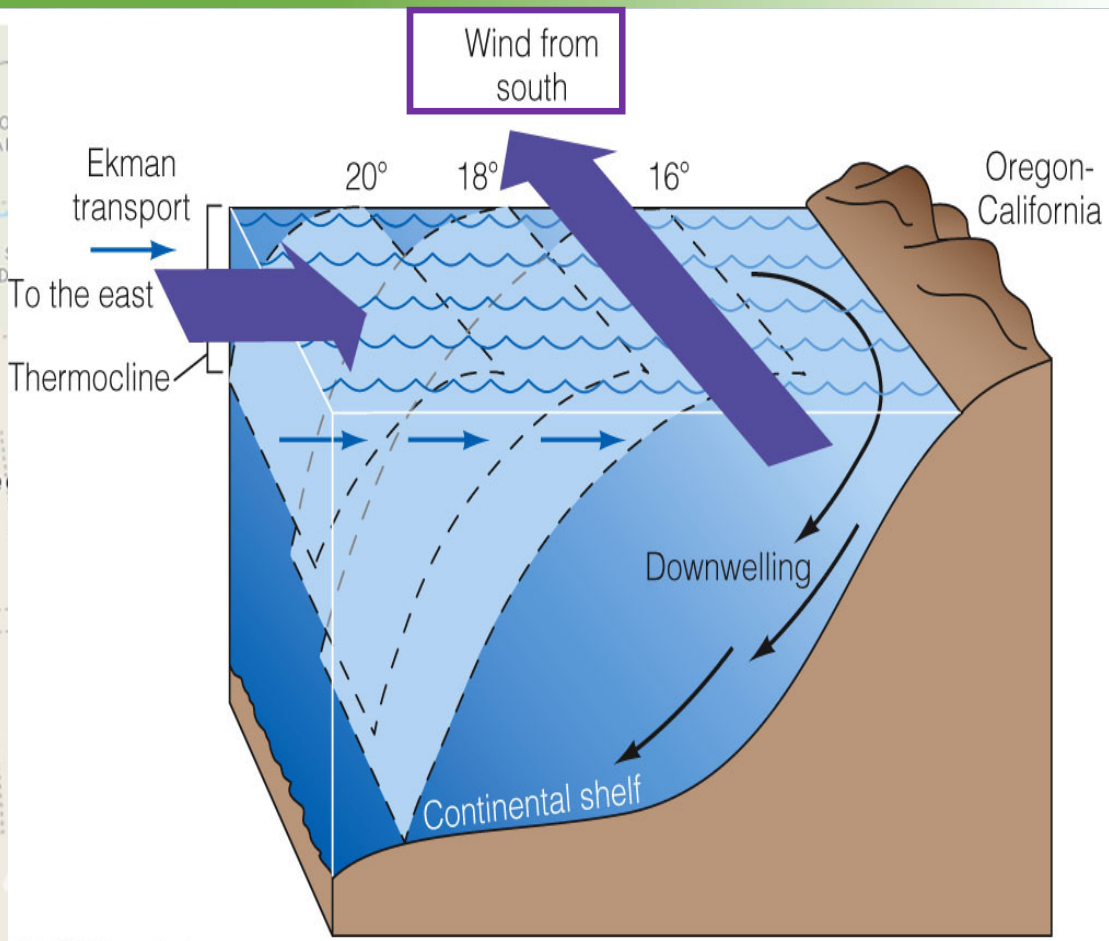
Image from: https://studentclimates.wordpress.com/2017/08/17/upwelling-zones-secrets-of-the-deep-ocean/

Upwelling & Fish



Wind can also Induce Coastal Downwelling



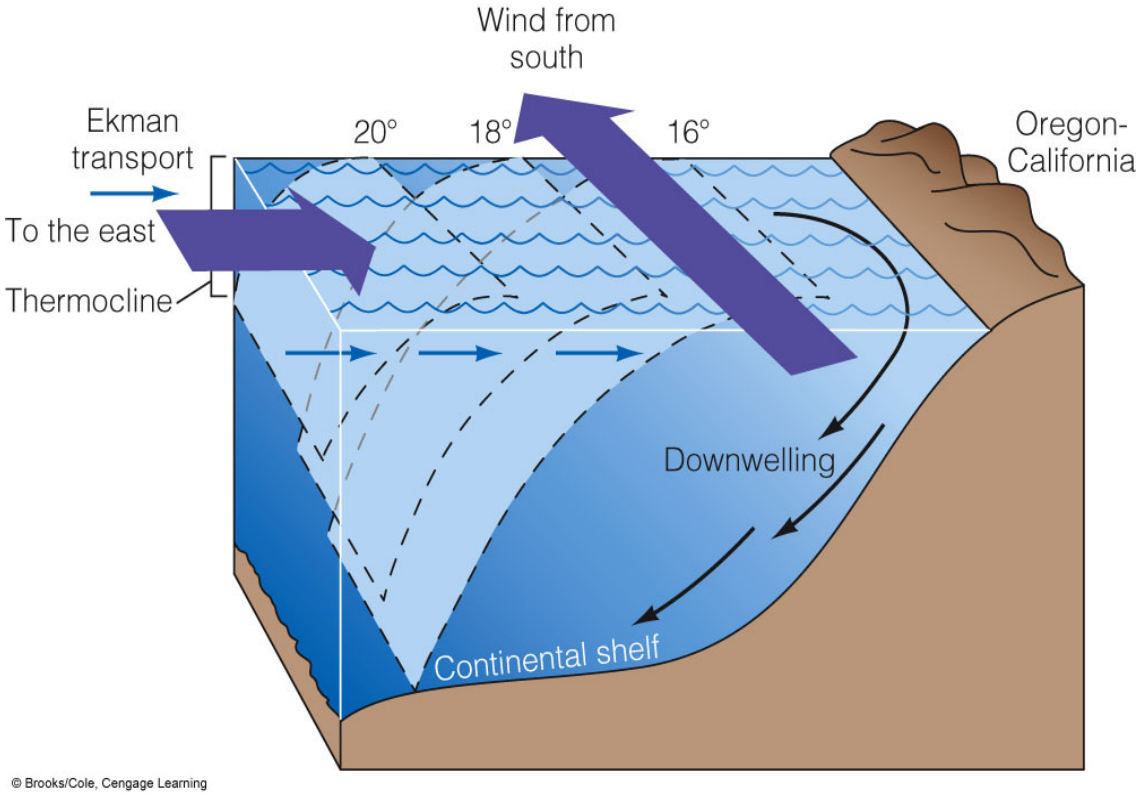


Wind can also Induce Coastal Downwelling

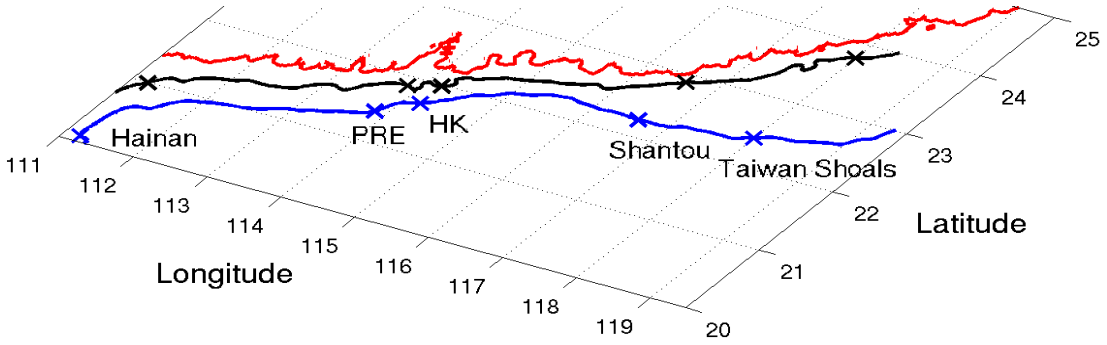
Coastal Downwelling

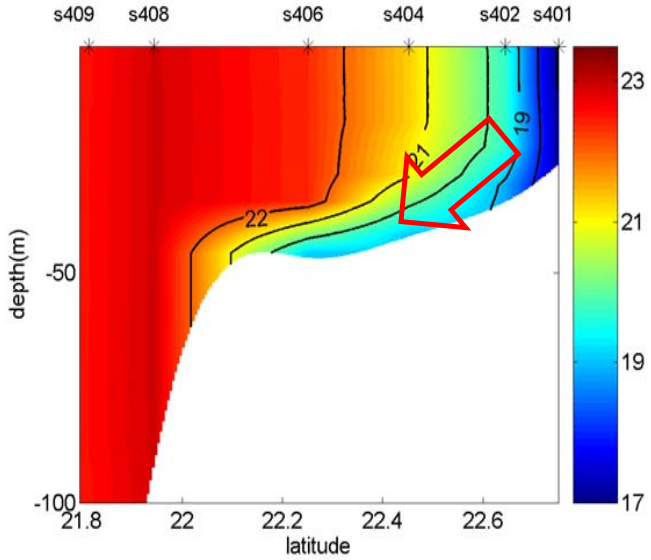
- **Wind blowing from the south** along a **Northern Hemisphere** west coast for a prolonged period can result in **downwelling**

- Areas of downwelling are often **low in nutrients** and therefore **relatively low in biological productivity**



Observed Downwelling – Example



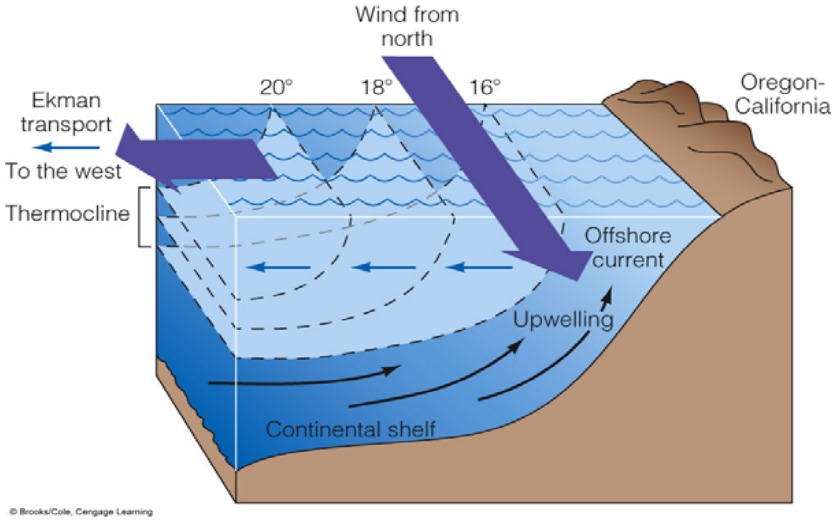


Gan *et al.* (2012)

Observed downwelling off Guangdong.

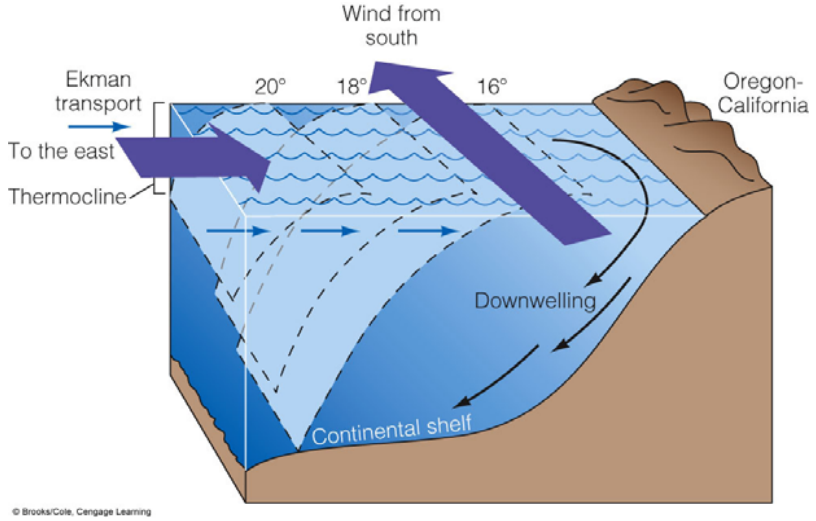
Cold coastal water is transported downslope during downwelling.

Summary – Coastal Upwelling & Downwelling Transport



Upwelling

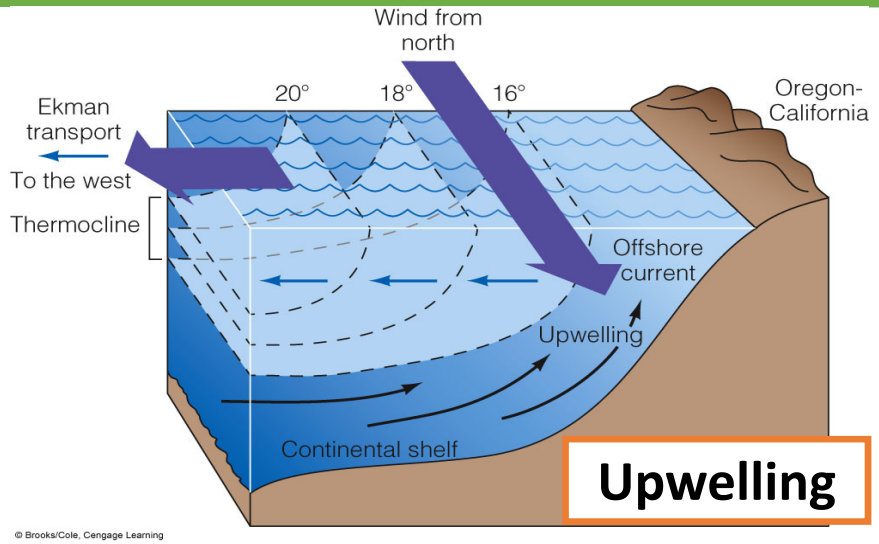
- Where Ekman transport moves surface water **away from the coast** (land), surface waters are replaced by water that **wells up from below**.

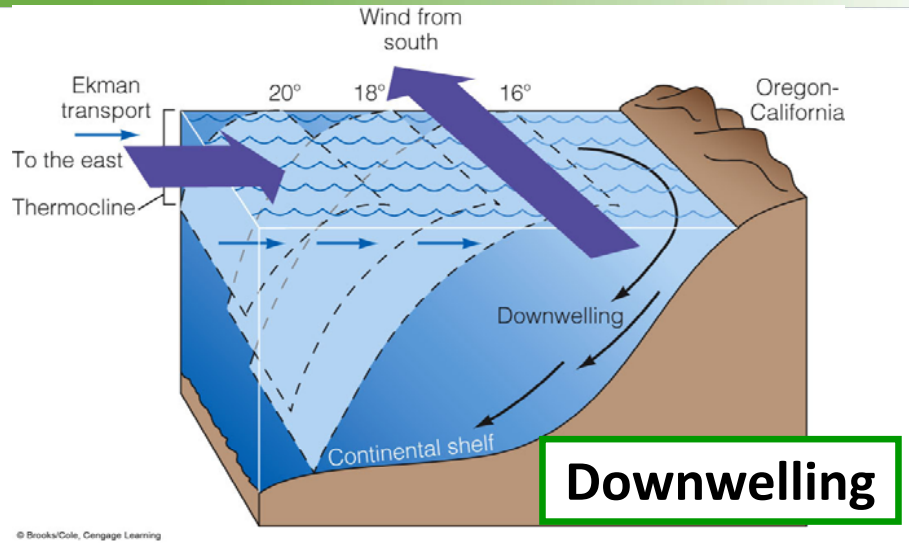


Downwelling

- Where Ekman transport moves surface water **towards the coast** (land), water **piles up and sinks** towards the bottom.

Summary – Coastal Upwelling & Downwelling Transport





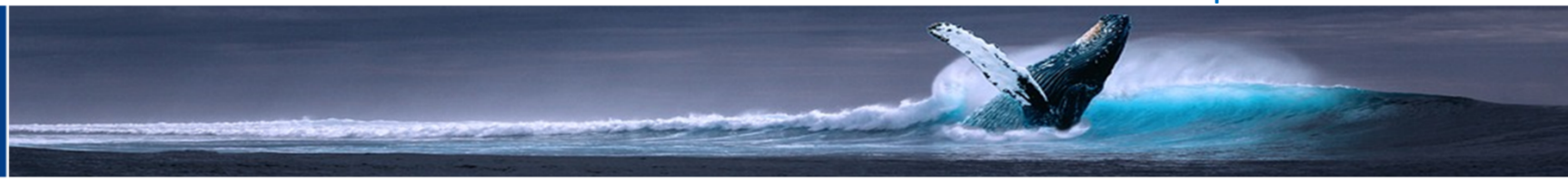
Combined effects of coastal ocean **characteristics** (e.g. shallow water, presence of coast) and wind-induced **Ekman transport**, coastal ocean forms **coastal upwelling (downwelling) or upslope (downslope) transport of the deep (surface) water.**

Summary – What is Coastal Upwelling & Downwelling?

- **What is Upwelling and Downwellling?**
  - **Upwelling (wind from Northern Hemisphere)** – Where Ekman transport moves surface water ***away from*** **the coast (land),** surface waters are **replaced by water that wells up** from below.
  - **Downwelling (wind from Southern Hemisphere)** – Where Ekman transport moves surface water ***towards*** **the coast (land), water piles up and sinks** towards the bottom.

- **What is the outcome in the processes of Coastal Upwelling?**
  - **Upwelling zones contain cold, nutrient-rich waters** that are lifted from deep ocean to the shelf

- **What is the relationship between upwelling and fish?**
  - **Upwelling of nutrients** gives rise to **bursts of phytoplankton, zooplankton, and fish landing**, which provide human with rich fishing grounds.



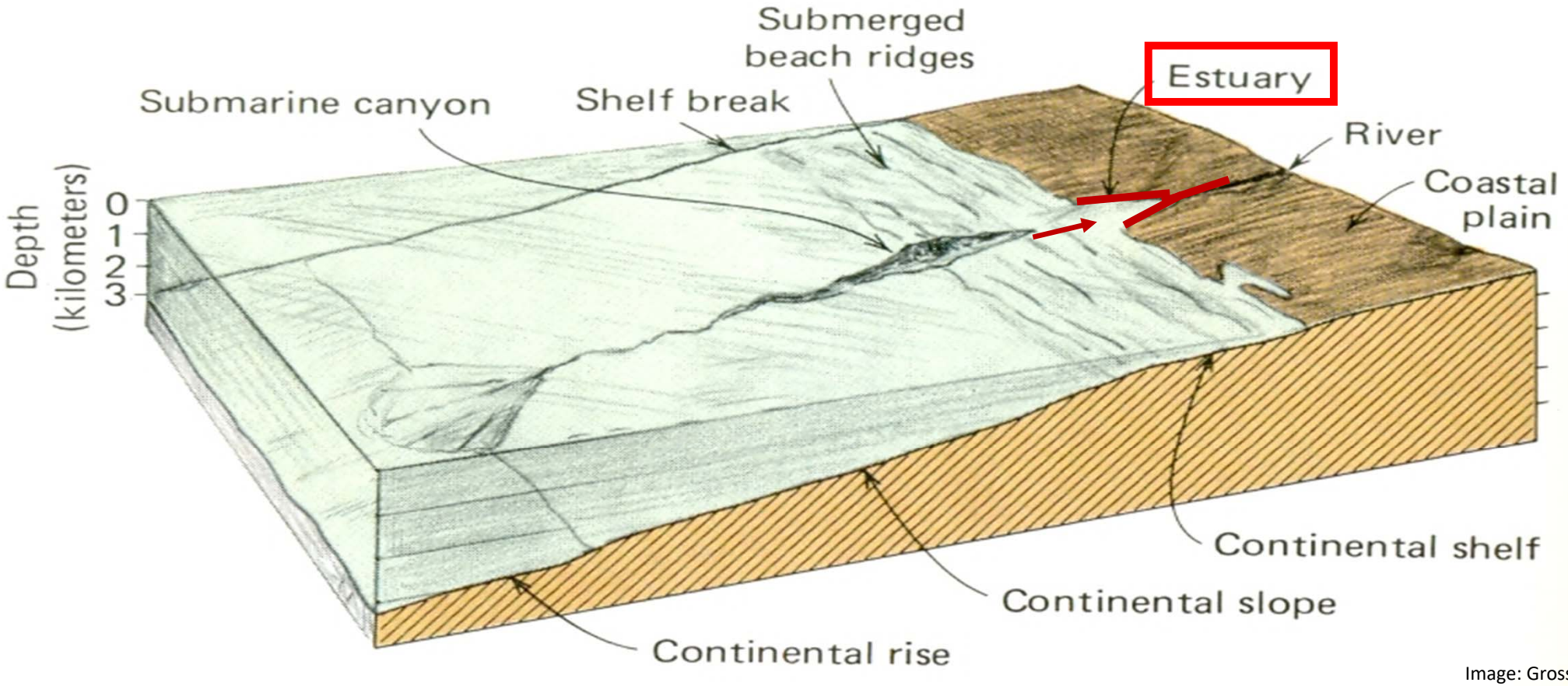


Image: Gross

DEPARTMENT OF OCEAN SCIENCE

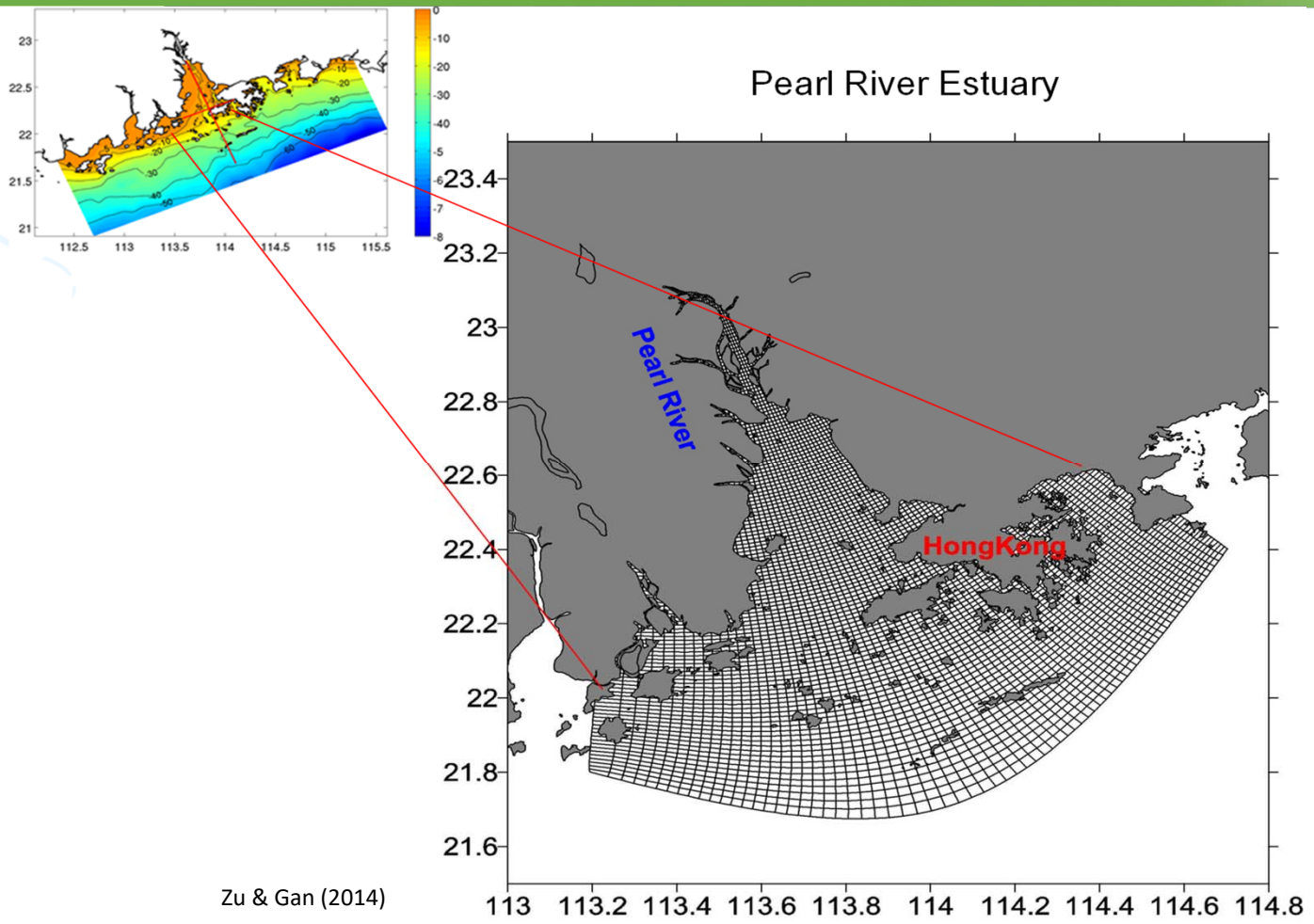
Estuary & Estuarine Circulation

Overview – Estuary & Estuarine Circulation

Estuary

- A **semi-enclosed** coastal body of water which has a **free connection with the open sea** at the entrance and **receives freshwater from river at the head**
- The place **where lighter freshwater and heavier seawater meet**
- **Freshwater from river moves seaward in the *upper* layer** and **saltwater from ocean flows landward in the *lower* layer**

Example – Pearl River Estuary



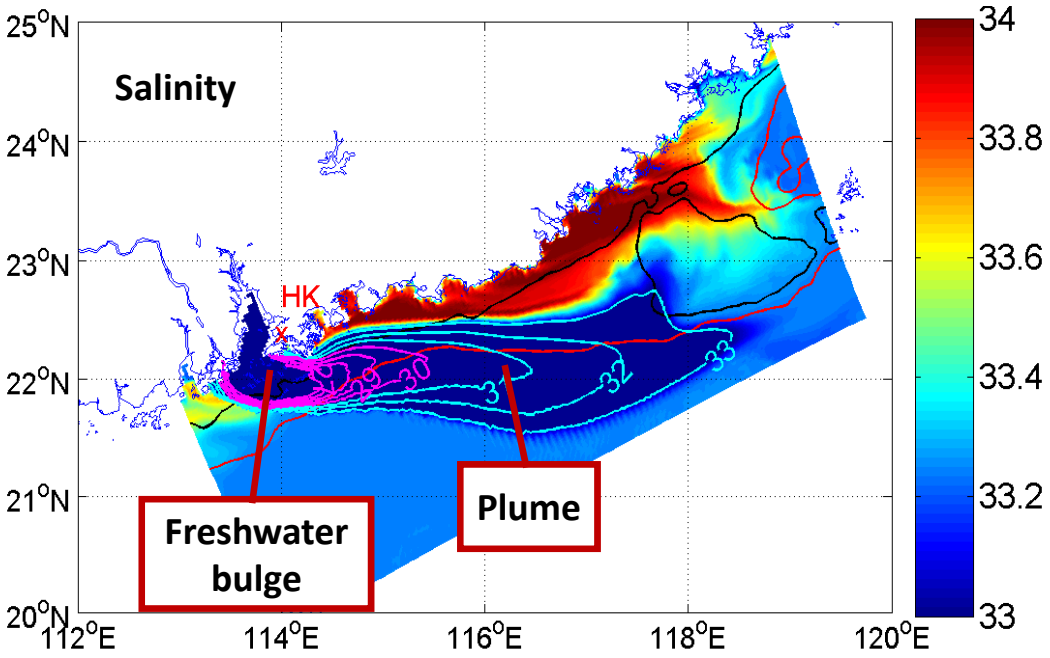
Zu & Gan (2014)

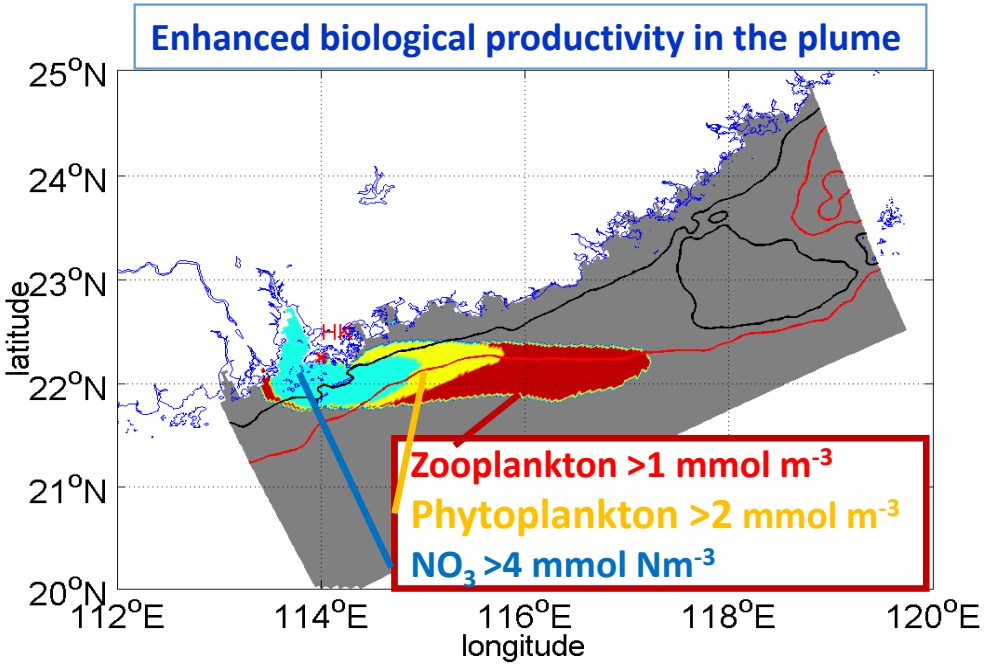
Pearl River Estuary

- Situated along the southern coast off China as a **semi-closed coastal embayment**
- A typical estuary that links with **Pearl River at the head** of the estuary, and with **continental shelf at the entrance**

River Plume

River Plume – The freshwater from the river discharges onto the shelf region in which **biological productivity is increased**

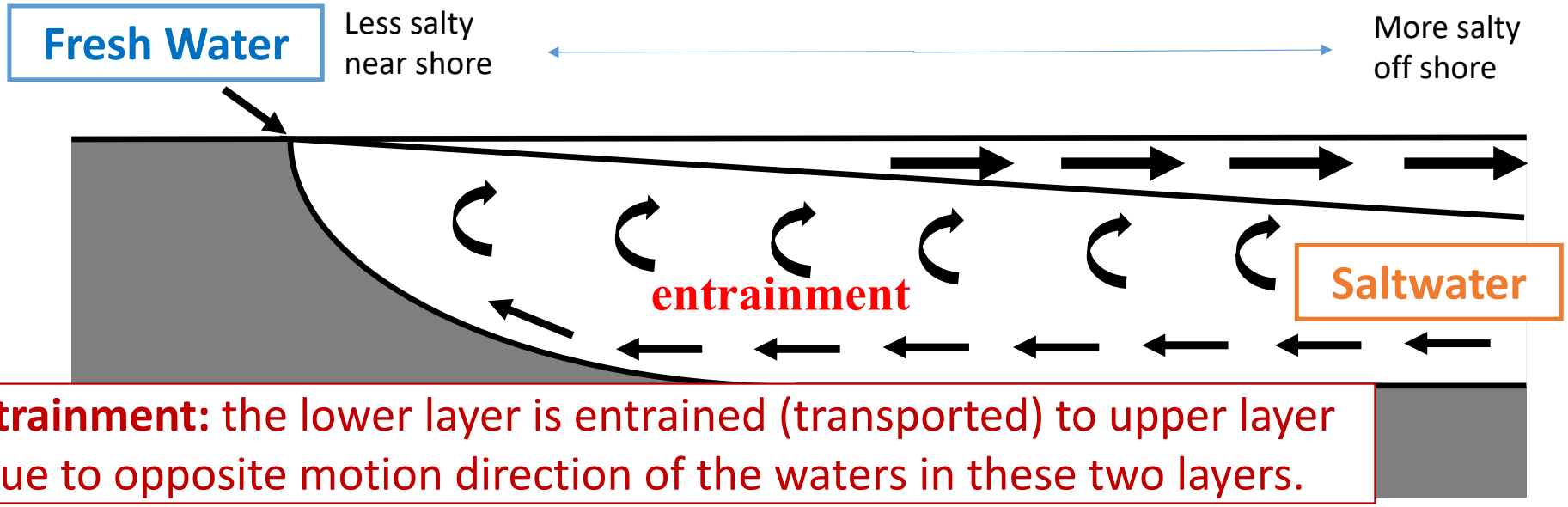




Gan *et al.* (2008)

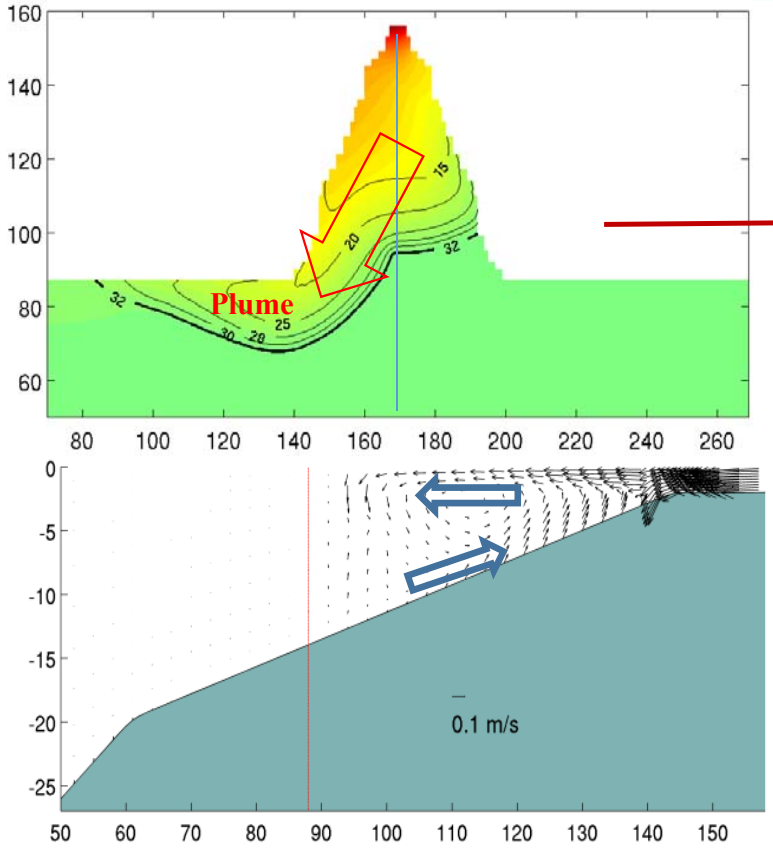
Estuarine Circulation

Estuarine Circulation – Freshwater entering the head of the estuary creates an **outflow of freshwater in the surface, and a compensating inflow of saltier water**. The **upper layer gets thicker** as it moves offshore because saltwater is entrained from below.



Entrainment: the lower layer is entrained (transported) to upper layer due to opposite motion direction of the waters in these two layers.

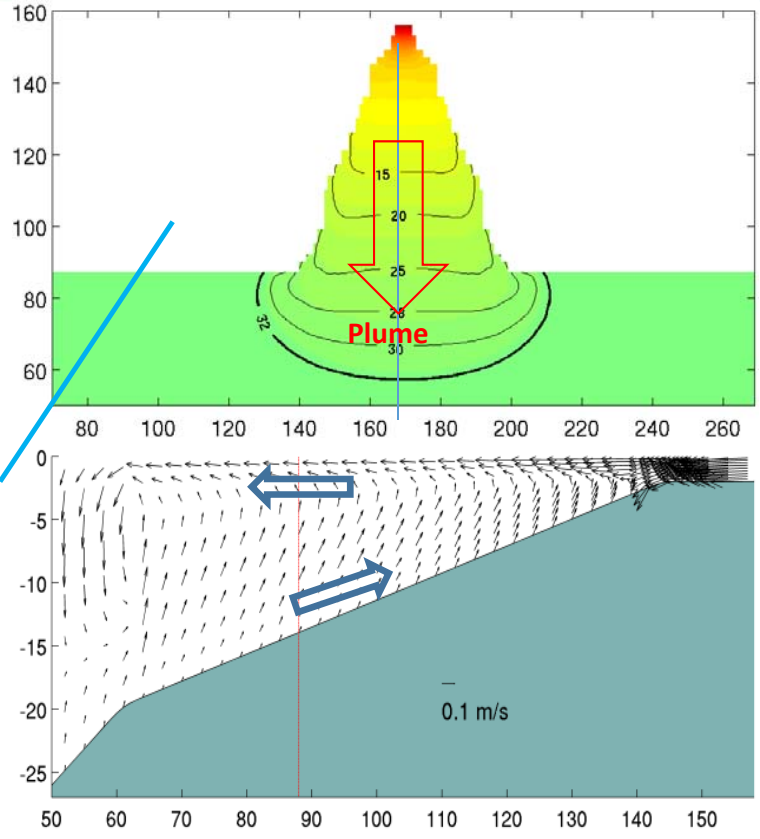
Plume due to Discharge from River



With Earth rotation

Left: Without forcing from wind and tide, the plume swings westward due to Earth rotation effect.

Right: Without forcing of Earth rotation effect, wind and tides, the plume moves offshore in a symmetric fashion.

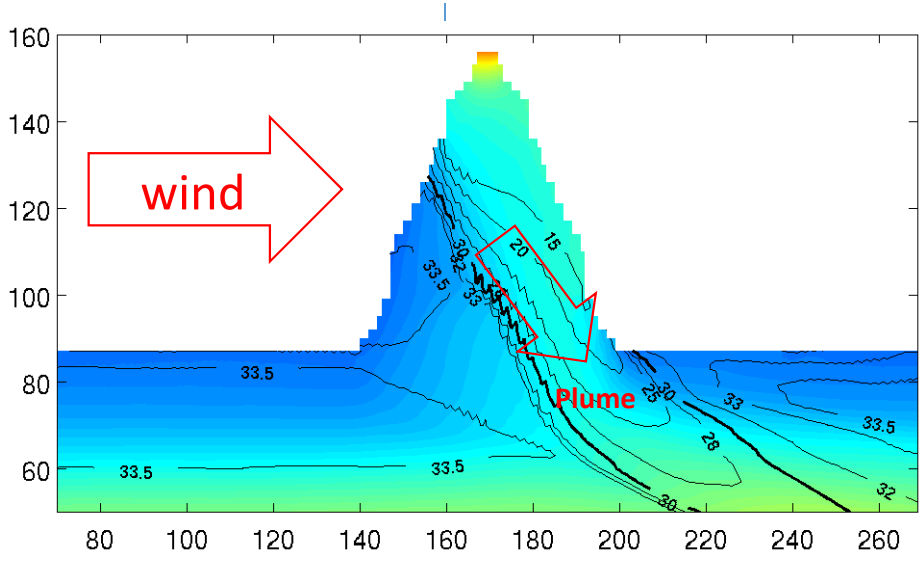


Without Earth rotation

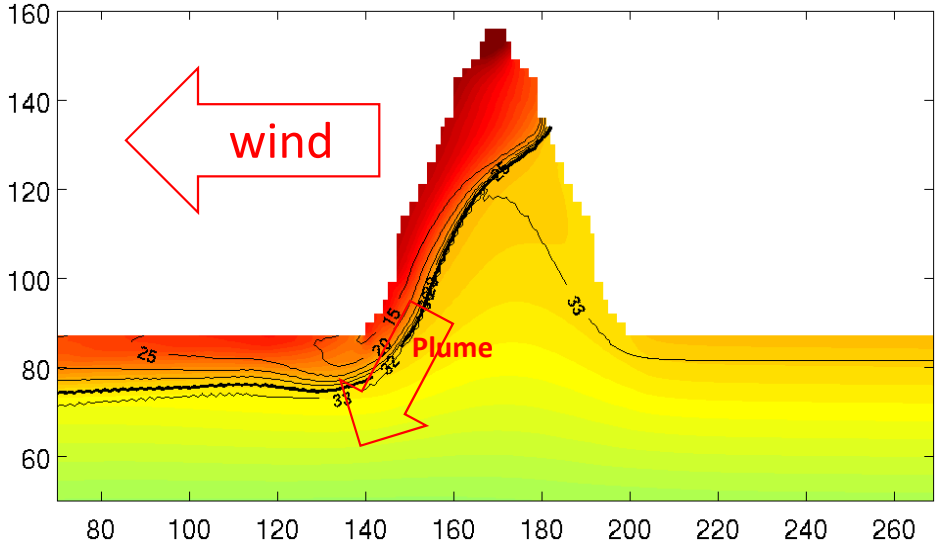
Zu & Gan (2008)

Surface Salinity due to River Discharge & Wind-Driven Coastal Currents

Freshwater discharged from the estuary forms river plume over the adjacent continental shelf. The plume moves eastward/westward during westerly (eastward)/ easterly (westward) wind forcing.



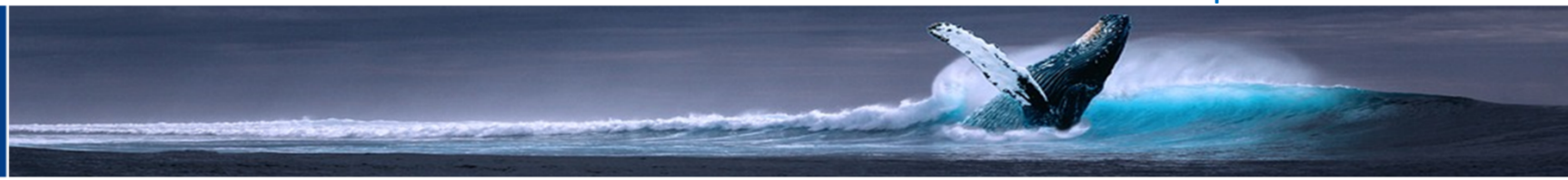
River + Westerly



River + Easterly

Summary – Estuary & Estuarine Circulation

- **What is the Estuary influenced by?**
  - Contains **lighter freshwater discharged from the river** and **heavier seawater from the open ocean**.
  - Their density difference creates the unique **two-layer circulation**, i.e. **seaward current in the upper layer** and **landward current in the lower layer.** This is called the **Estuarine Circulation** inside of estuary.
- **What forces play a key role in the Estuarine Circulation inside of Estuary?**
  - **Density difference** between river water and sea water and **easterly or westerly winds**.
- **What is River Plume and why is it important?**
  - The **freshwater discharged to the adjacent continental shelf** forms **River Plume**, which carries **lighter and nutrient-rich water** and greatly affects the **coastal flow pattern and biological productivity.**



DEPARTMENT OF OCEAN SCIENCE

Classification of Estuaries

Overview – Classification of Estuaries

Do all the estuaries have same estuarine circulation?

Key points:

- The **volume ratio** between the **freshwater volume from river** and **seawater volume from ocean** characterizes the estuary and estuarine circulation;

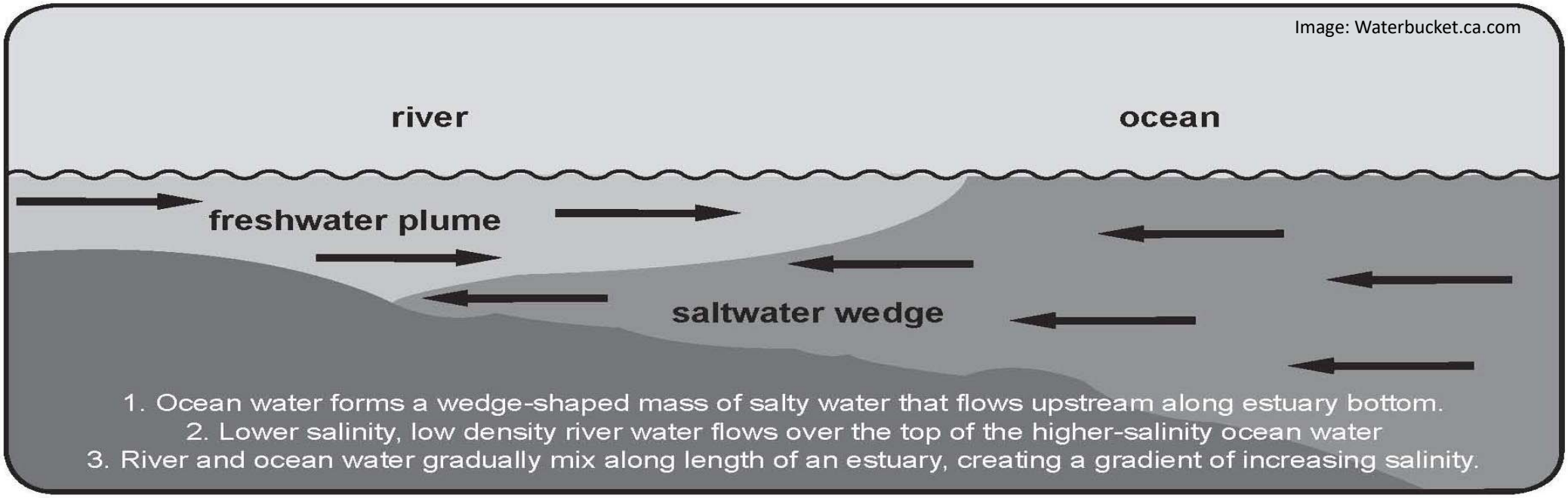
- Since the seawater volume from ocean is relatively stable, the **ratio or type of estuary is mainly determined by freshwater volume from the river**.

Classification of Estuaries – Variation in Salinity

- **Salt Wedge Estuary**
  - **River volume larger** than tidal volume
- **Highly Stratified Estuary**
  - **River volume comparable** to tidal volume but still larger than tidal volume
- **Slightly Stratified Estuary**
  - **River volume small** compared to tidal volume
- **Vertically Mixed Estuary**
  - **River volume insignificant** compared to tidal volume

Salt Wedge Estuary

Salt Wedge Estuary – **Seawater intrusion** in an estuary as a **wedge-shaped bottom layer** which hardly mixes with the overlying freshwater layer.

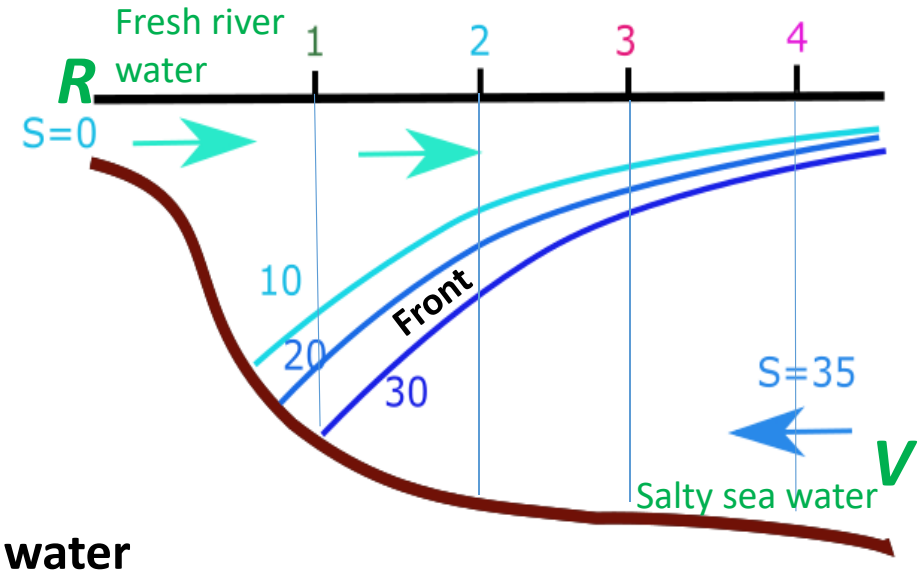


Salt Wedge Estuary – Salinity

Salt Wedge Estuaries occur when a *rapidly* flowing river discharges into the ocean where oceanic intrusive currents are *weak*.

- ***R/V* is large**

(**R**: fresh water volume; **V**: seawater volume)

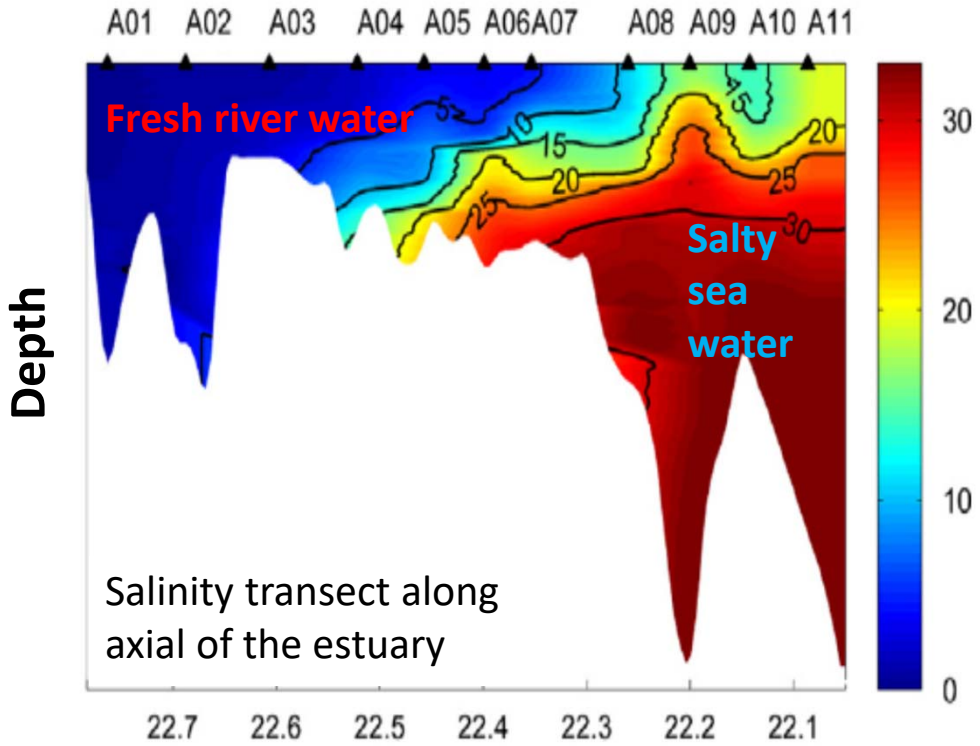


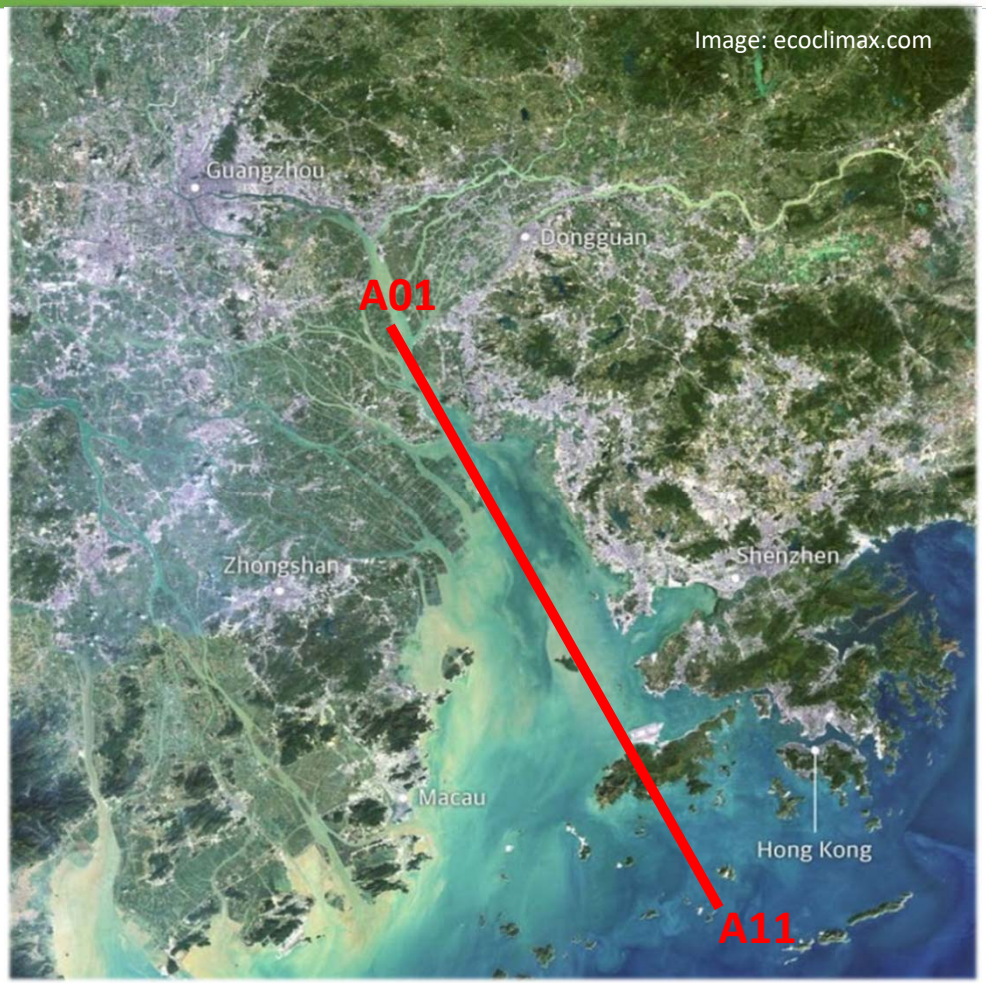
Salinity transect along the estuary

Front between freshwater and oceanic water at the surface near the estuary mouth.

Salt Wedge Estuary

Example: Pearl River Estuary during summer

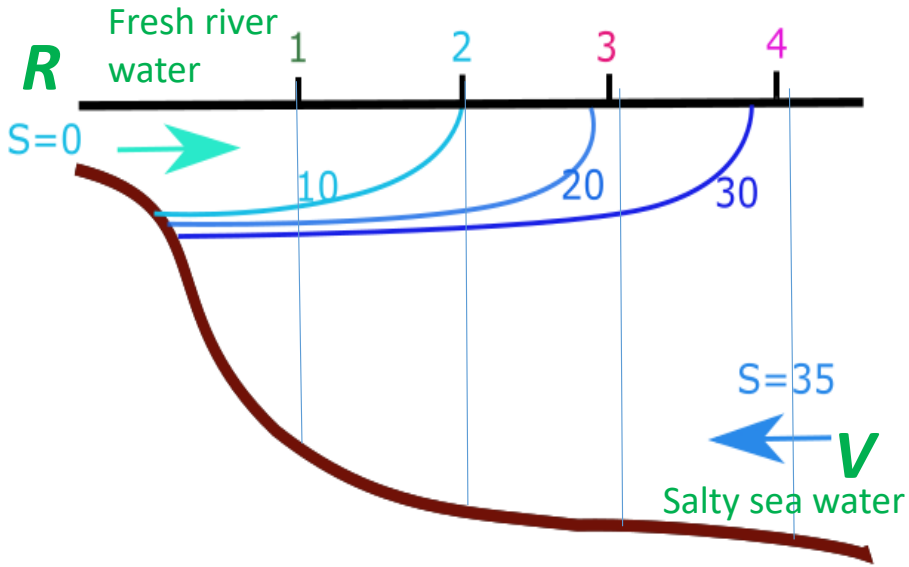




Highly Stratified Estuary – Salinity

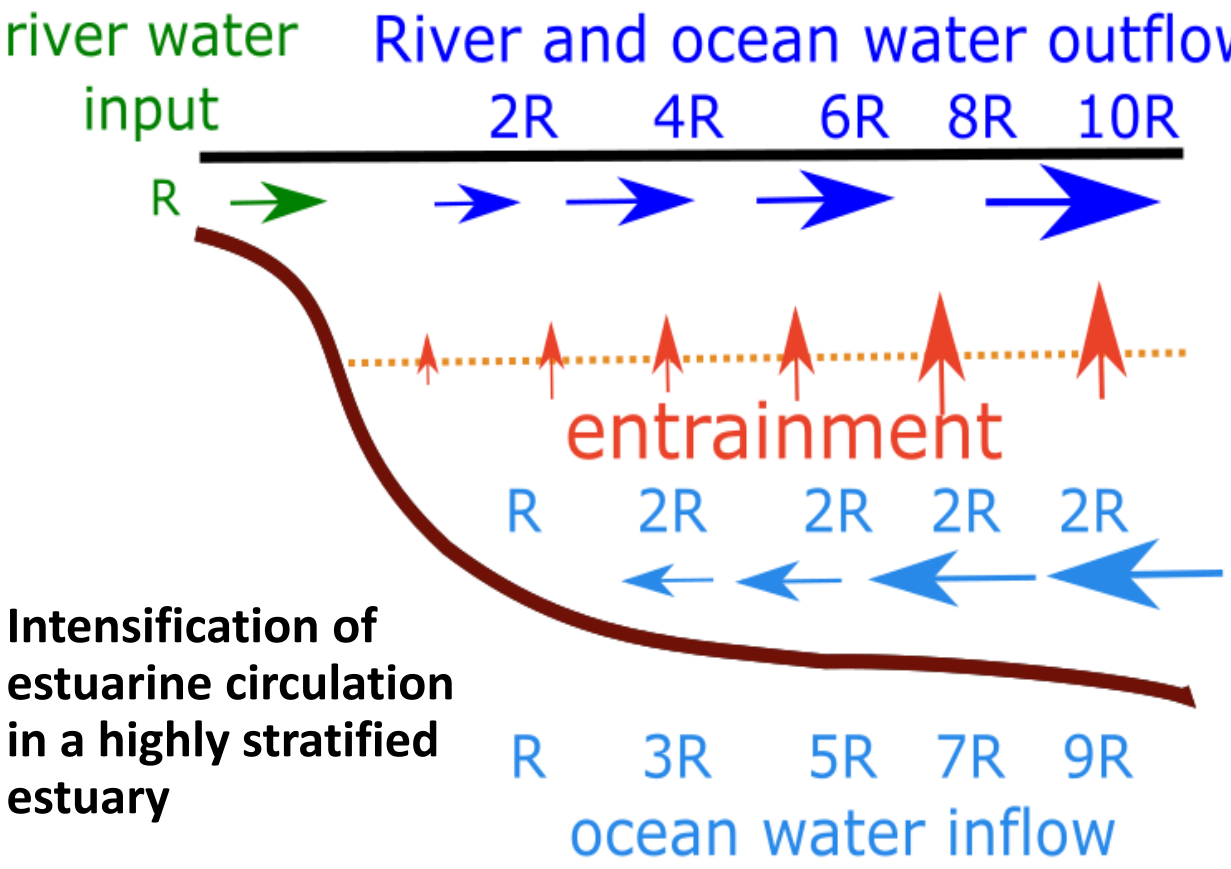
Highly Stratified Estuaries occur when a flowing river discharges into the ocean is *slower than* oceanic intrusive currents.

- ***R/V* 0.1 - 1, stronger oceanic intrusive current at the bottom**
- Create **instability and internal waves**
- A **net upward transport of mass and salt** (entrainment)
- **Intensified circulation** induced by entrainment
- The dense seawater seldom reaches the upper estuary (river)

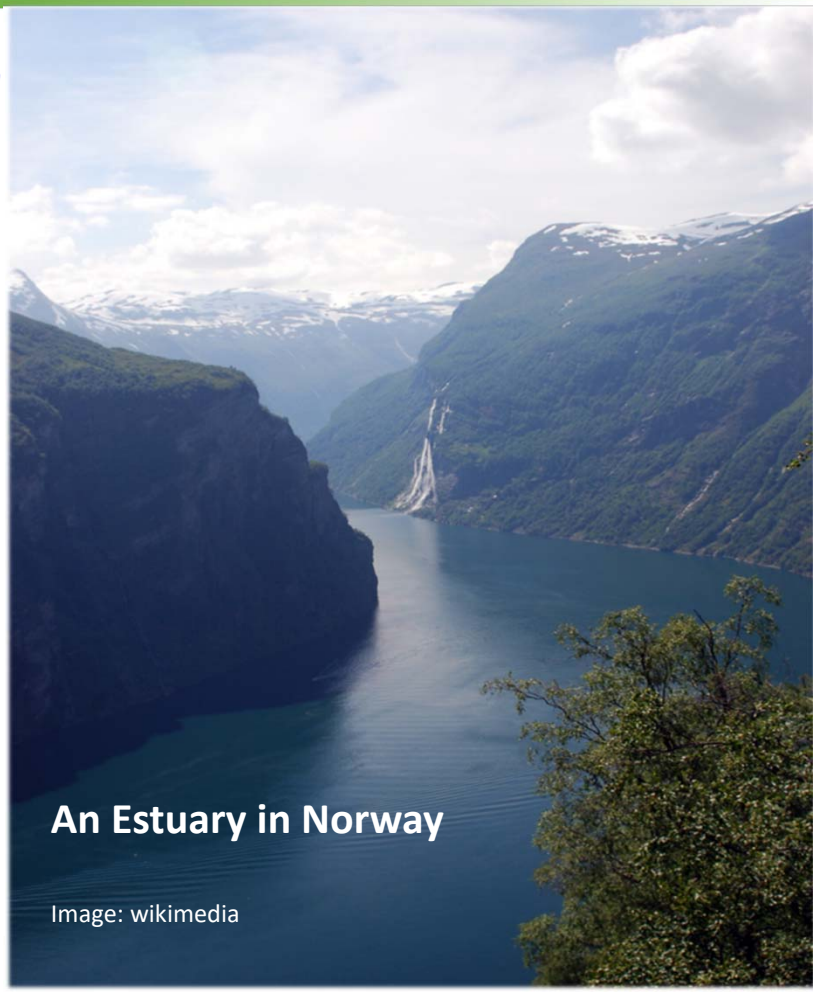


Salinity transect along the estuary

Highly Stratified Estuary – Circulation



Intensification of estuarine circulation in a highly stratified estuary



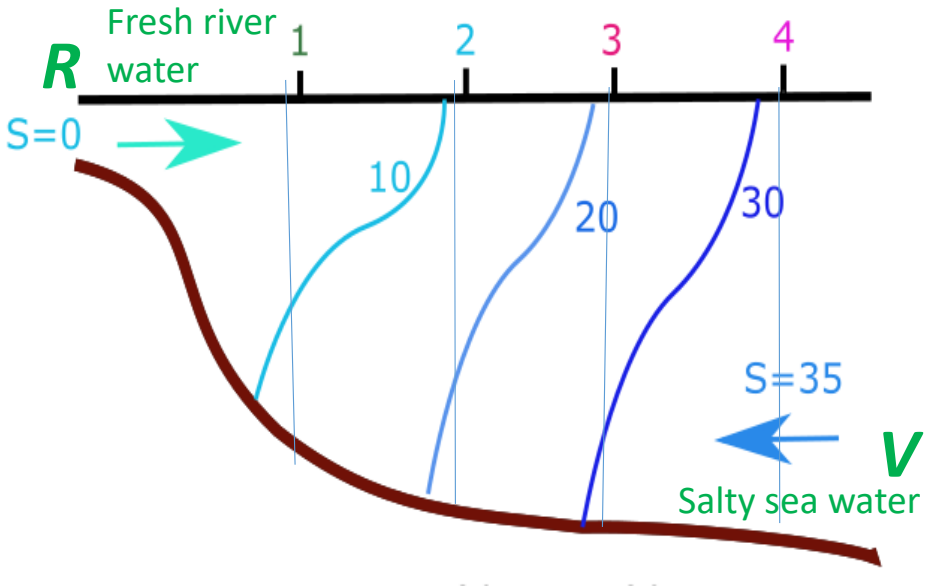
An Estuary in Norway

Image: wikimedia

Slightly Stratified Estuary – Salinity

Slightly Stratified Estuaries occur when a flowing river discharges into the ocean is *much slower* than oceanic intrusive currents.

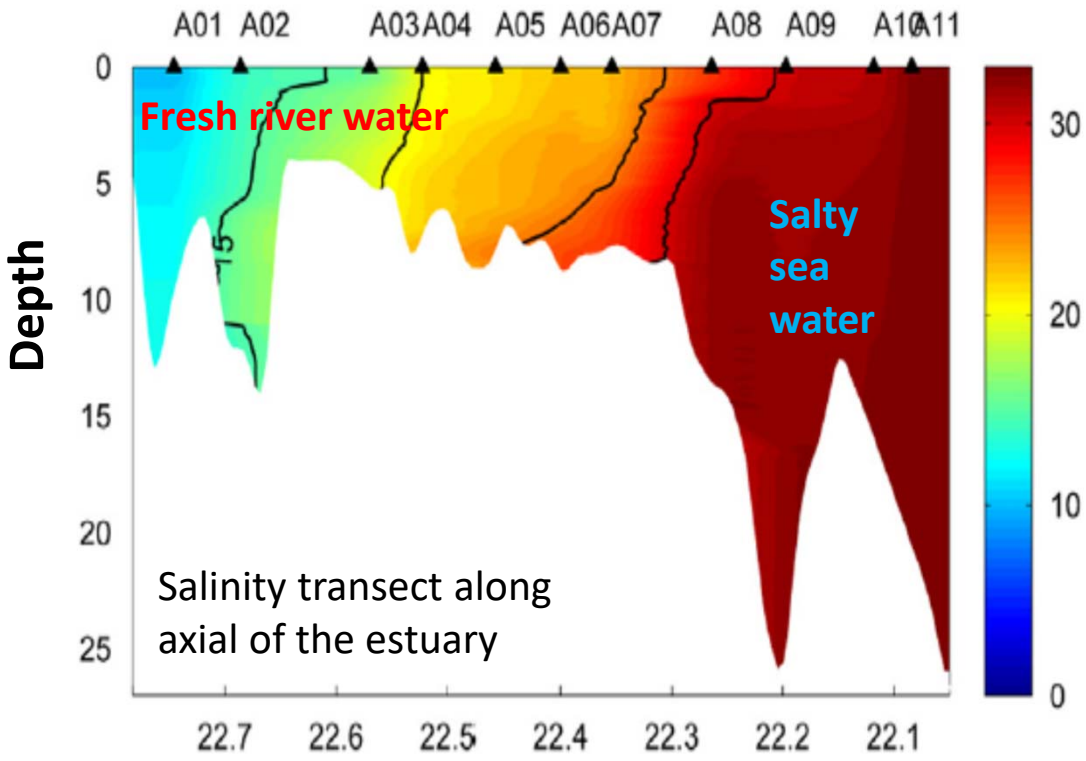
- ***R/V*** **0.005 - 0.1, much stronger tidal current**
- **Saltwater and freshwater mix at all depths**
- **Salinity is greatest at the mouth of the estuary,** and **decreases upstream**
- **Strong turbulence everywhere**, mass and salt vigorously mix between two layers

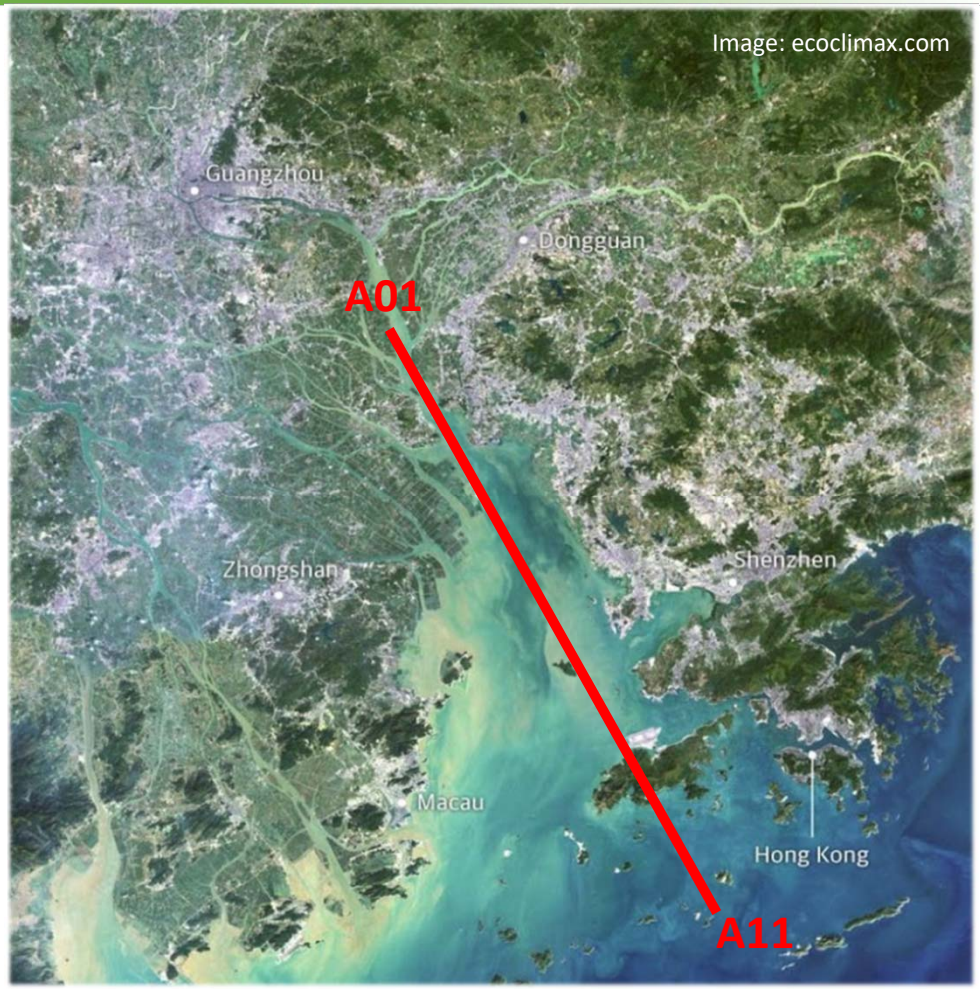


Salinity transect along the estuary

Slightly Stratified Estuary – Salinity

Example: Pearl River Estuary during winter



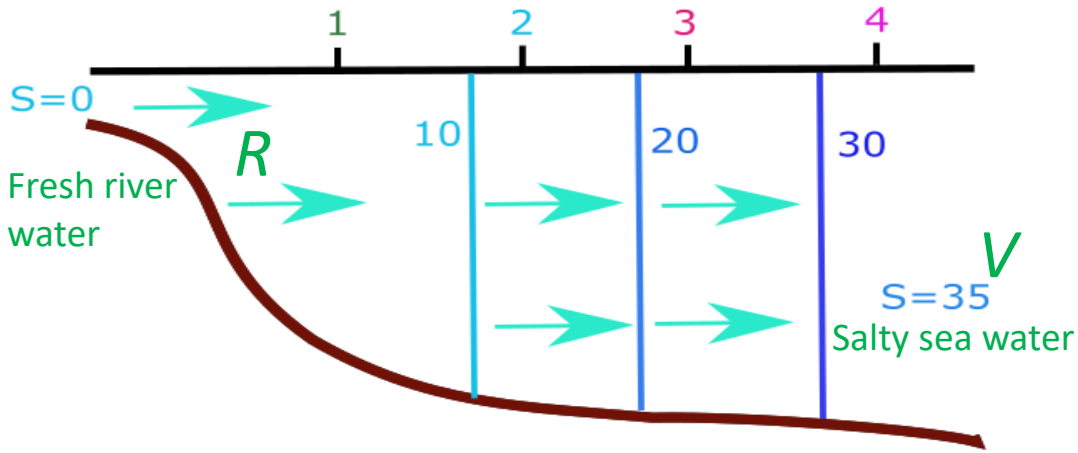


Vertically Mixed Estuary - Salinity

Vertically Mixed or Well-mixed

Estuaries occur when river flow is *very low* and intrusive oceanic currents are *moderate to strong*.

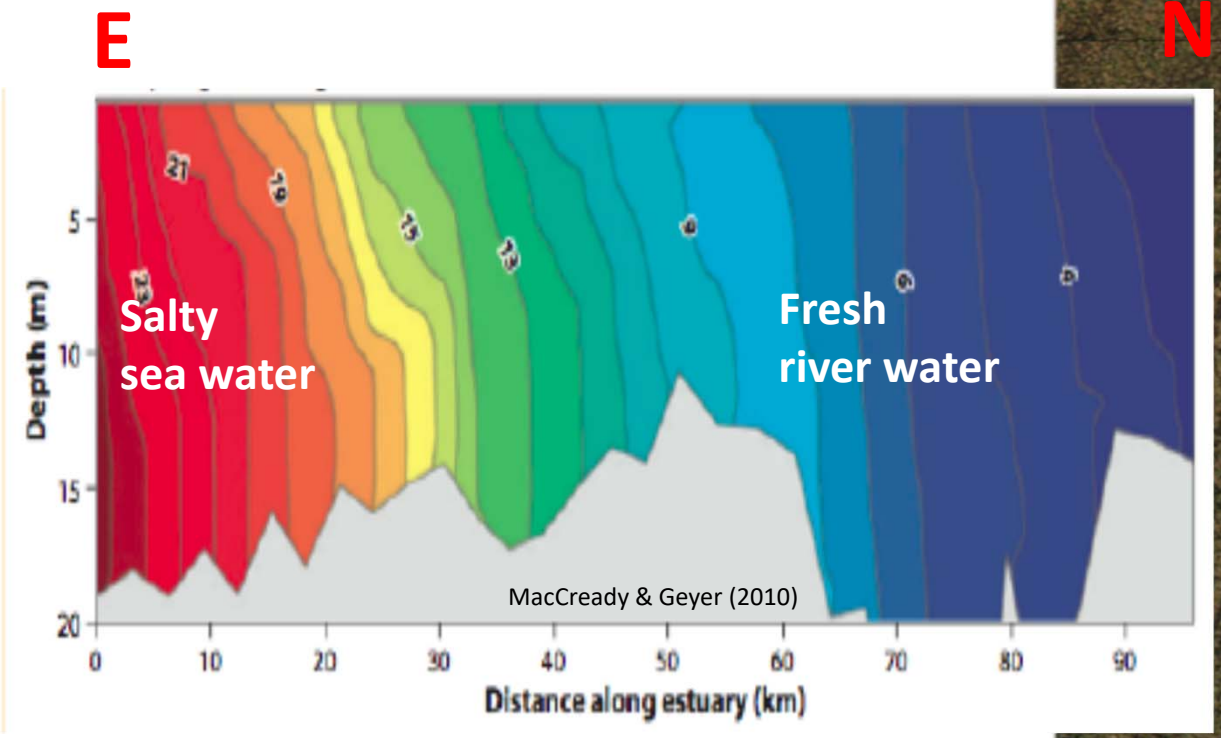
- ***R/V* <0.005**
- **Efficient turbulent mixing**
- **No distinction between upper and lower layers**



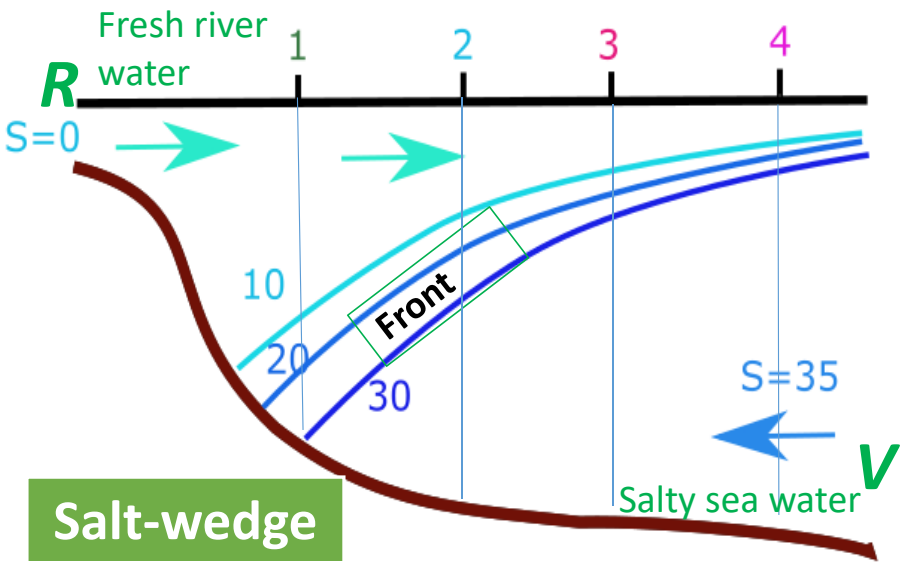
Salinity transect along the estuary

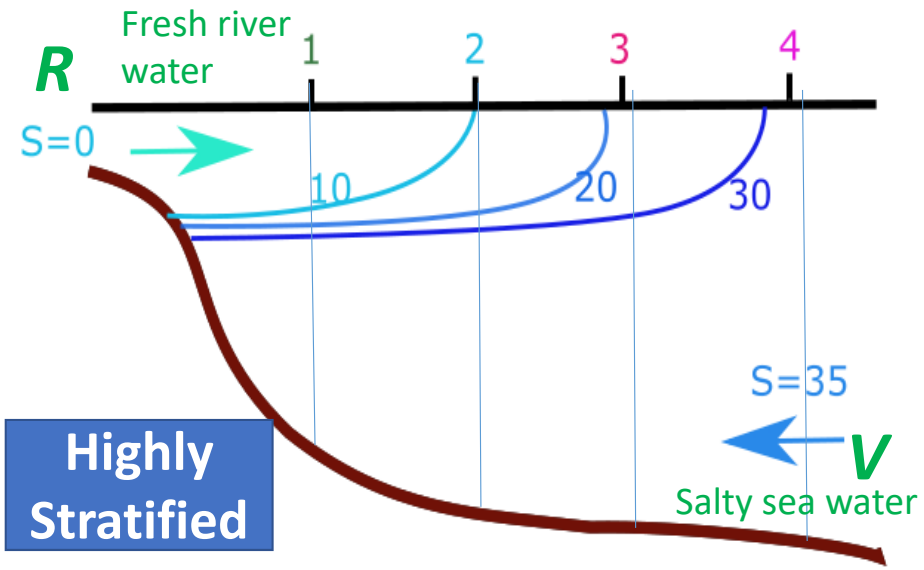
Vertically Mixed Estuary – Salinity

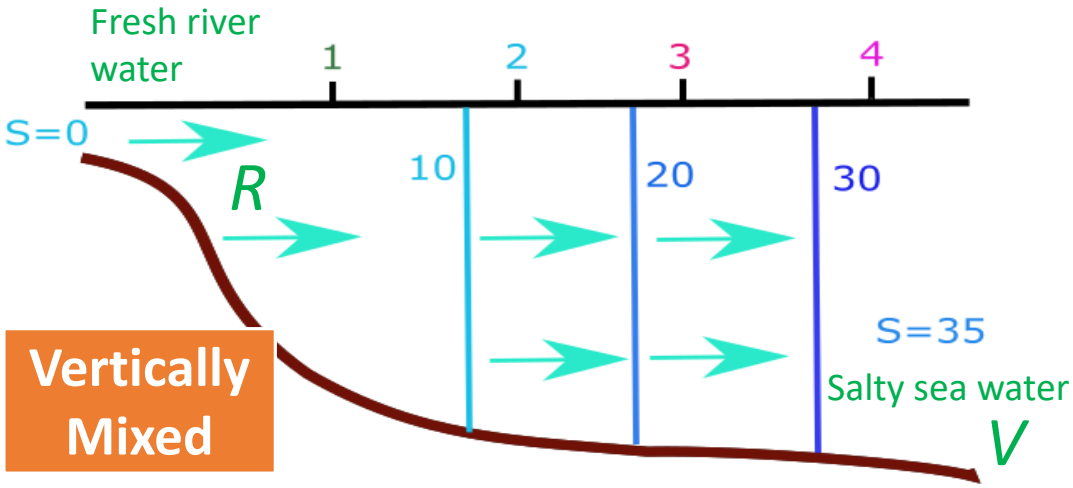
Example: Delaware Bay

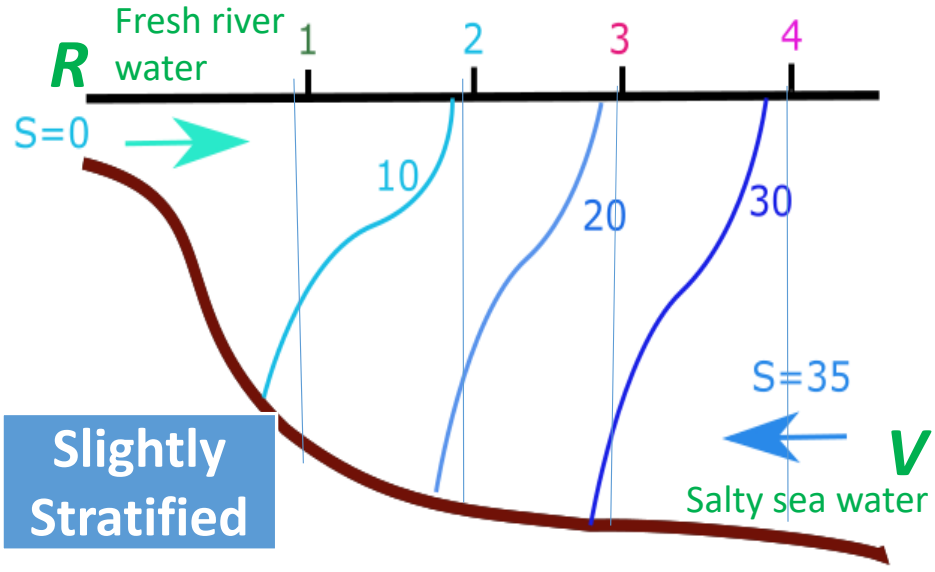


Salinity transect along axial of the estuary


Fresh river water
R
1
2
3
4
S=0
10
20
30
Front
S=35
V
Salty sea water
Salt-wedge


Fresh river water
R
1
2
3
4
S=0
10
20
30
S=35
V
Salty sea water
Highly Stratified

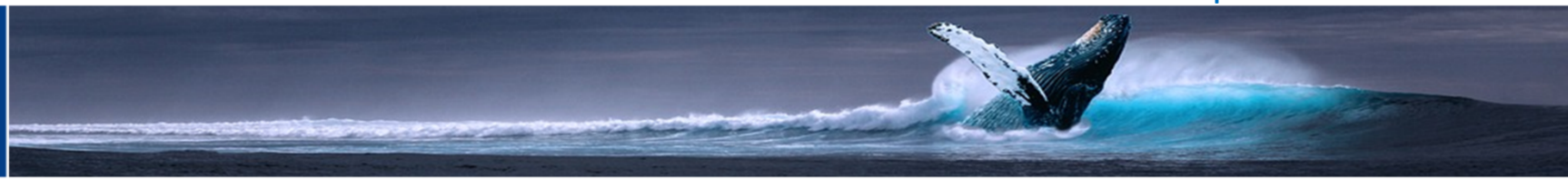

Fresh river water
1
2
3
4
S=0
R
10
20
30
S=35
Salty sea water
V
Vertically Mixed


Fresh river water
R
1
2
3
4
S=0
10
20
30
S=35
V
Salty sea water
Slightly Stratified

Summary – Classification of Estuaries

How are the types of estuaries determined?

- **Ratio of freshwater volume and seawater volume**
- The **structure of the salinity** in the estuary
- The pattern of the **estuarine circulation**
- The type and associated estuarine circulation **varied with seasonal river freshwater discharge**, as the volume of salty water intrusion by tides from ocean is relatively fixed



DEPARTMENT OF OCEAN SCIENCE

Tides

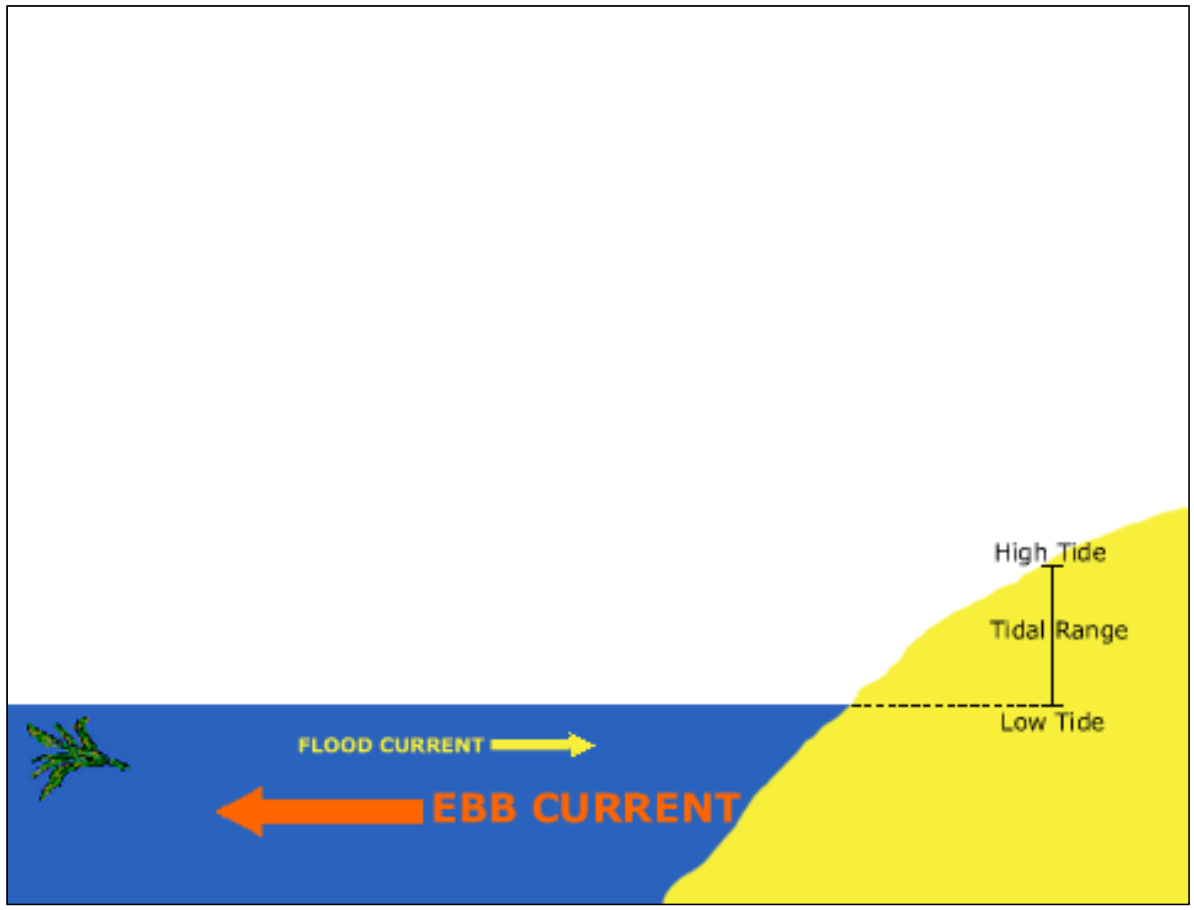
Overview – Tides

What causes the sea level to move up and down every day in the seaside off HKUST?

Key points:

- Periodical **sea-level increase/decrease** in **diurnal or semi-diurnal** period is **caused by Ocean Tide**
- **Ocean Tides** are caused by a combination of the **gravitational force of the moon and sun** and **the motion of the Earth**

Flood Tide vs. Ebb Tide



Animation: NOAA

Flood Tide (High Tide)

- As the **tide rises**, water moves **towards the shore**

Ebb Tide (Low Tide)

- As the **tide recedes**, water moves **away from the shore**

Flood Tide vs. Ebb Tide

Ebb Tide (Low Tide)

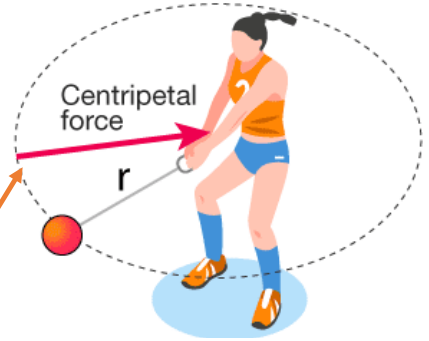
Flood Tide (High Tide)

Tides & the Forces that Generate Them

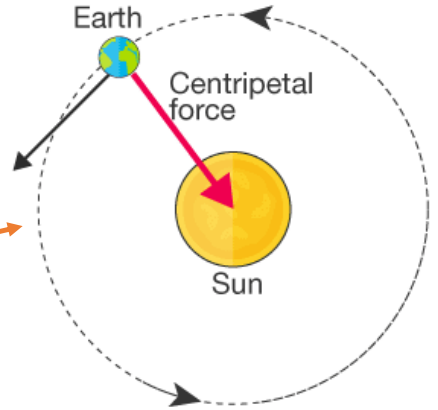
- **Tides** are formed when the **sea level rises and falls** (once or twice a day)
  - **Flood Tide** – High Tide
  - **Ebb Tide** – Low Tide

- Tides are caused by the **gravitational force of the moon and sun** and the **motion of the Earth**

- The **Centripetal force** required to keep the ocean water along with Earth and Sun rotating in the Earth-moon pair



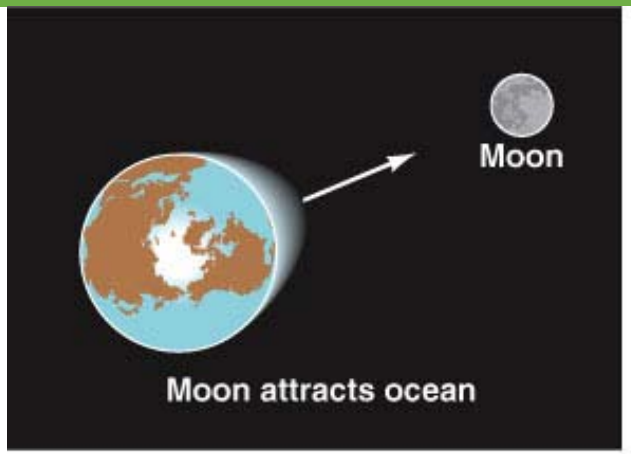
Spinning a ball on a string

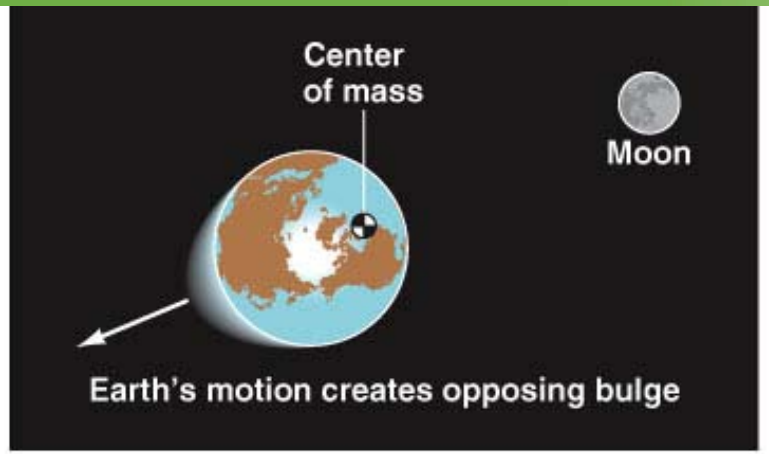


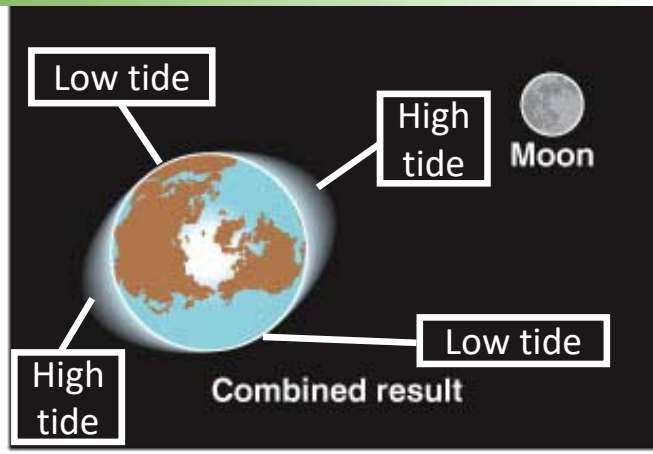
Planets orbiting the sun

Images from byjust.com

Gravitational Pull Forms Two Tidal Bulges







The ***moon's*** **pull** creates a **tidal bulge on *one* side**

- The **moon's gravity attracts the ocean towards it**

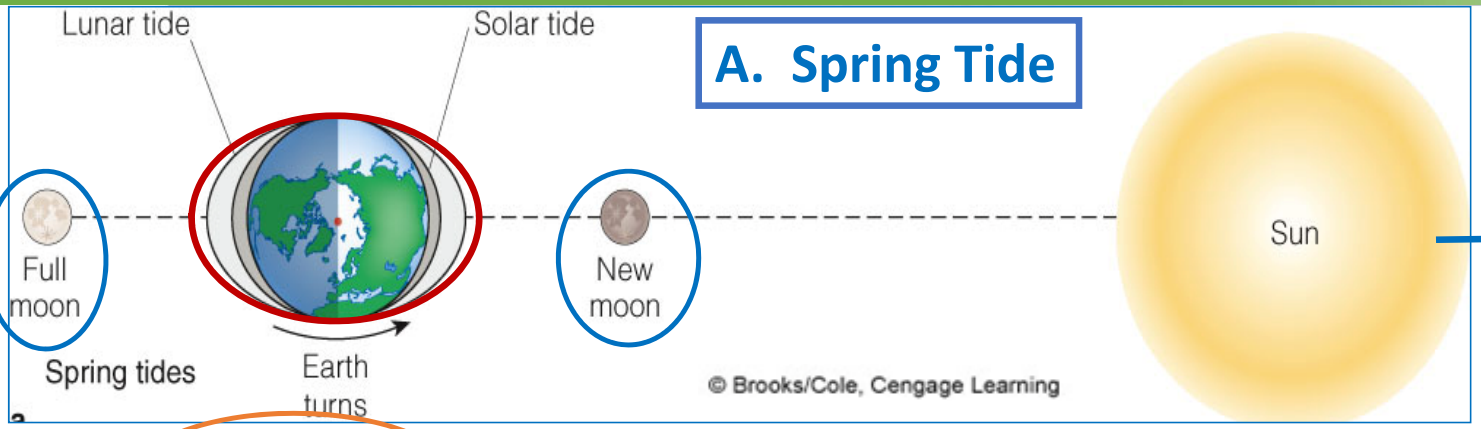
The ***Earth's*** **motion pull** creates a **tidal bulge on *the other* side (or Centripetal effect)**

- The motion of the Earth around the center of mass of the Earth – the moon system throws up **a bulge on the side of Earth** opposite the moon

Both create **two areas of High Tides and Low Tides**

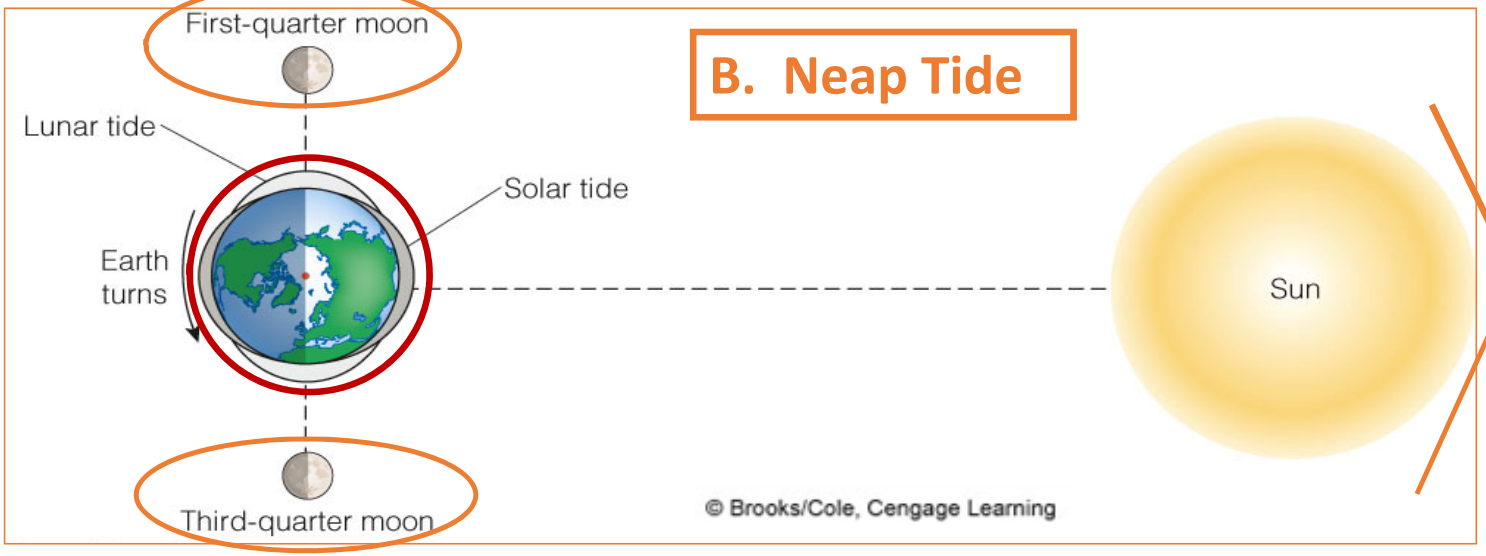
- The combination of the two effects creates **two tidal bulges** on **both** sides

The Sun & the Moon Influence Tides (Lunar Tides)



Spring Tide (Big Tide)

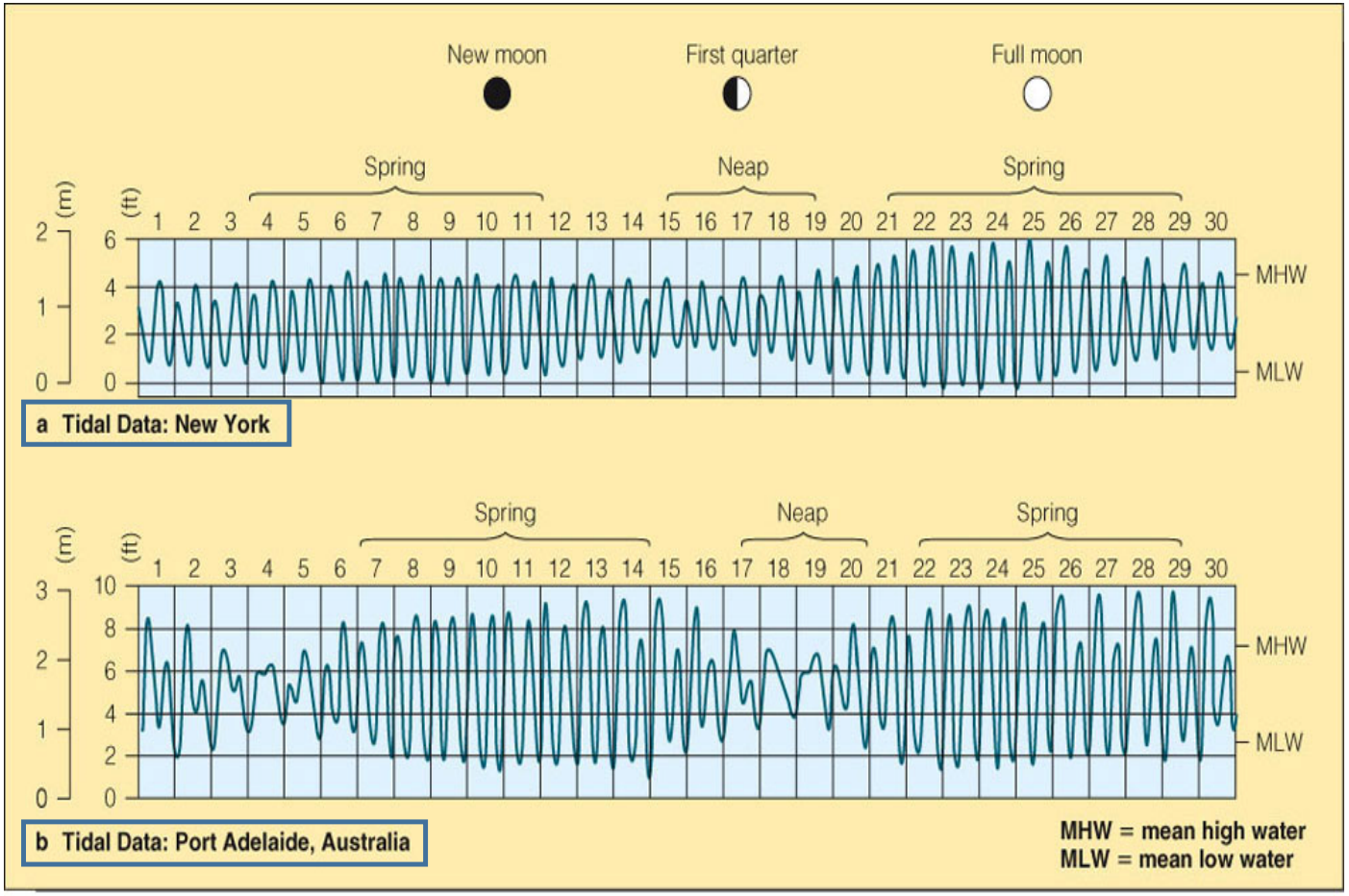
- When the positions of the **Sun, the (new/full) moon and Earth are aligned** to each other



Neap Tide (Small Tide)

- When positions of the **Sun, the moon (quarter phases) and Earth are at right angle** to each other

Tidal Records for Spring & Neap Tides



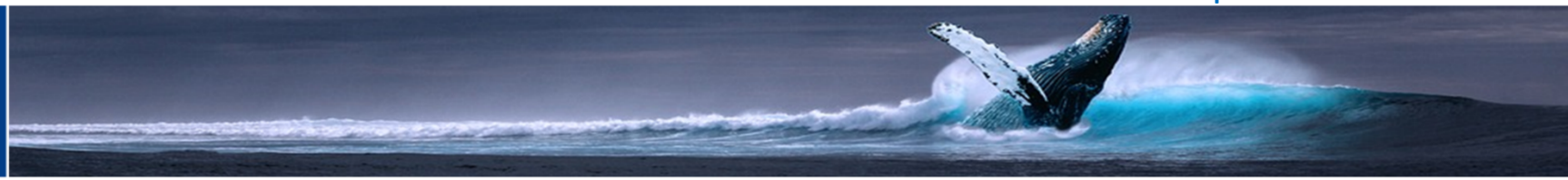
Tidal records for a typical month at

(a) New York, and

(b) Port Adelaide, Australia

Summary – Tides

- **What are Tides?**
  - When the **sea level rises and falls (Flood Tide – high, Ebb Tide - low)**
- **How are Tides Formed?**
  - Combination of the **gravitational force of the moon and sun** and **the motion of the Earth (Centripetal).** The **moon's influence is almost twice that of the sun's** influence.
- **What causes Tidal Bulges to form?**
  - The **attraction of the Earth and the moon. Gravity and Centripetal effect cause the ocean surface to bulge.** Tides occur as Earth rotates beneath the bulges.
- **Spring Tides** – when **Earth, sun & moon are aligned**; **Neap Tides** – when Earth, sun & moon are at an **angle** to each other.



DEPARTMENT OF OCEAN SCIENCE

Waves

Overview – Waves

Waves are created by energy passing through water.

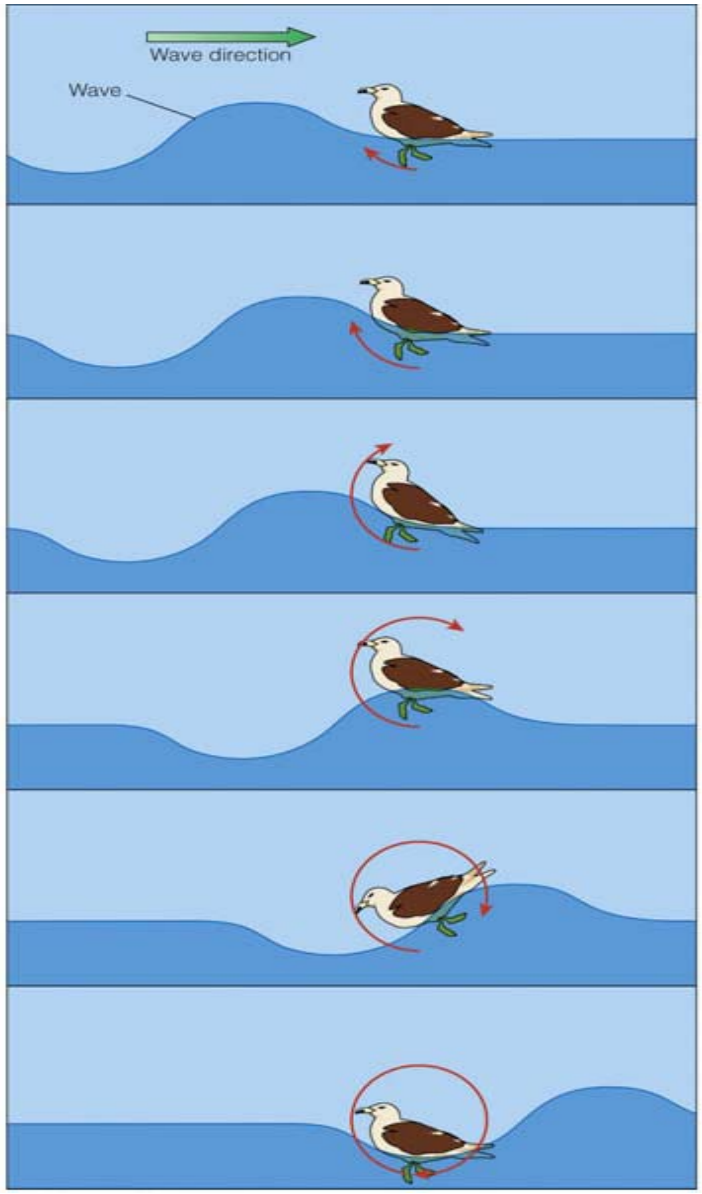
Key points:

- Waves are a **periodic disturbance** that is caused by **both external force and internal restoring force**
- Wave travels through a medium, **transporting energy from one location (its source) to another** location without transporting matter
- Most waves **change shape and speed** as they approach shallow coastal waters
- **Tsunami – seismic waves due to faulting of seafloor and underwater volcanic eruption**

Ocean Waves Move Energy across the Sea Surface

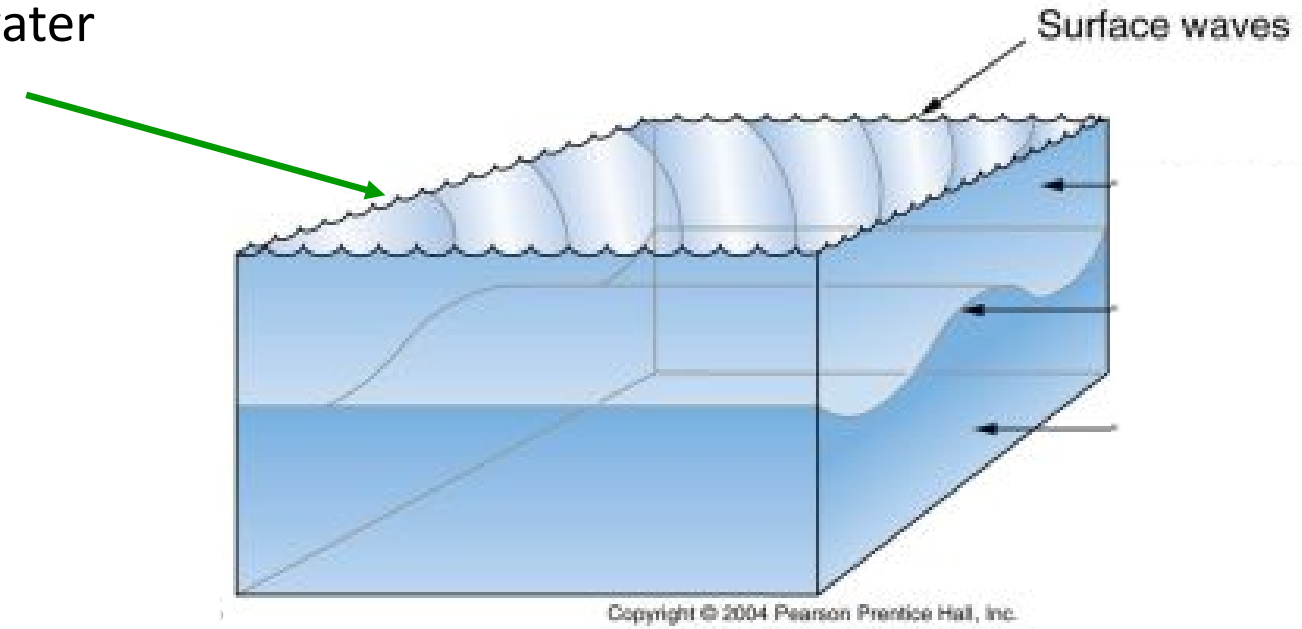
Ocean waves are visual proof of the transmission of energy across the surface of the ocean.

- A floating sea gull demonstrates that ***wave forms travel*** **but the** ***water itself does not***.
- In this sequence, a **wave moves from left to right** as the gull (and the water in which it is resting) revolves in a circle, moving slightly to the left up the front of an approaching wave, then to the crest, then sliding to the right down the back of the wave.



Waves in the Ocean

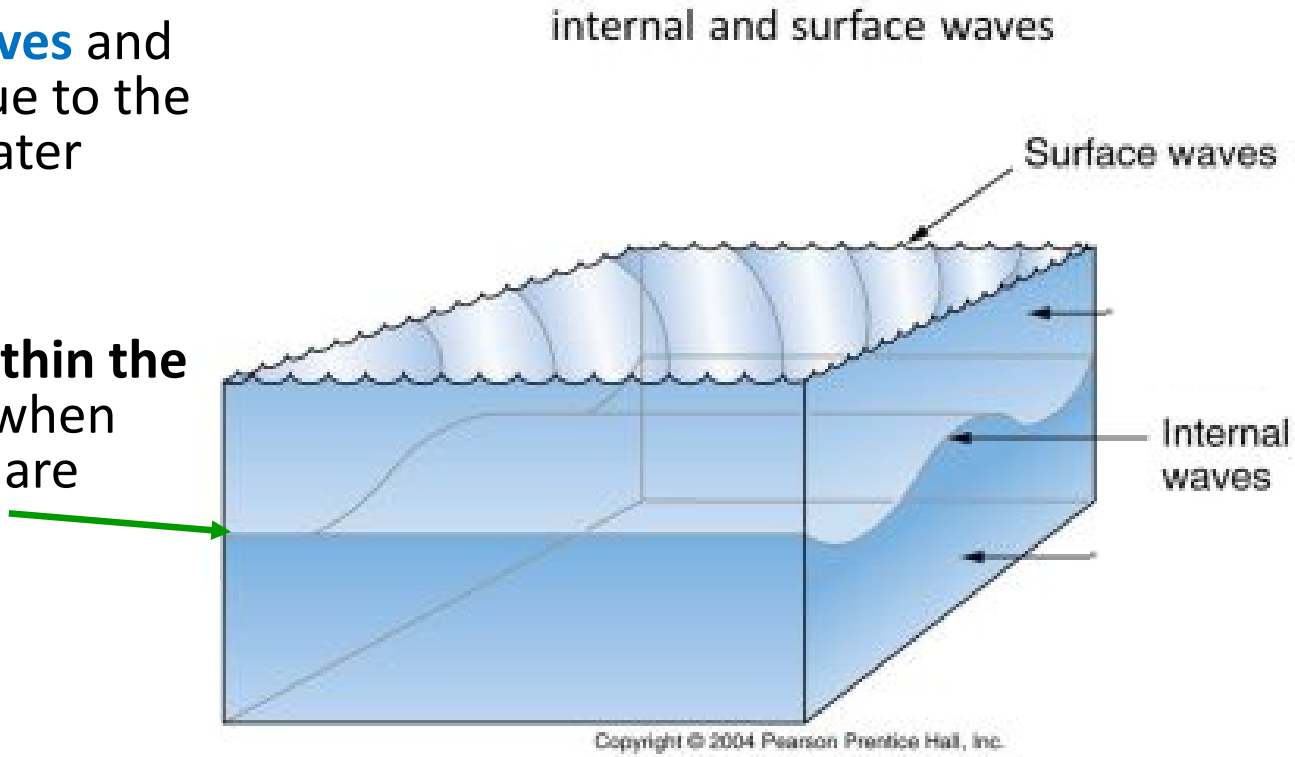
- **Capillary waves**, **wind waves** and **swells** – near **surface** due to the **wind effects** on the air/water interface



Waves in the Ocean

- **Capillary waves, wind waves** and **swells** near the **surface** due to the **wind effects** on the air/water interface

- **Internal waves** – **occur within the water** not on the surface when vertical density variations are present

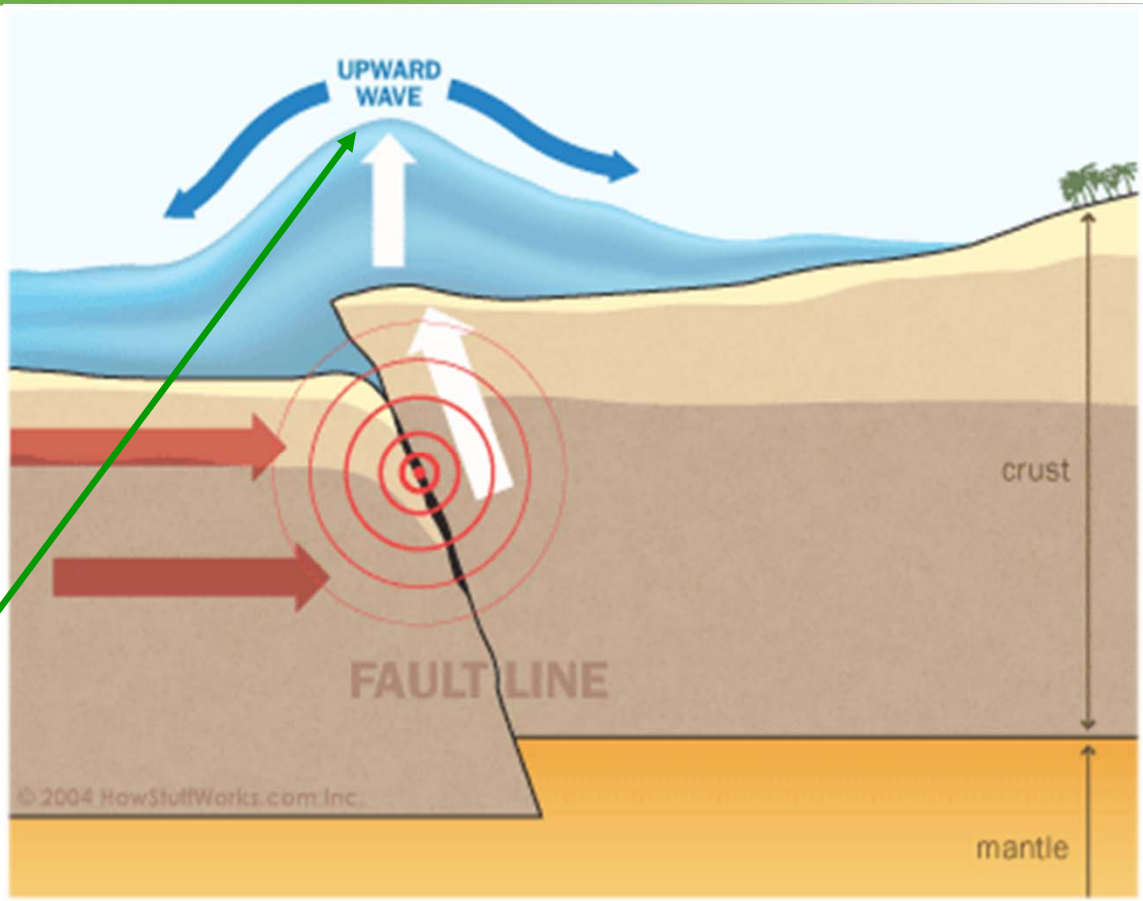


Waves in the Ocean

- **Capillary waves, wind waves** and **swells** – near **surface** due to the **wind effects** on the air/water interface

- **Internal waves** – **occur within the water** not on the surface when vertical density variations are present

- **Tsunamis** – very long waves **generated by seismic disturbances of the sea bottom or shore**



Capillary Waves – Small Disturbances

Capillary Waves form ahead of a slowly moving hand in a swimming pool.

Image: wikimedia

Each has a wavelength <2 cm (about 2⁄3 of an inch).

Wave Formation – Fetch, Swell & Surf

- **Wind Waves** – generated by the wind blowing on the sea surface
- **Fetch (length of wind over water)** – durations over a sea surface, many kilometers long

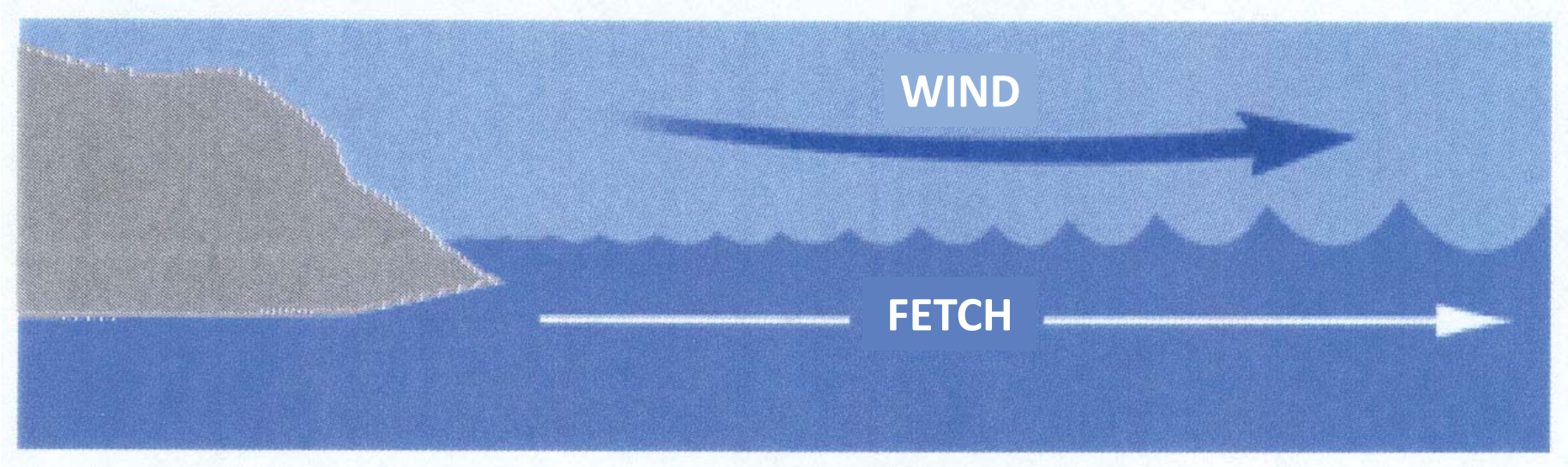


Image: NOAA

Wave Formation – Fetch, Swell & Surf

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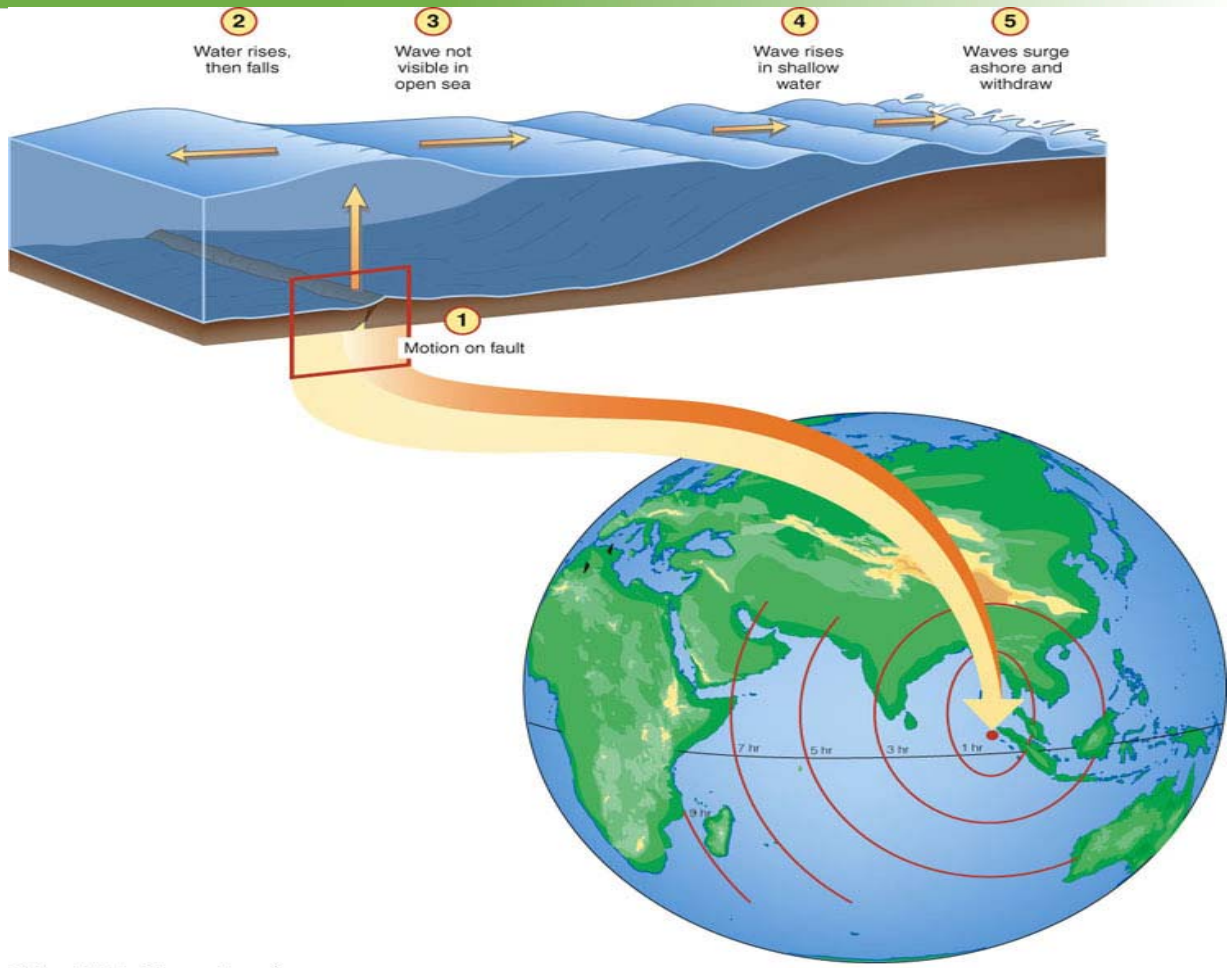
- **Surf (wave starts to break)** – as it enters shallow water, wave speed and length decrease and height increases, and peaks up into waves and is **dissipated as surf.**

Water Displacement – Causes Tsunami & Seismic Sea Waves

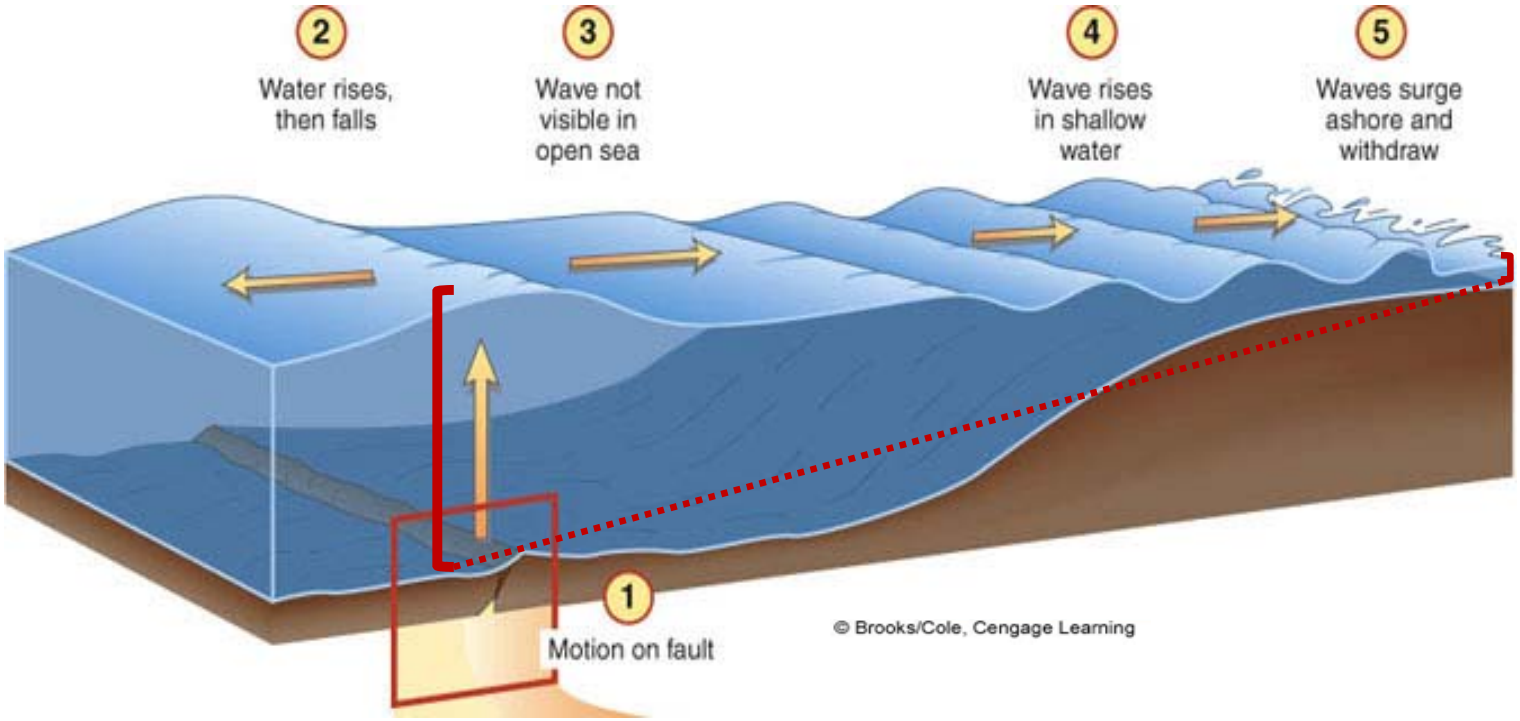
Seismic (Tsunami) waves can reach tremendous size, causing destruction and loss of life.



Water Displacement – Causes Tsunami & Seismic Sea Waves

The great **Indian Ocean Tsunami** (26 December 2004) began when a **rupture along a plate junction lifted the sea surface above**. The wave moved outward at the speed of 212 meters per second (472 miles per hour).

At this speed, it took only about **15 minutes** to reach the nearest Sumatran coast and **28 minutes** to travel to the city of Banda Aceh, Indonesia.



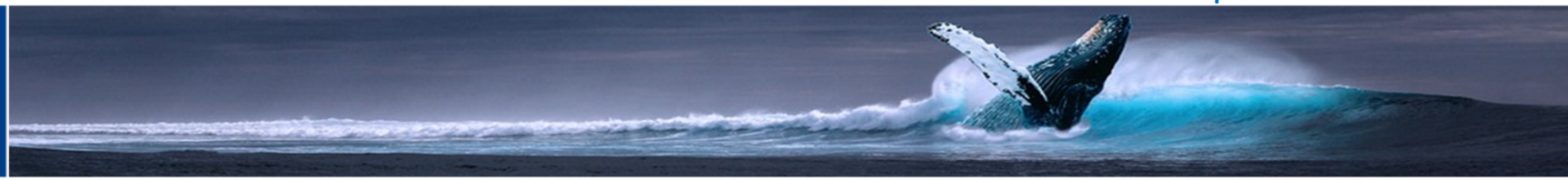
Summary – Waves

How are Waves created?

- **Waves are created by energy passing through water,** not water mass, transporting energy from one location to another across the ocean's surface.
- **Fetch, Swell, Surf:** Most waves change speed and shape as approaching the shore

How are Ocean Waves created?

- **Ocean Waves** – generated by very small disturbances **(Capillary Waves)**, wind **(Wind Waves)**, **density difference (Internal Waves),** seismic and volcanic activity or other sudden displacements **(Tsunami)**, and gravitational attraction **(Tides)**
- **Gravity** – the **restoring force** for most of the waves



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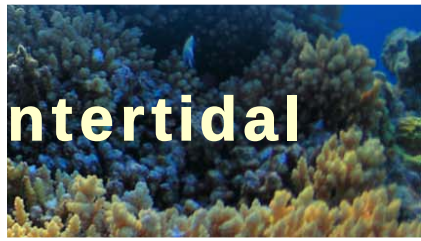
Summary:
Marine Ecosystems – The Coastal, Intertidal & Subtidal



Marine Ecosystems: The Coastal, Intertidal & Subtidal

- Characteristics of Coastal & Shelf Sea
- Ekman Transport
- Wind-driven Current
- Coastal Upwelling
- Coastal Downwelling
- Estuary & Estuarine Circulation
- Classification of Estuaries
- Tides
- Waves

Ekman Transport & Wind-Driven Circulation

- Ocean motion (current) is mainly driven by **wind forcing**
- Wind forcing forms **Ekman Spiral**
- The averaged transport in Ekman spiral layer is **net Ekman Transport or Ekman Drift**
- Ekman Drift is directed **90^{o} to the right of wind direction**

Coastal Upwelling & Downwelling

Upper & bottom layer water movement are consequences of wind-driven Ekman transport

(1) Upper layer water movement:

- **Upwelling:** water moves offshore

- **Downwelling:** water moves onshore

Coastal Upwelling & Downwelling

Upper & bottom layer water movement are consequences of wind-driven Ekman transport

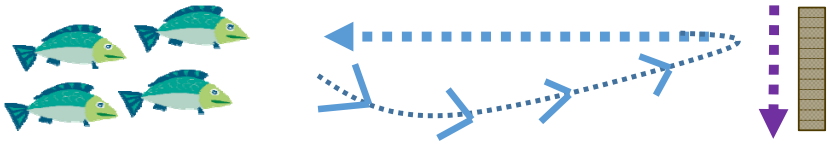
(1) Upper layer water movement:

- **Upwelling:** water moves offshore

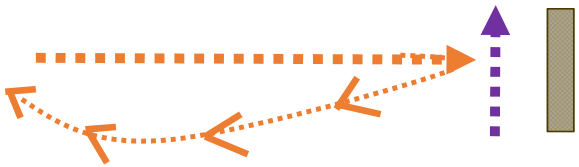
- **Downwelling:** water moves onshore

(2) Bottom layer water movement:

- **Upwelling:** nutrient rich water moves upward to compensate water moving offshore



- **Downwelling:** water moves downward to compensate water piling onshore



- **High bio-productivity**

Coastal Upwelling & Downwelling

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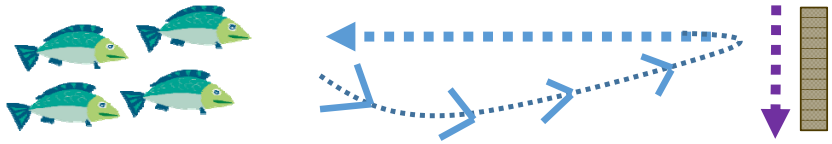

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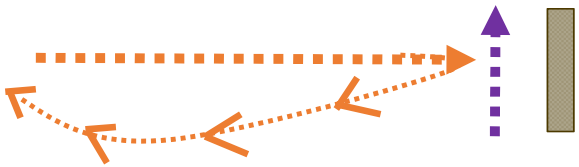

- **High bio-productivity**

Estuary, Estuarine Circulation & Classification

- **Estuary** – characterized by both **freshwater discharge from river in the upper layer** and **seawater intrusion in the lower layer**

- **Estuarine Circulation** – a **two-layer** circulation with **seaward flow in the upper layer** and **landward in the lower layer**

- **Classification of Estuaries** – the **pattern and intensity** of the estuarine circulation – subjecting to the control of **volume ratio between river discharge and sea water intrusion**

Tides & Waves

Tides

- Formed when **sea level rises and falls**
- It is formed from the **gravitational force of the *moon* and *sun*** and the **rotation of the *Earth***
- The **gravitational pull** causes the ocean surface to **bulge**

Waves

- Created by energy passing through water, **transporting energy from one place to another**
- Ocean waves generated by **small disturbances, wind, internal waves,** and **seismic and volcano activities** and **gravitational attractions (tides)**
- **Gravity** – the **restoring force** for most waves

Why should I Study these Topics?

- The motion of water or the ocean circulation is the first-order factor that controls the **transports of energy, heat, salt and biogeochemical substances**
- Understanding physics of the transport in the ocean is key to interpret the **biogeochemical processes** and **climate variability** in the coastal and shelf sea
- Ocean circulation is important for **coastal engineering, navigation and defense**