Agronomy 406
World Climates

January 30, 2018

Monsoons.

Ocean properties and circulation.

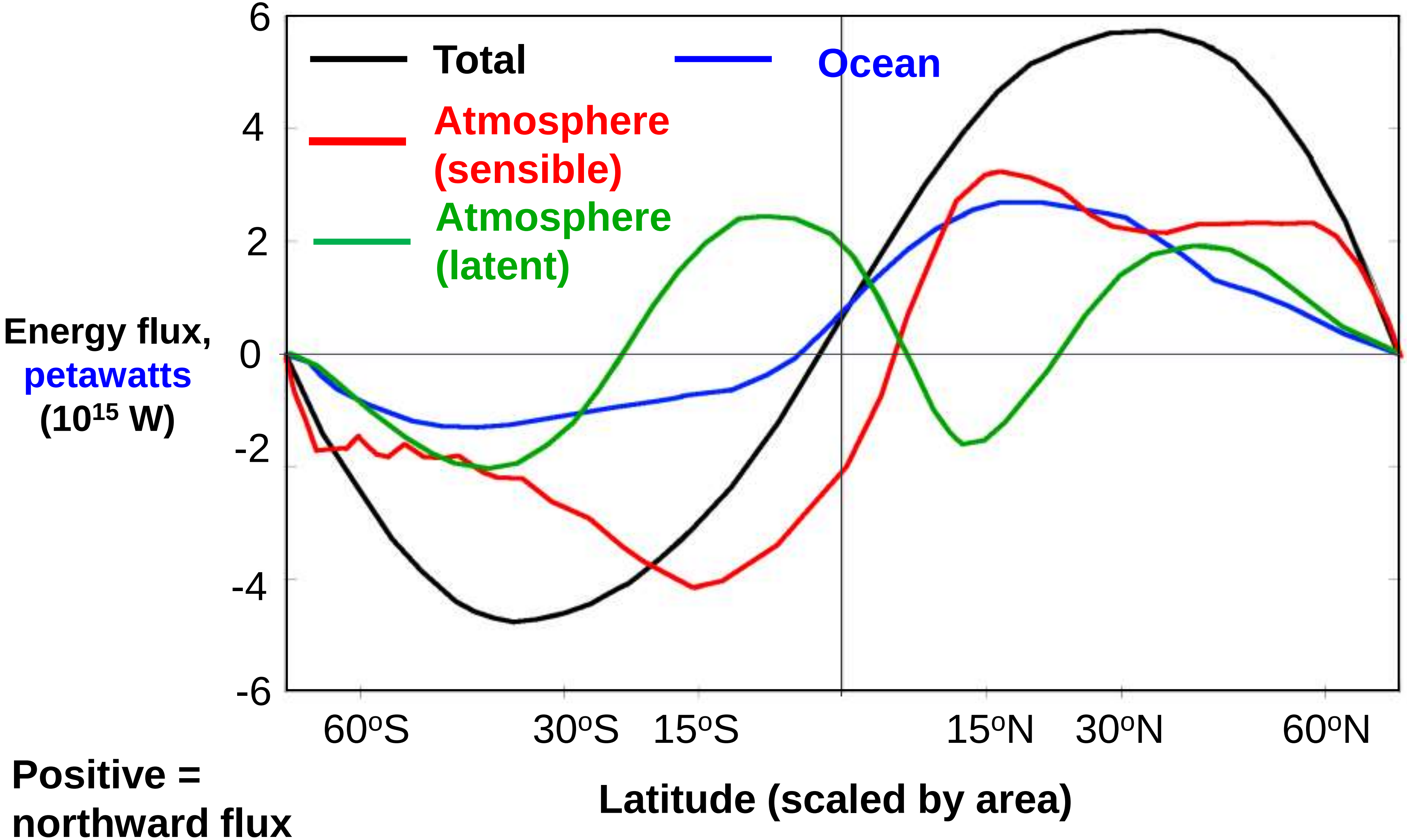
Review for today:

- Online textbook: 1.3.1 (Sea water) Composition and properties.

For Thursday:

- Rahmstorf, S.: The Ocean Thermohaline Circulation: A Brief Fact Sheet

Energy transport by sensible and latent heat fluxes



adapted from Bryden (2004)

Perturbations to the general circulation

Our basic picture of the general circulation can be changed by factors such as

- Land-sea contrasts
- Major mountain ranges
- Seasonal changes in land cover and snow or ice cover

Monsoons

Supply rain for **agriculture.**

Can cause **floods.**

Monsoons are caused by land-sea contrasts.

Monsoon flooding in Gauhati (India), September 2014.

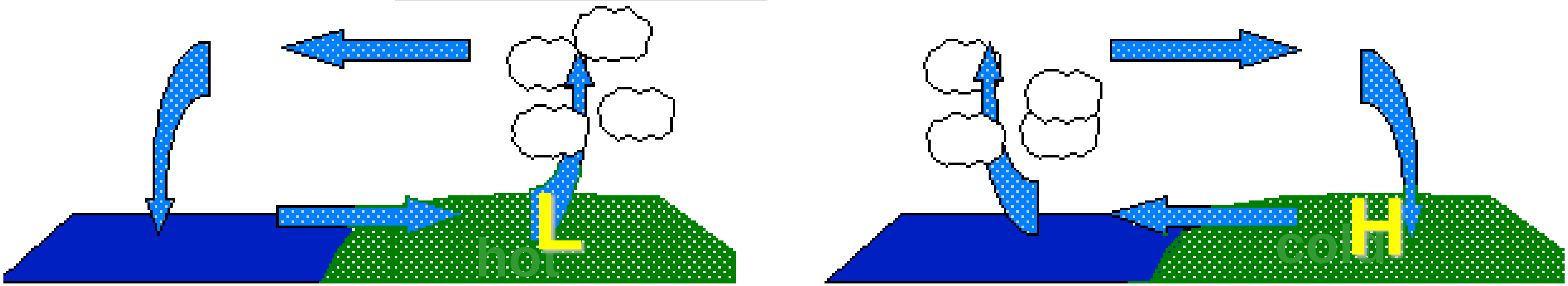
from cnn.com

Thermally direct circulation of the monsoon

summer

winter

warm air rises over land



hot land

cold land

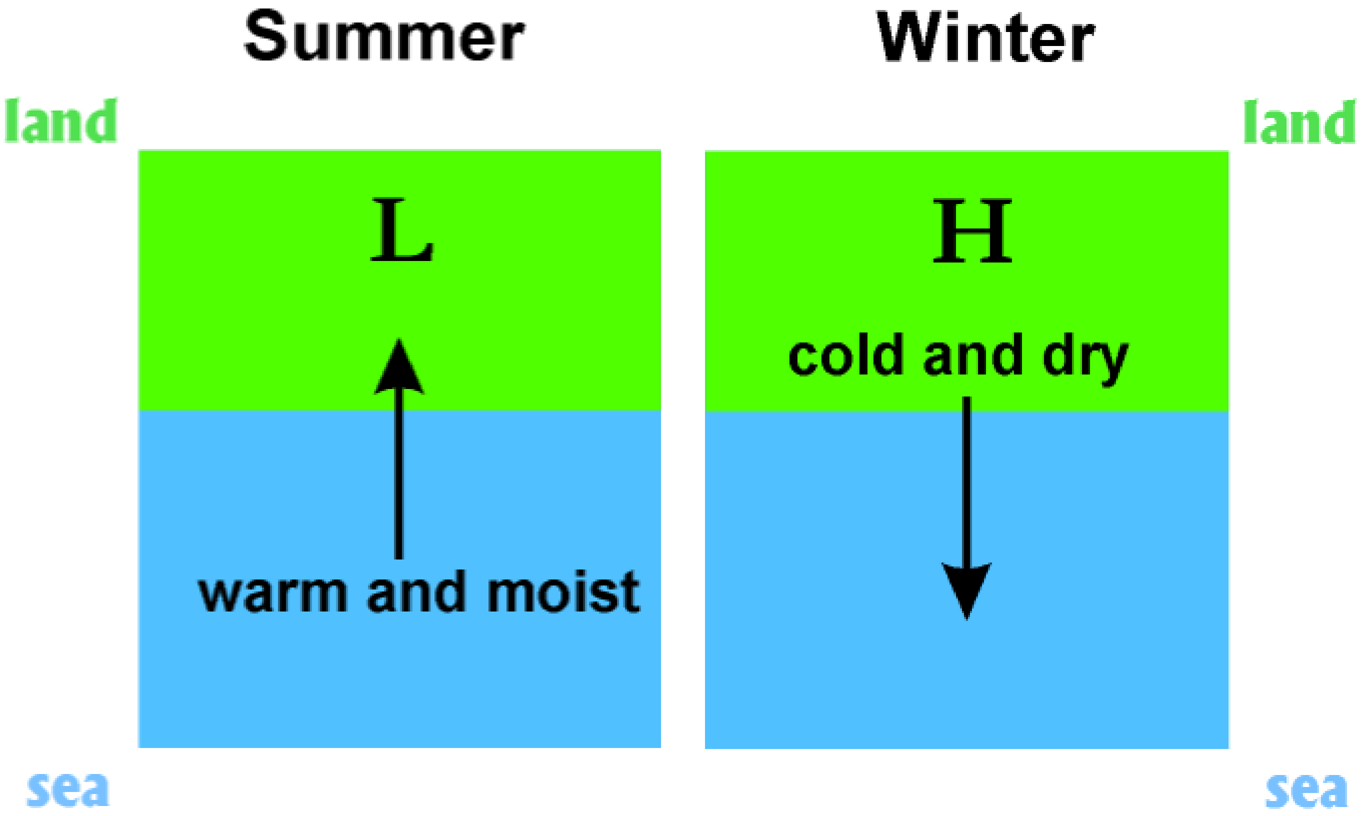
cold air sinks over land

Summer has low pressure over land.

Winter has high pressure over land.

Creates a pressure gradient from land to sea or vice versa.

Monsoons and moisture



Summer monsoon brings rain and high humidity.

Winter monsoon brings cold, dry air.

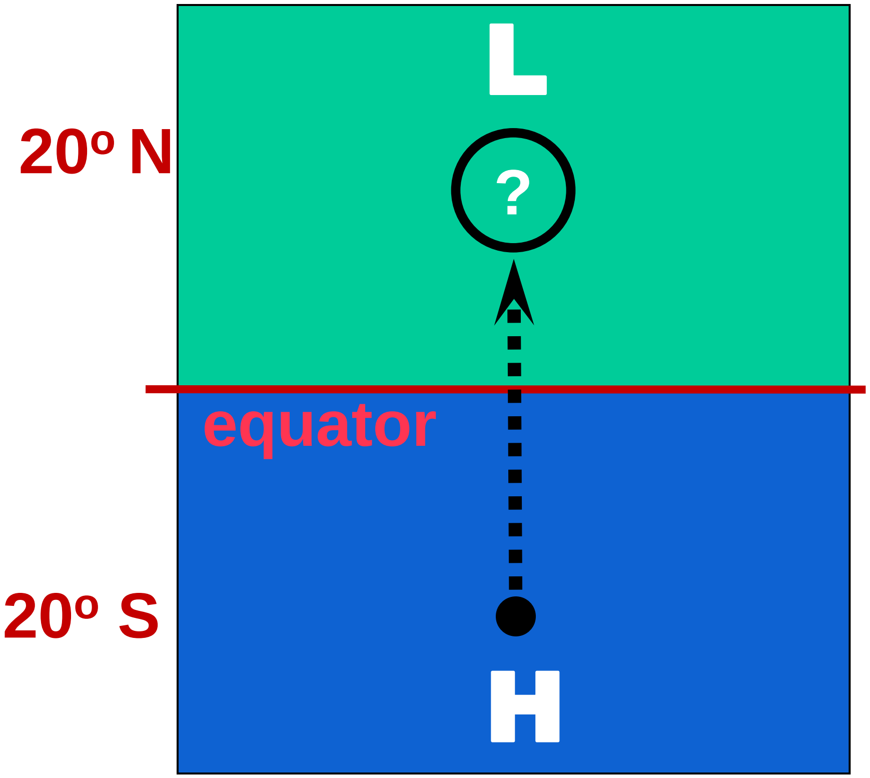
Team discussion

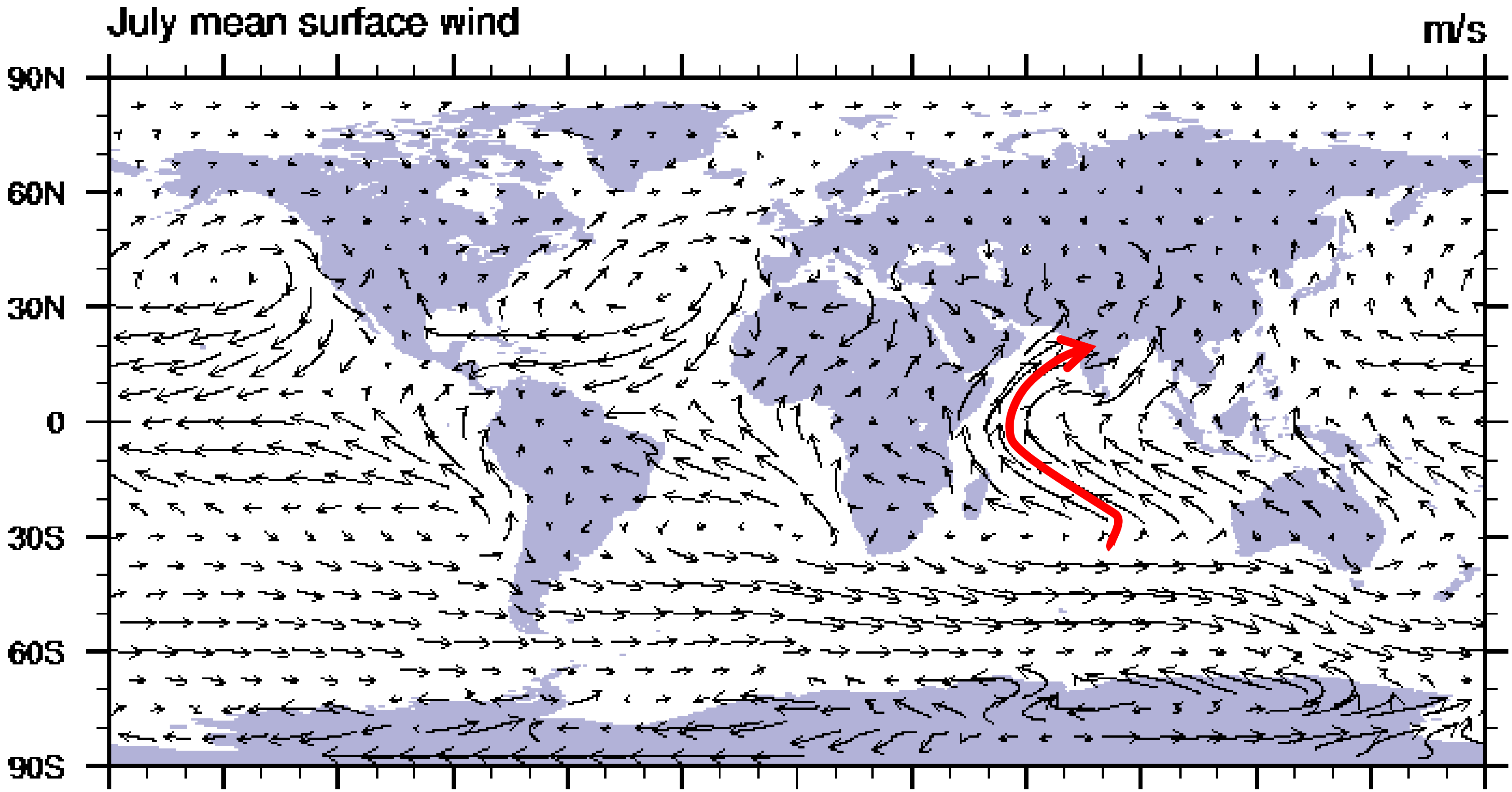
Suppose there is high pressure south of the equator and low pressure north of the equator.

What movement do you expect for a parcel of air that begins south of the equator and moves north of the equator?

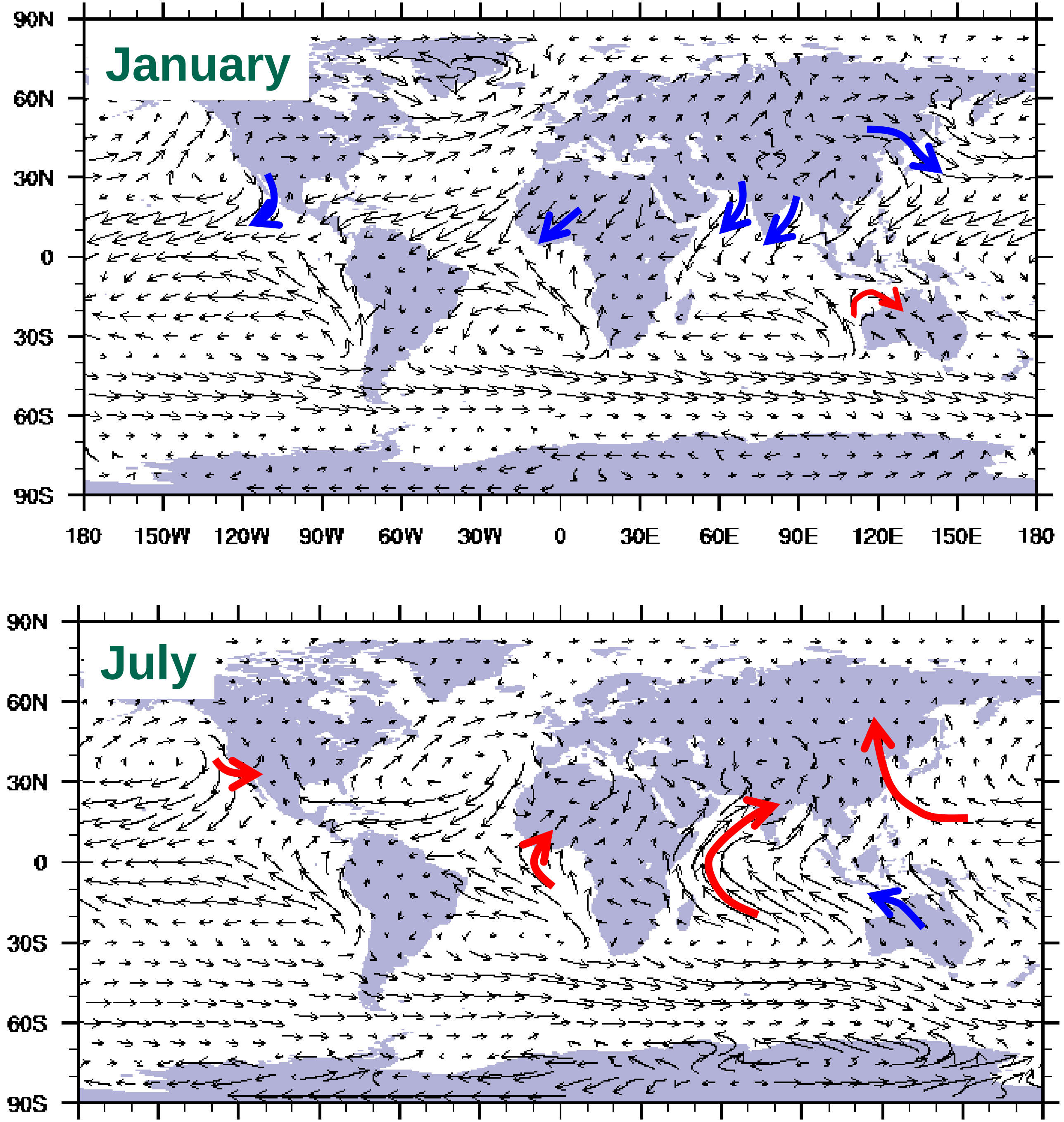
Draw the path that the air parcel would take when moving from 20^{o}S to 20^{o}N.

Keep the Coriolis force in mind.





July mean surface wind
m/s
90N
60N
30N
0
30S
60S
90S



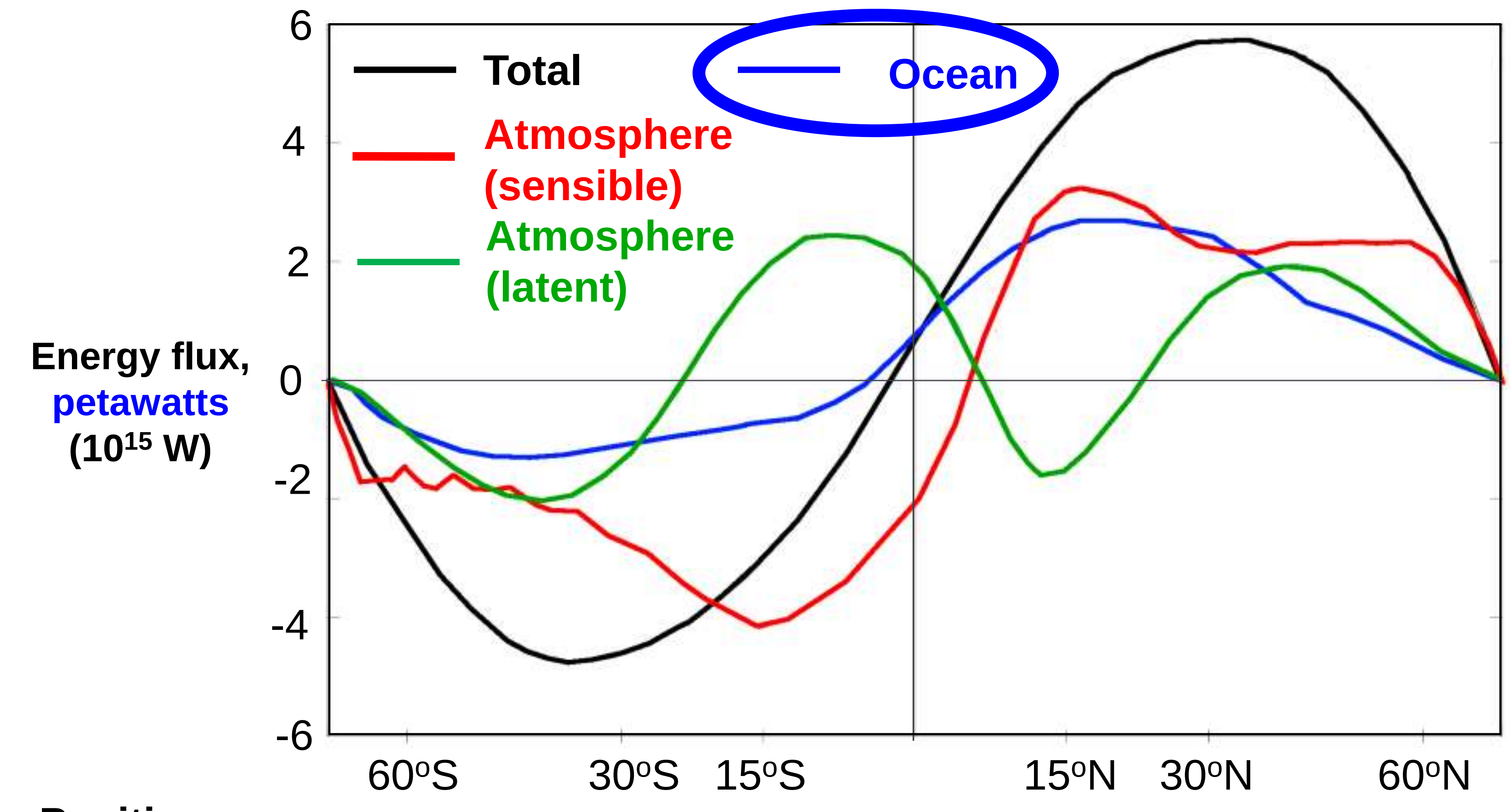
Many tropical regions near the coasts of large land masses experience monsoons.

Monsoon circulations tend to cause contrasting wet and dry seasons.

Red arrows: warm, moist air from oceans.

Blue arrows: cold, dry air from continents.

Look at global energy transport again



Positive = northward flux

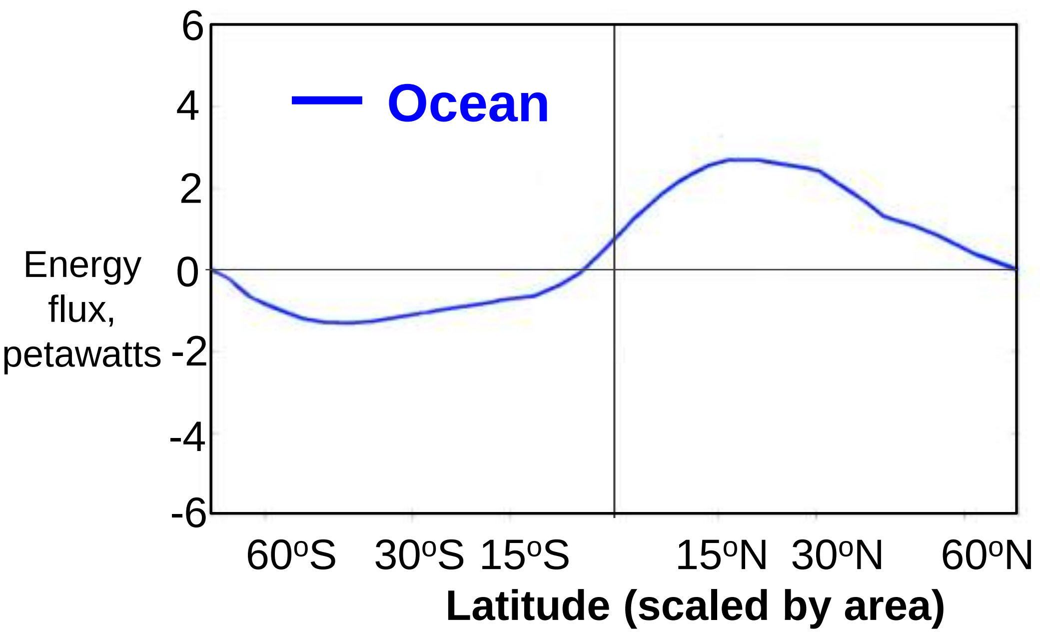
adapted from Bryden (2004)

Ocean circulations

Ocean circulations transport energy comparable to the atmospheric sensible or latent heat fluxes.

This has big effects on climate, such as warming by the Gulf Stream and North Atlantic Drift.

Look at processes that cause ocean circulation.



adapted from Bryden (2004)

What causes ocean circulations?

The oceans have three main types of large-scale motions:

- **Wind-driven** currents (mostly the upper ocean)
- **Thermohaline** circulation (extends deeper)
- Tides (we will not say much about these)

Wind moves the upper part of the ocean.

Thermohaline circulations come from the effect of temperature and salinity on **density** of water:

"thermo-" for temperature

"-haline" for salt (you may remember "halogens" in the periodic table)

First look at wind driven currents.

Wind stress

Wind stress is transfer of the wind's momentum to the surface (land or water).

Since the ocean is a fluid the **Coriolis force** can also act on the ocean.

Discuss:

- Begin with still water in the open ocean in mid-latitudes (exact latitude doesn't matter).
- Wind begins to blow over the water. Wind stress **transfers momentum from the air to the water.**
- **How does the water move in response?** (Hint: Think about the Coriolis force acting on the water.)

The Coriolis force affects wind-driven currents

Wind pushes on the ocean surface:

- The surface water begins moving in the direction of the wind.

Once the water starts to move, the Coriolis force **deflects it to the right** (in the N. Hemisphere).

- **Important:** Remember **Coriolis force = f V**, so it acts only when the water is moving (V > 0).

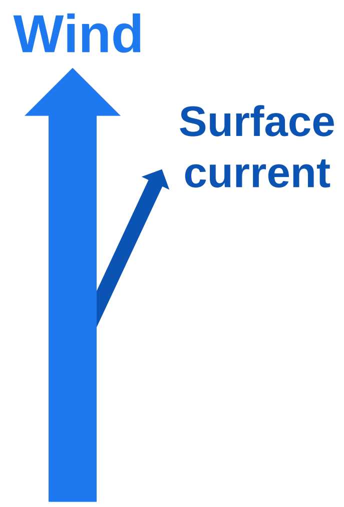
The Coriolis force affects wind-driven currents

Wind pushes on the ocean surface:

- The surface water begins moving in the direction of the wind.

Once the water starts to move, the Coriolis force **deflects it to the right** (in the N. Hemisphere).

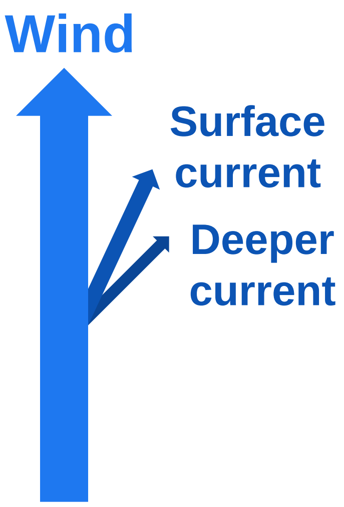
So, close to the ocean surface the current will flow at an angle to the **right** of the wind direction.



Wind-driven circulation extends below the surface

The surface water – which is moving to the right of the wind – drags against the water just below it.

- The water just below the surface starts moving in the same direction as the surface water - a little to the right of the wind.
- When this water starts moving, the Coriolis force deflects it more to the right.

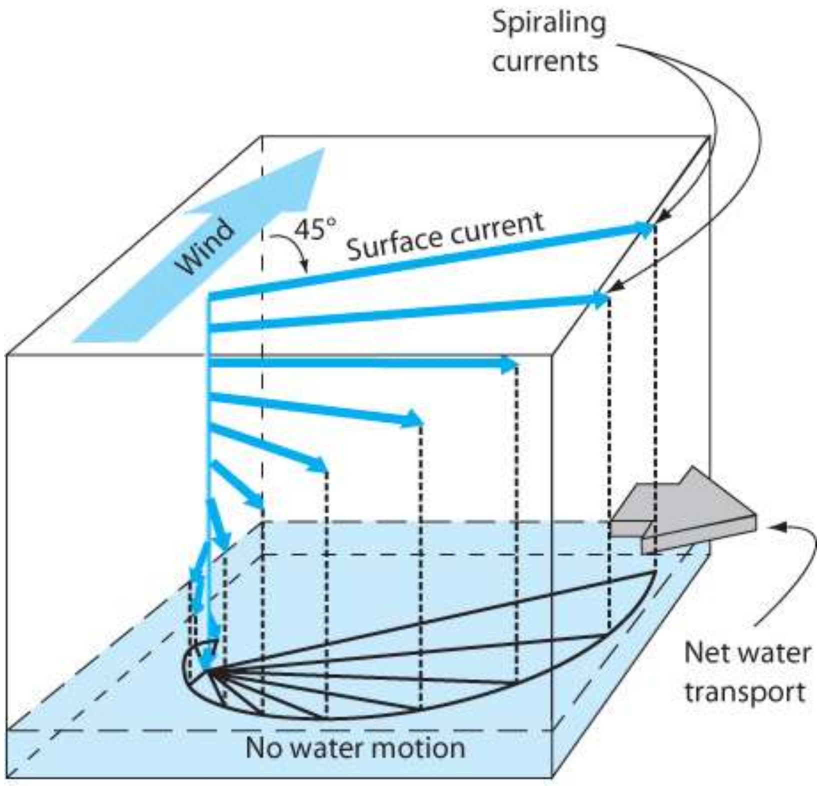


Water moves to the right of the wind

Each deeper layer moves a little more to the right than the layer above.

Looking from the top, the motion appears to "spiral" rightward with depth.

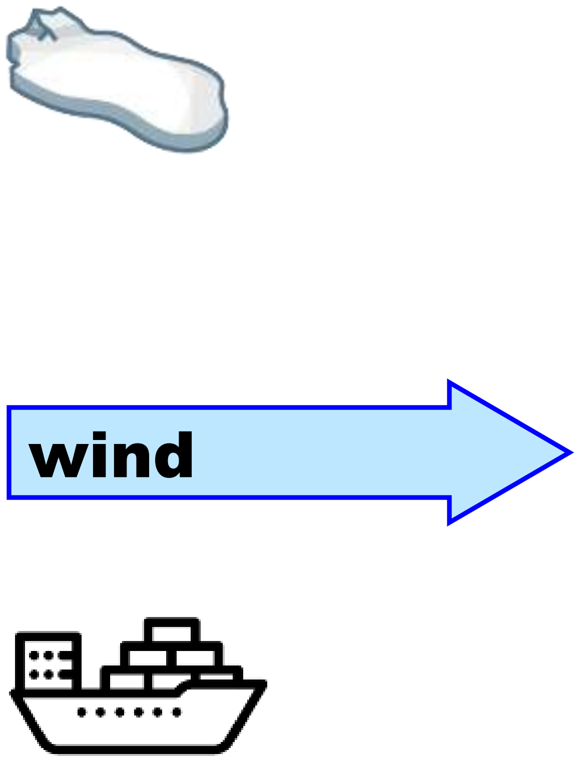
- This is the Ekman spiral (after V. Ekman, who first solved the equations for it).
- Averaged over the whole depth, the water moves 90º to the right of the wind.



(a) Ekman spiral in the northern hemisphere

- Theoretical result – real world differs somewhat.

Icebergs move with the upper part of the ocean – at an angle to the right of the wind



Large scale winds and ocean circulation

We showed that winds in the **mid-latitudes** of both hemispheres are (on average) **westerly:**

- i.e., they blow from west to east

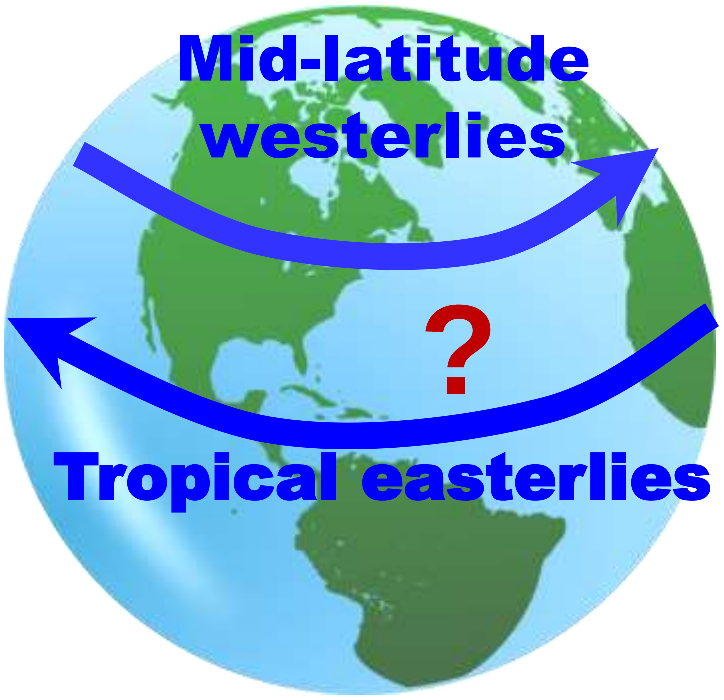
We also showed that winds in the **tropics** of both hemispheres are (on average) **easterly:**

- i.e., they blow from east to west

And we showed that wind-driven currents move **to the right of the wind** (in the Northern Hemisphere).

What is the effect of large-scale winds on the ocean?

Wind driven forcing of the ocean



Given:

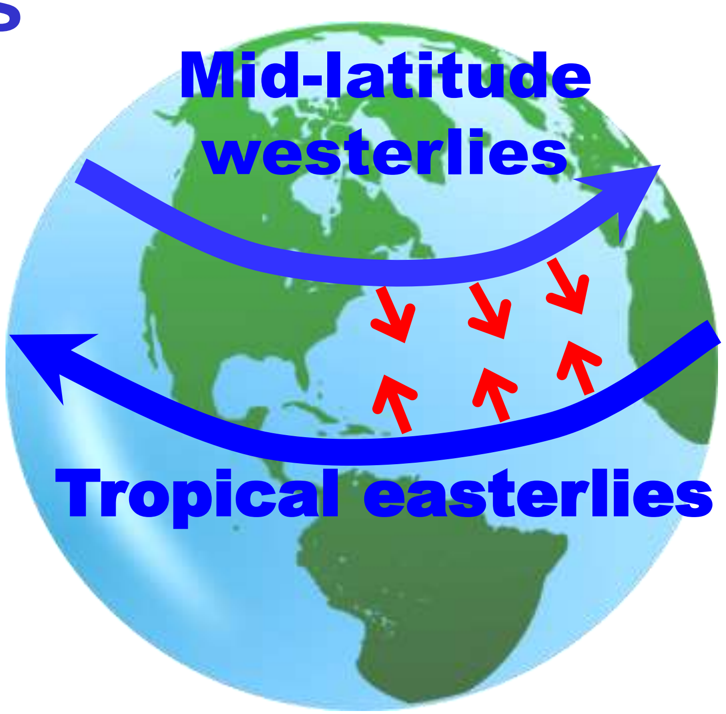
- Winds in the mid-latitudes are westerly.
- Winds in the tropics are easterly.
- Coriolis force causes water to move **to the right of the wind** in the Northern Hemisphere.

Discuss: What happens to ocean water in the region <u>between</u> the easterlies and westerlies?

Wind forcing causes convergence of ocean water in subtropics

Given:

- Winds in the mid-latitudes are westerly.
- Winds in the tropics are easterly.
- Coriolis force causes water to move **to the right of the wind** in the Northern Hemisphere.

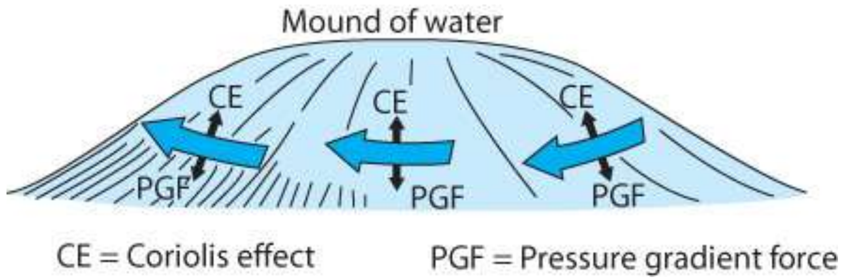


This causes water to converge in the region between the easterlies and westerlies.

Ocean Circulation

Wind driven currents

Because of the Coriolis force, water **converges** between the easterlies and westerlies.

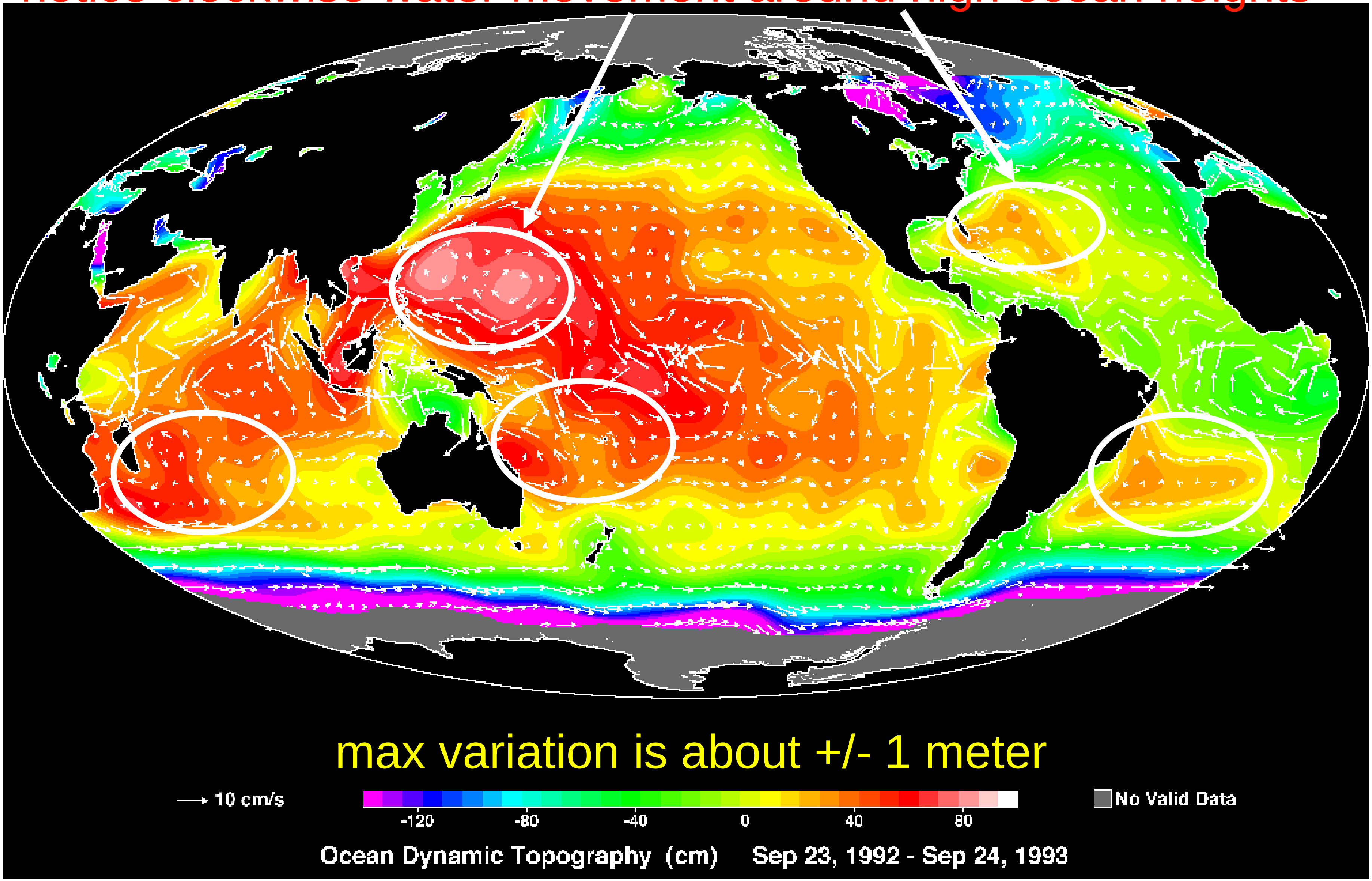


Produces a "mound" of water with sea height greater than the surroundings:

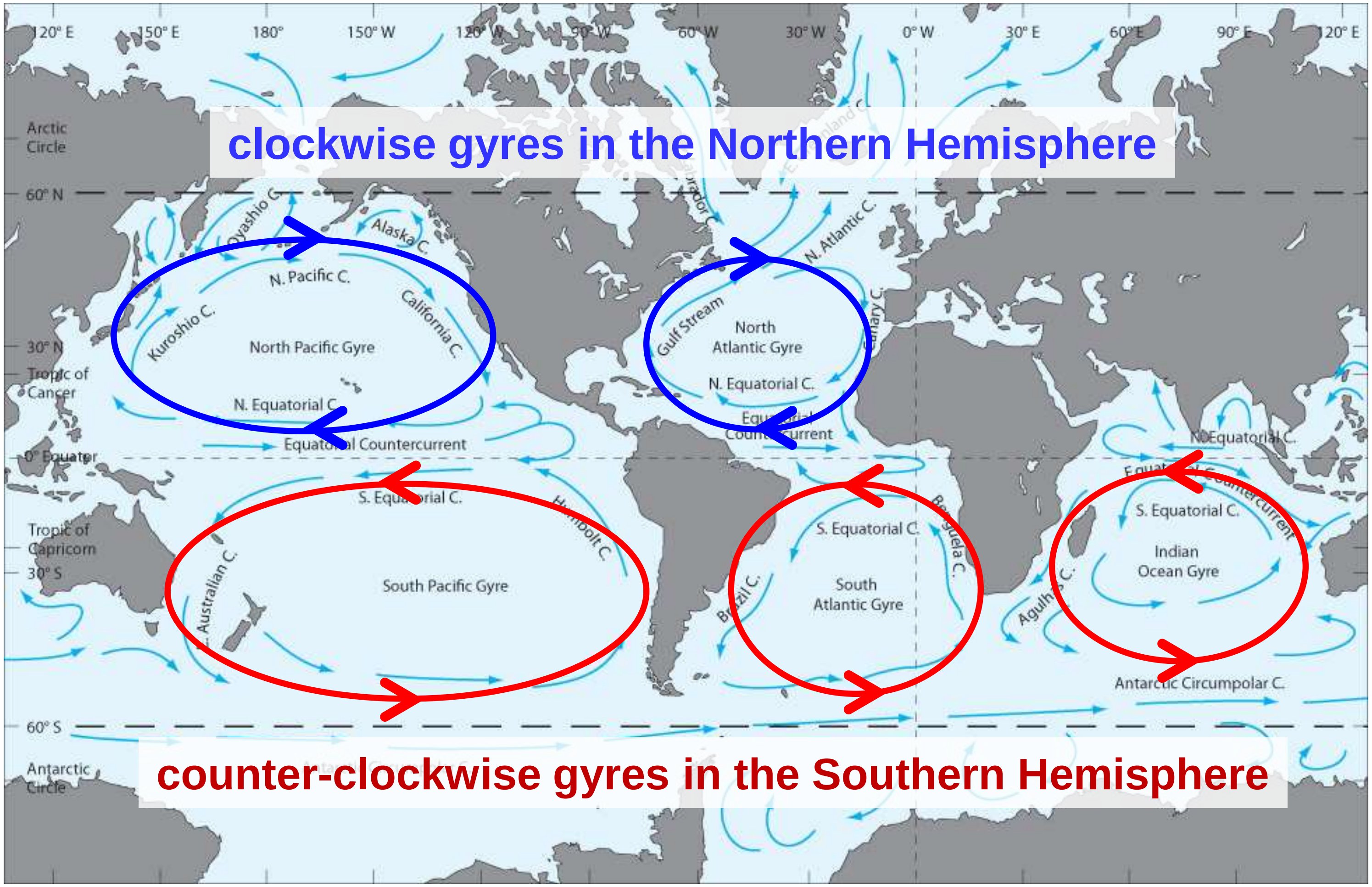
- The mound of water causes a **pressure gradient force** directed away from it (just like high pressure in the atmosphere).
- The Coriolis force then deflects the water to the right (NH) or left (SH).
- Result is a gyre in each ocean basin.

Ocean topography and surface currents

notice clockwise water movement around high ocean heights



Ocean gyres


clockwise gyres in the Northern Hemisphere
counter-clockwise gyres in the Southern Hemisphere
Arctic Circle
60° N
30° N
Tropic of Cancer
0° Equator
Tropic of Capricorn
30° S
60° S
Antarctic Circle
120° E
150° E
180°
150° W
120° W
90° W
60° W
30° W
0° W
30° E
60° E
90° E
120° E
Oyashio C.
Alaska C.
N. Pacific C.
California C.
Kuroshio C.
North Pacific Gyre
N. Equatorial C.
Equatorial Countercurrent
S. Equatorial C.
Humboldt C.
Australian C.
South Pacific Gyre
Gulf Stream
North Atlantic Gyre
N. Atlantic C.
Canary C.
Equatorial Countercurrent
Brazil C.
South Atlantic Gyre
Benguela C.
Agulhas C.
Indian Ocean Gyre
Antarctic Circumpolar C.

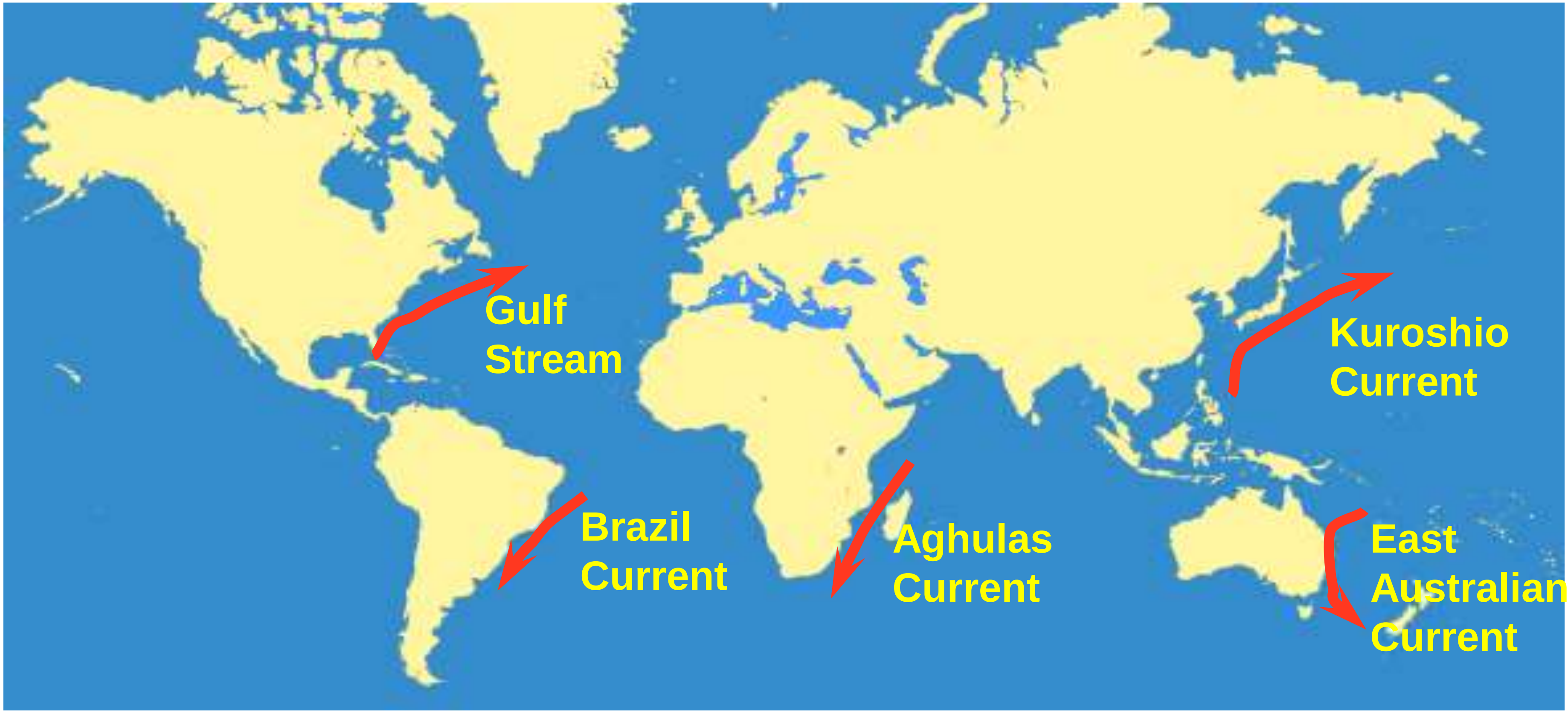
Why do we care?

The large-scale gyres transport warm water poleward off the east coasts of continents, and cold water equatorward off the west coasts.

This heat transport has big effects on the climate not just near the coasts but well inland.

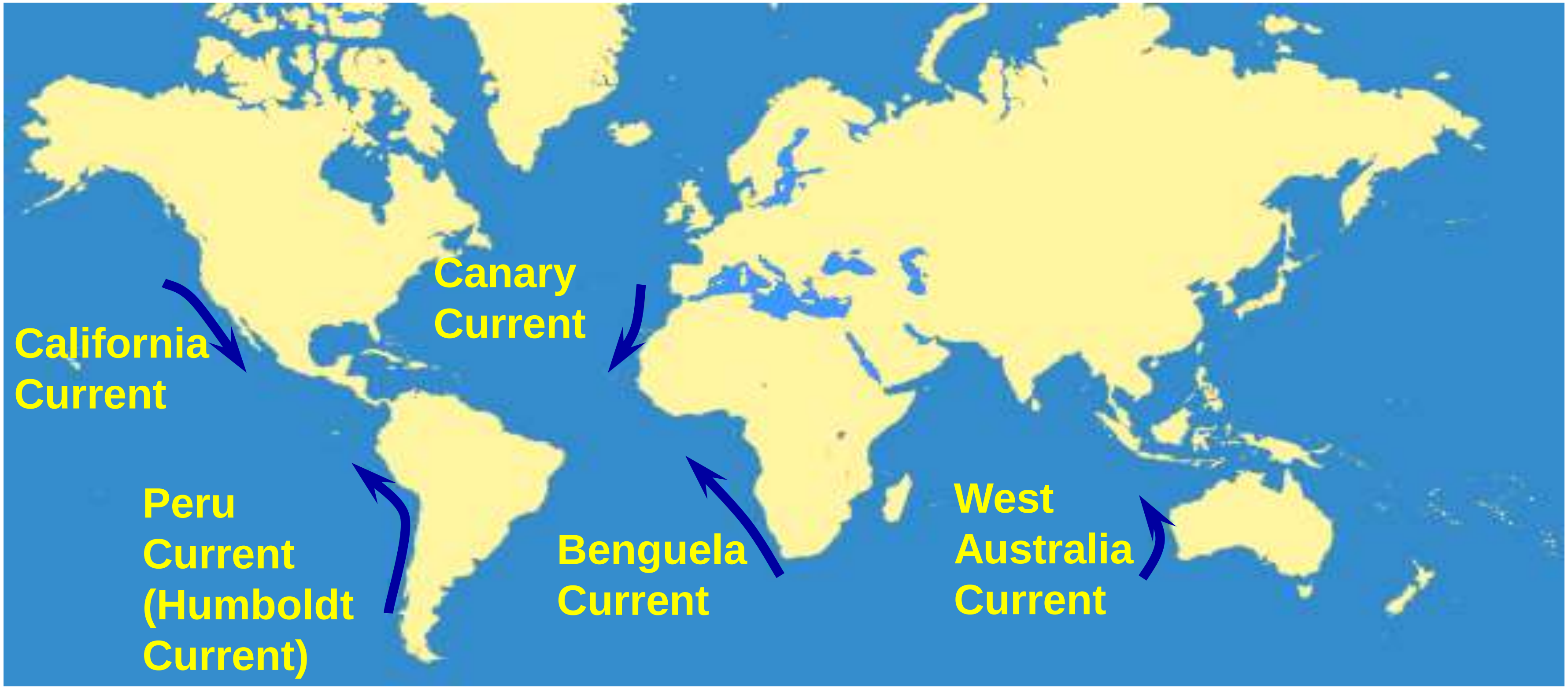
Western boundary currents

These are **warm currents.** Why?



Eastern boundary currents

These are **cold currents**



Coastal upwelling and downwelling

Water that is pulled away from the coast by wind-driven circulation must be replaced by water from elsewhere:

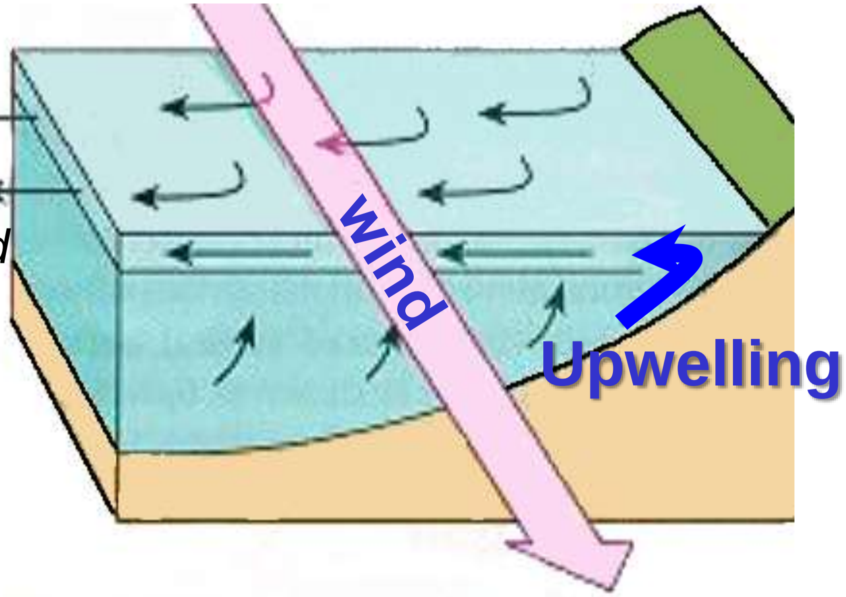
- the result may be upwelling

Water that is pushed toward the coast by wind-driven circulation must be transported away:

- the result may be downwelling

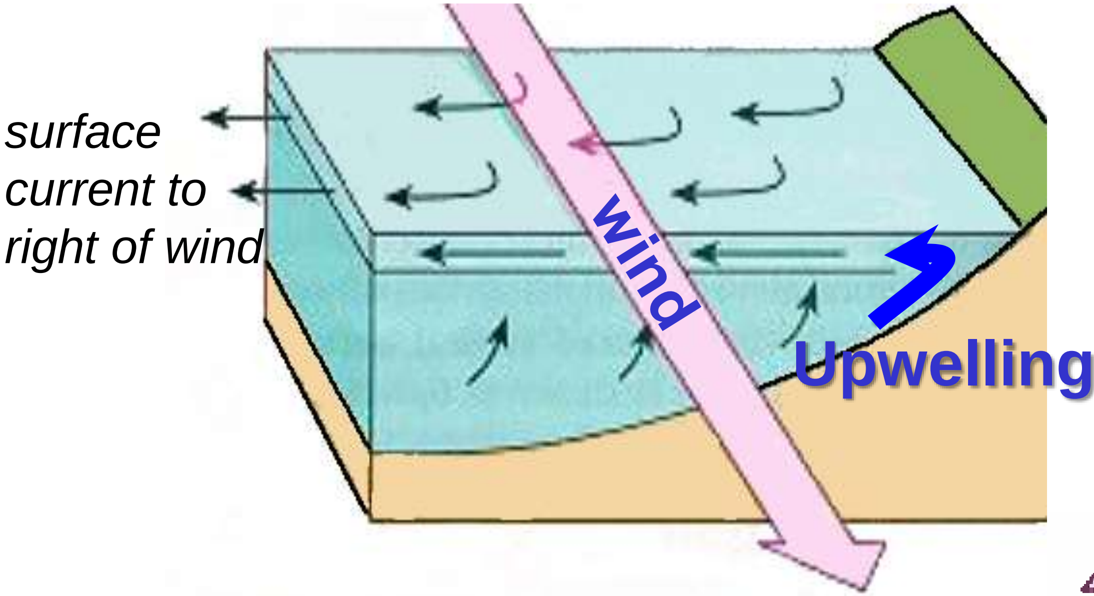
Remember **water doesn't necessarily move in the same direction as the wind** because of the effect of the Coriolis force (and coastline or basin shape).

Upwelling and downwelling (Northern Hemisphere)



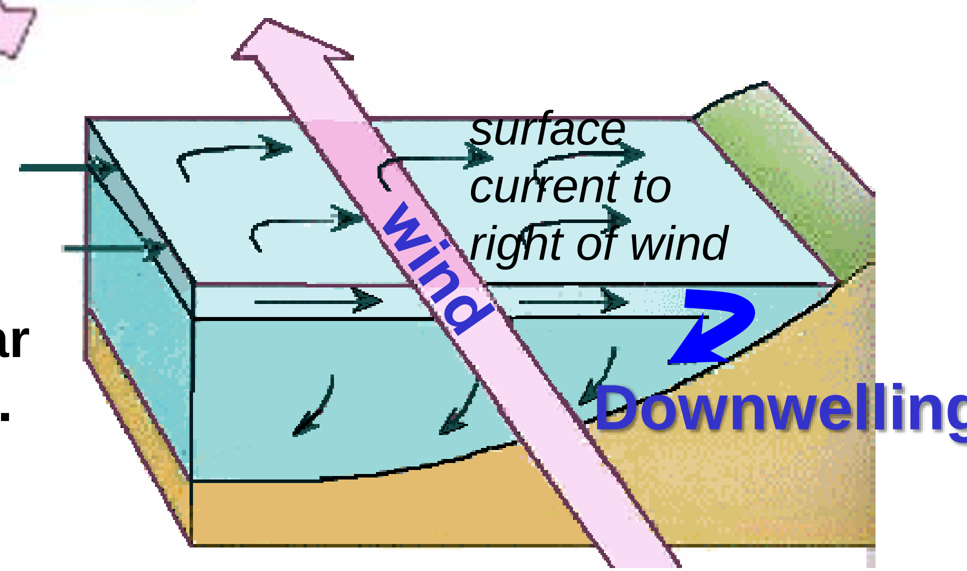
Water moves to the right of the wind: water carried away from the shore is replenished from below.

Upwelling and downwelling (Northern Hemisphere)



Water moves to the right of the wind: water carried away from the shore is replenished from below.

Water moves to the right of the wind: water "piles up" near the shore and sinks.



Why do we care?

Upwelling and downwelling affect **climate** near the coast:

– Cold ocean waters due to upwelling makes climate cooler and can suppress thunderstorms, as well as causing coastal fog.

image from www.washington.edu

Effect on ocean **ecosystems:**

– Upwelling replenishes nutrients.

– By one estimate, up to **50%** of the world's fish catch takes place in upwelling areas that cover only **0.1%** of the ocean surface.

Thermohaline circulations

Thermohaline circulations come from the effect of temperature and salinity on **density** of water:

- "thermo-" for temperature
- "-haline" for salt

Unlike wind-driven circulations, thermohaline circulations can extend through great depths.

- **Thermohaline circulations link the surface with the deep ocean.**

Start by looking at basic properties of ocean water.

Temperature and salt

Ocean water is affected by **salt content:**

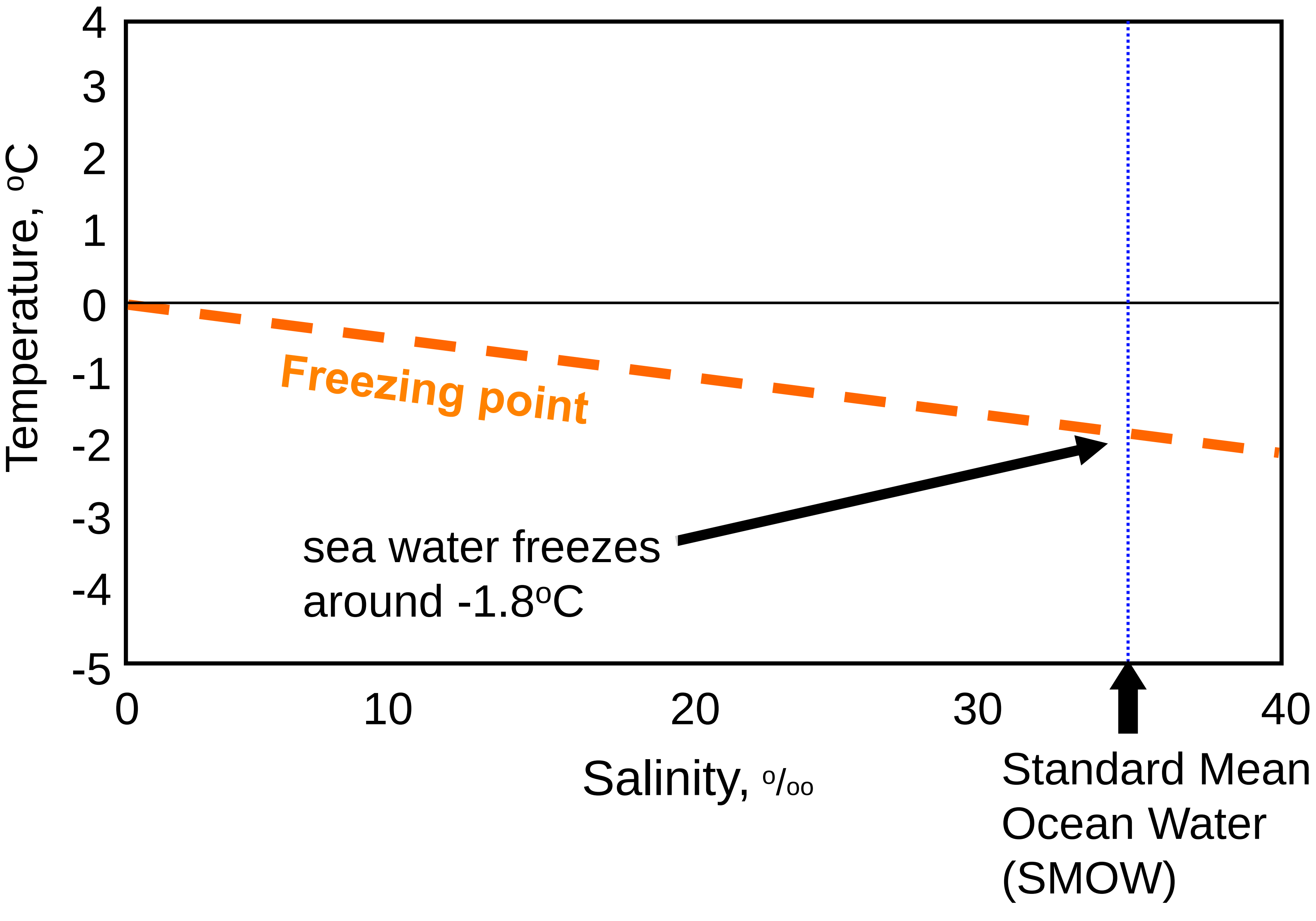
- Average salinity is about 35 parts / thousand (‰).

Salty water freezes at lower temperature than fresh water.

Density depends on both temperature and salinity:

- **Density increases with increasing salt content.**
- **Density increases with decreasing temperature.**
- Unlike fresh water, **sea water becomes denser with colder temperature until it freezes.**

Effect of salinity on density and freezing



Effect of salinity on density and freezing