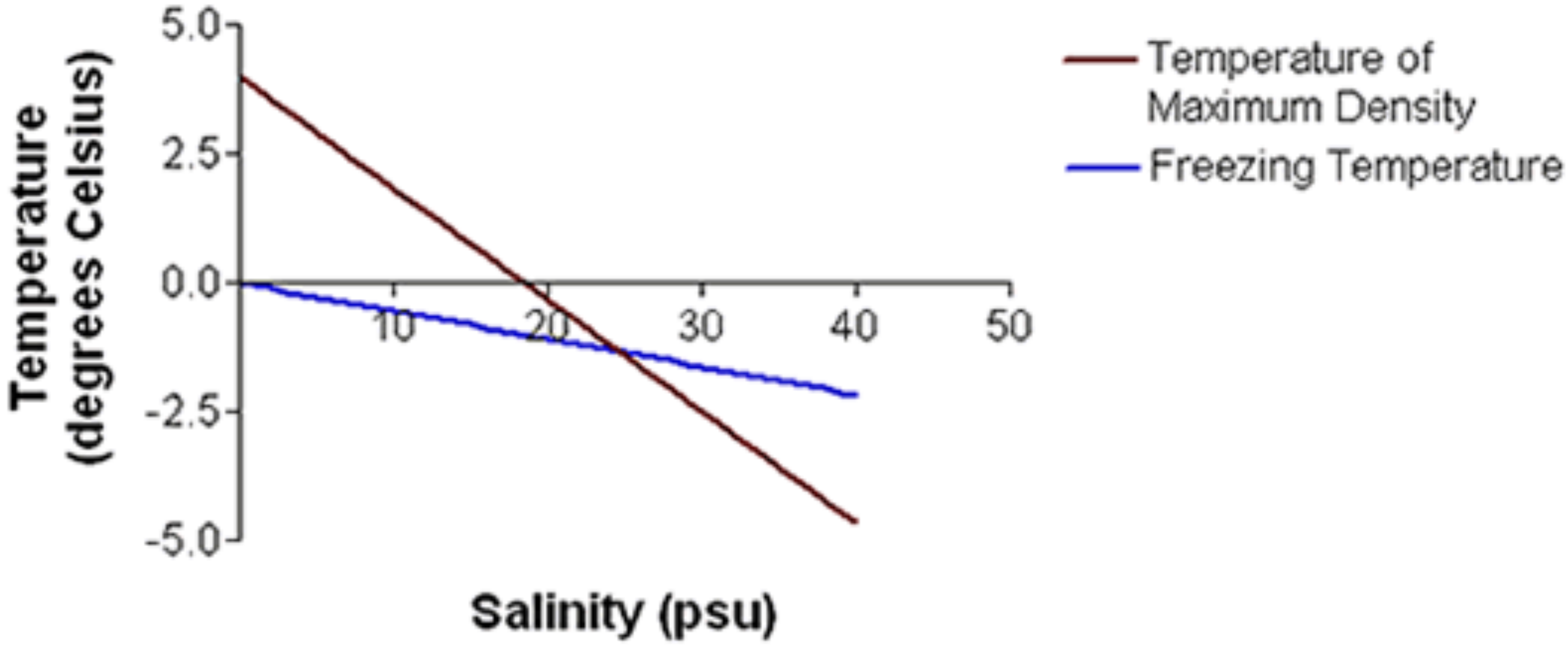
AOS 103

Week 10 Discussion

Temperature of Maximum Density



The brown line on the curve represents the temperature (as a function of salinity) that is the <u>temperature of maximum density</u>: this means that at any given salinity (e.g., 0 g/kg), the temperature indicated by the curve (e.g., ~3C) is the temperature at which maximum density is reached.

<u>If the temperature were lowered past this point (3C —> 1C), the density would not change (even though the water is getting colder)</u>

ENSO

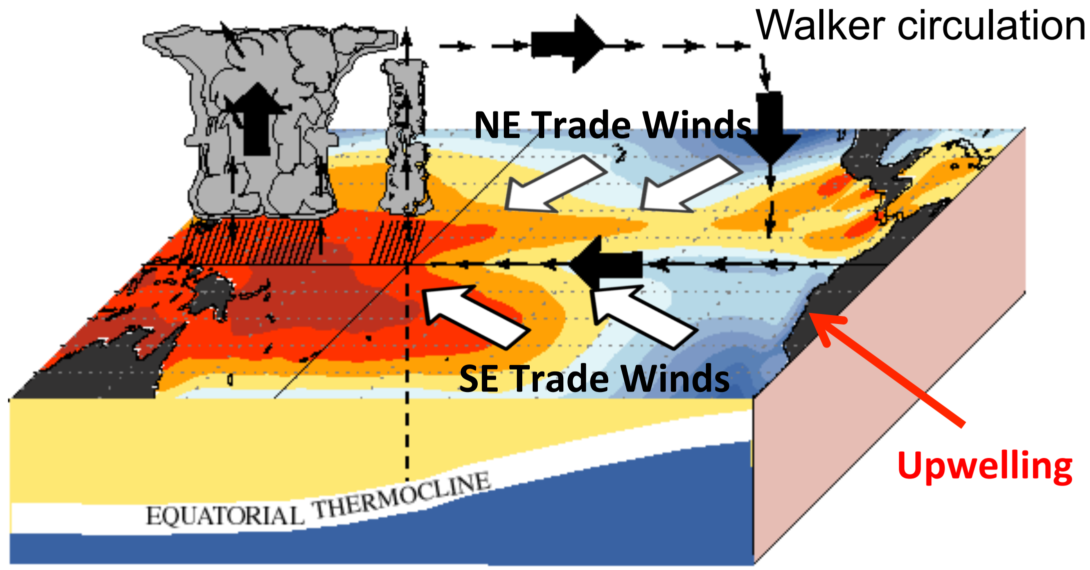
1) Draw the equatorial “bathtub” for neutral, El Nino and La Nina conditions (explain/draw the winds, sea surface, thermocline and currents)

2) What type of physical process is responsible for sending warm water up to CA during an El Nino?

3) Why does southern California experience more storms during El Nino years?

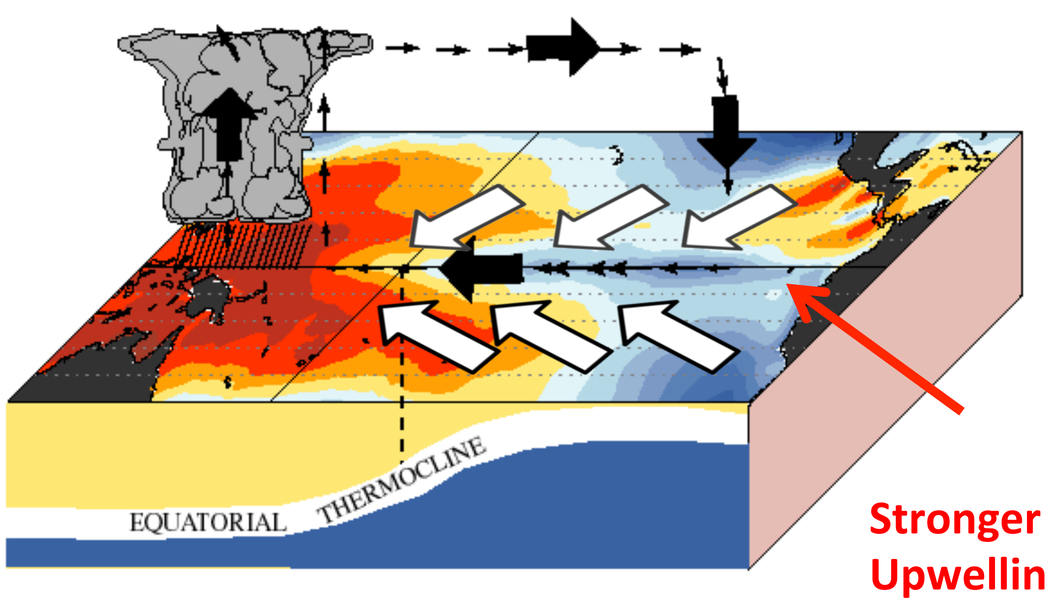
1) **Draw the equatorial "bathtub" for neutral, El Nino and La Nina conditions (explain/draw the winds, sea surface, thermocline and currents)**

Neutral (Normal)

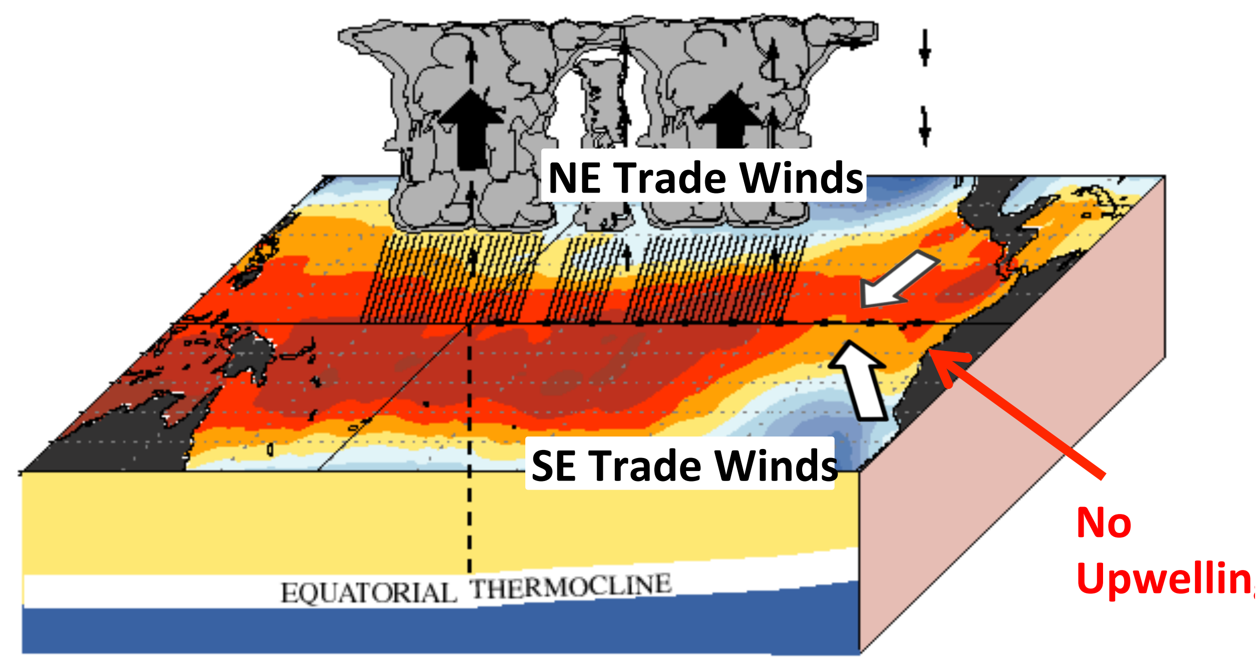


La Nina

December - February La Niña Conditions



El Nino



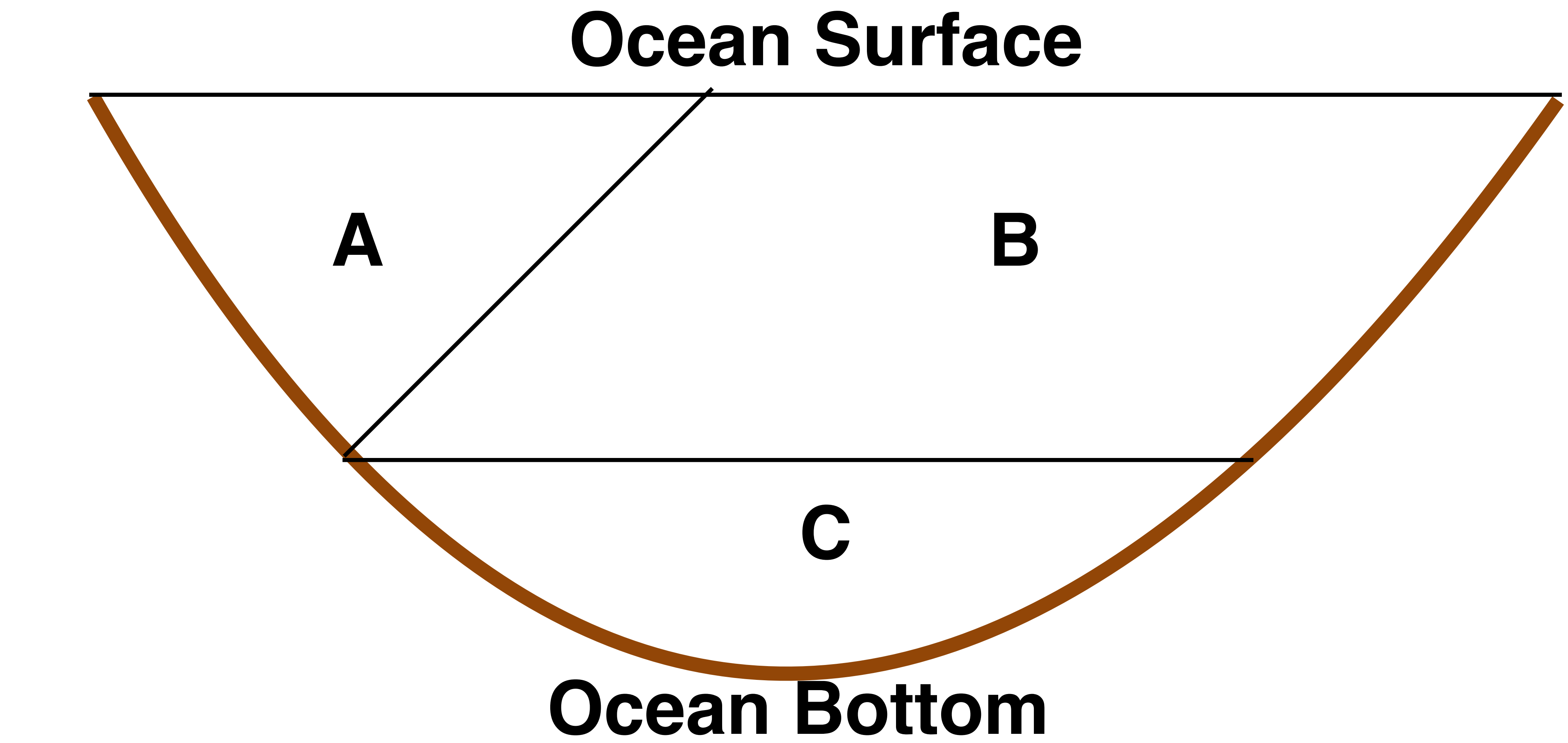
2) **What type of physical process is responsible for sending warm water up to CA during an El Nino?**

A equatorial Kelvin wave is triggered by a collapse of the equatorial winds and sends warm water along the equator and eventually up the California coast (analgously the same Kelvin wave propagates poleward down the South American Coast in the Southern Hemisphere)

3) **Why does southern California experience more storms during El Nino years?**

The normal storm tracks for the west coast of the United States usually lies in the Pacific Northwest. This is coincident with the latitudinal placement of the jet stream, which is a baroclinically unstable flow (i.e., it produces eddies, eddies = storms). During El Nino, the jet stream shifts south and thus the storms produced by the jet stream lie further to the south than normal (e.g., near southern California)

Conservation



1) Write an equation (w/ velocity (V) and area (A) as variables) that describes the conservation of volume for this ocean basin

2) How would you modify that equation to have it express the conservation of mass?

1) **Write an equation (w/ velocity (V) and area (A) as variables) that describes the conservation of volume for this ocean basin**

$$\psi_A = V_B A_B$$

$$\psi_B = V_B A_B$$

$$\psi_C = V_C A_C$$

$$\psi_A + \psi_B + \psi_C = 0$$

2) How would you modify that equation to have it express the conservation of mass?

$$\rho\psi ==> \frac{kg}{m^3}\frac{m^3}{s} = \frac{kg}{s}$$

$$\rho_A\psi_A + \rho_B\psi_B + \rho_C\psi_C = 0$$

Conservation of mass implies a conservation of a unit of mass per second. So we multiply volume transport by density to get [kg/s]. Analogously we can derive relationships for conservation of "stuff" by multiplying the volume transport by units of "stuff"

Force Balances

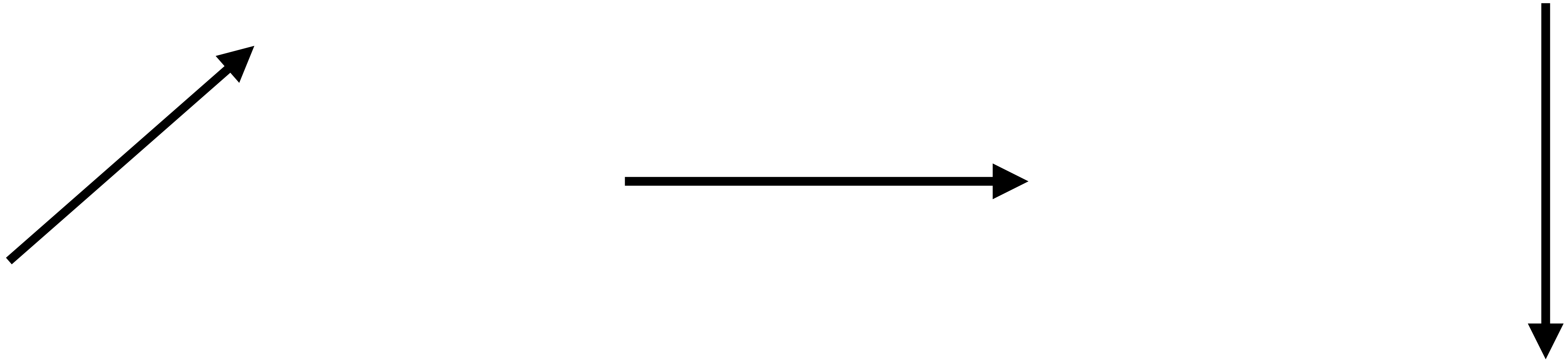
1) Explain (w/ words,equations,sketches, etc) the following force balances:
    1) Hydrostatic
    2) Geostrophic
    3) Ekman

2) Draw the sea surface height for the following geostrophic flows :

North Hemi

South Hemi

North Hemi



1) **Explain (w/ words,equations,sketches, etc) the following force balances:**

1) **Hydrostatic**

$$\frac{\partial p}{\partial z} = -\rho g$$

Pressure at any depth is proportional to the weight of fluid lying above it

2) **Geostrophic**

$$\frac{\partial p}{\partial x} = \rho_0 f v$$

$$\frac{\partial p}{\partial y} = -\rho_0 f u$$

Velocity is driven by a balance between the Coriolis and pressure gradient forces

3) **Ekman**

Velocity is driven by a balance between the Coriolis force and wind stress (force)

$$M^{(x)} = \rho h u = \frac{\tau^{wind,y}}{f}$$

winds in y-direction drive transport in x-direction

$$M^{(y)} = \rho h v = -\frac{\tau^{wind,x}}{f}$$

winds in x-direction drive transport in y-direction

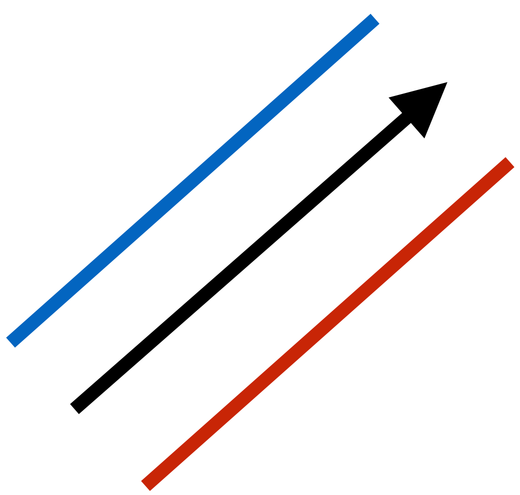
2) Draw the sea surface height for the following geostrophic flows :

Geostrophic flow is ALWAYS PARALLEL TO LINES OF CONSTANT PRESSURE (e.g., sea surface height). In the North Hemi, the geostrophic flow is to the right of the pressure gradient <u>force </u>(H—-> L) and to the left of the pressure gradient <u>force</u> in the Southern Hemi

Contour of LOW sea surface height

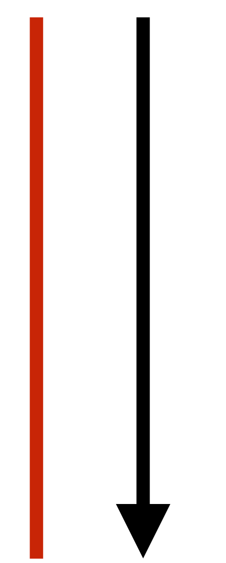
Contour of HIGH sea surface height

North Hemi



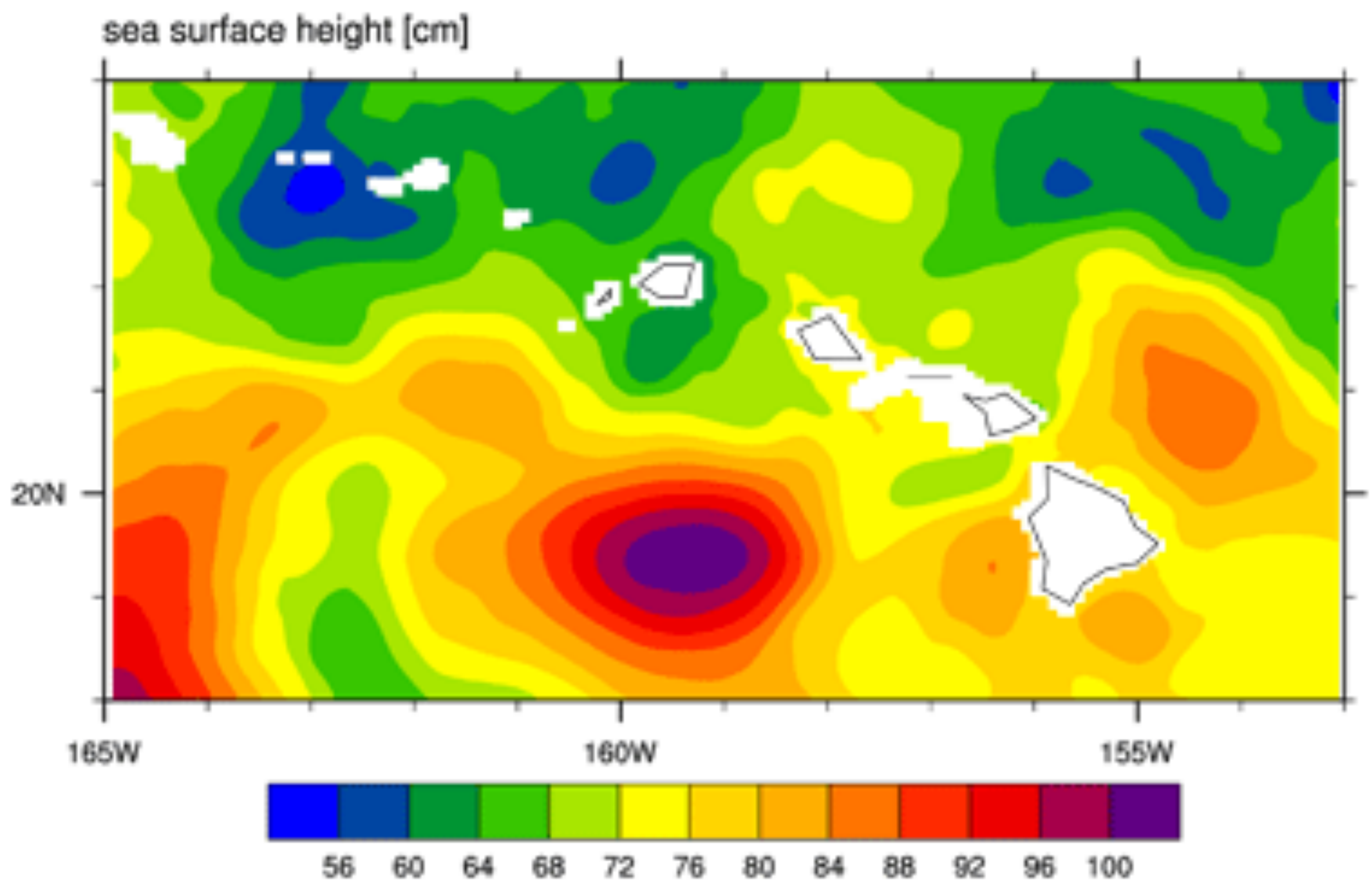
South Hemi

North Hemi

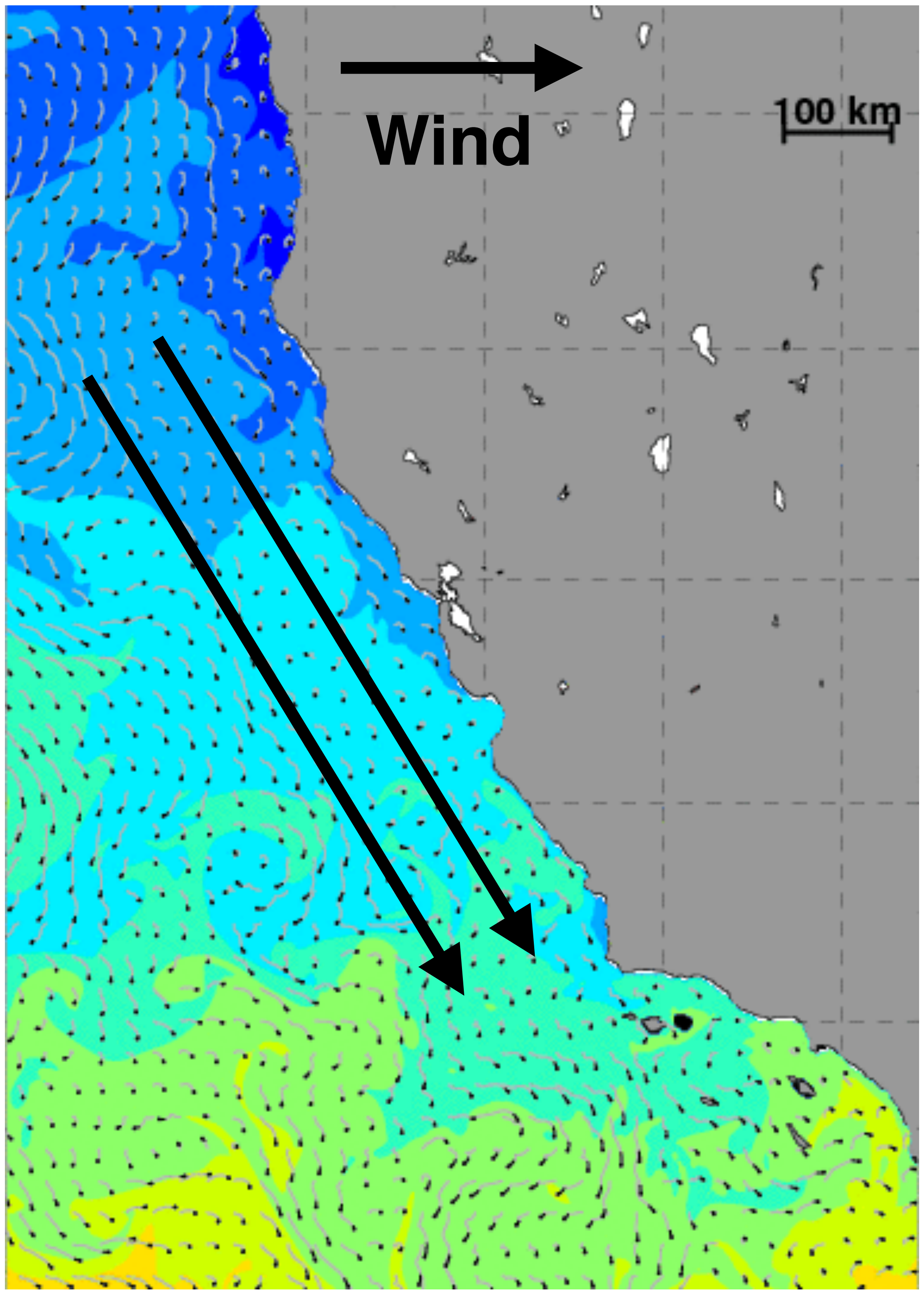


3) Draw/describe the geostrophic velocity for this SSH data (is the velocity you are describing barotropic or baroclinic?)

This is too difficult to draw in Keynote accurately , but if you have to do this on an exam, remember that geostrophic flow is PARALLEL TO THE LINES OF CONSTANT PRESSURE (SEA SURFACE), so you draw flow that runs in between the contour lines and its direction depends on the direction of the pressure gradient force). The geostrophic flow should never run perpendicular to a contour line.



Putting everything together: California Current Case Study



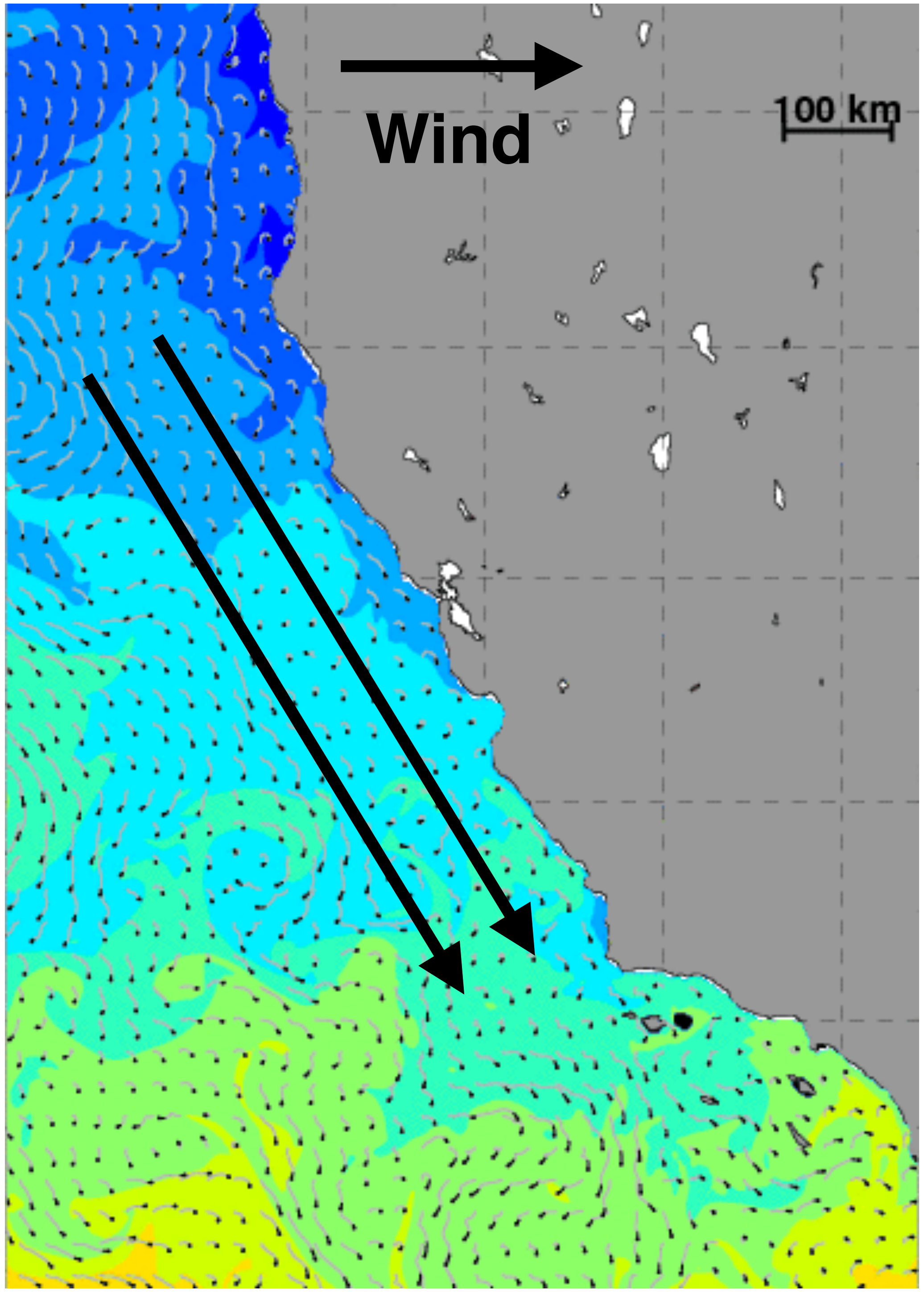
Surface winds blow along the CA coast as indicated by the black arrows on the left (over the area indicated by the 2 arrows)

The length of coast the winds blow over is given by a distance L (in meters)

What direction is the Ekman transport?

Given the wind stress, what would you need to calculate the volume transport (in units of Sv) for the Ekman current?

Putting everything together: California Current Case Study



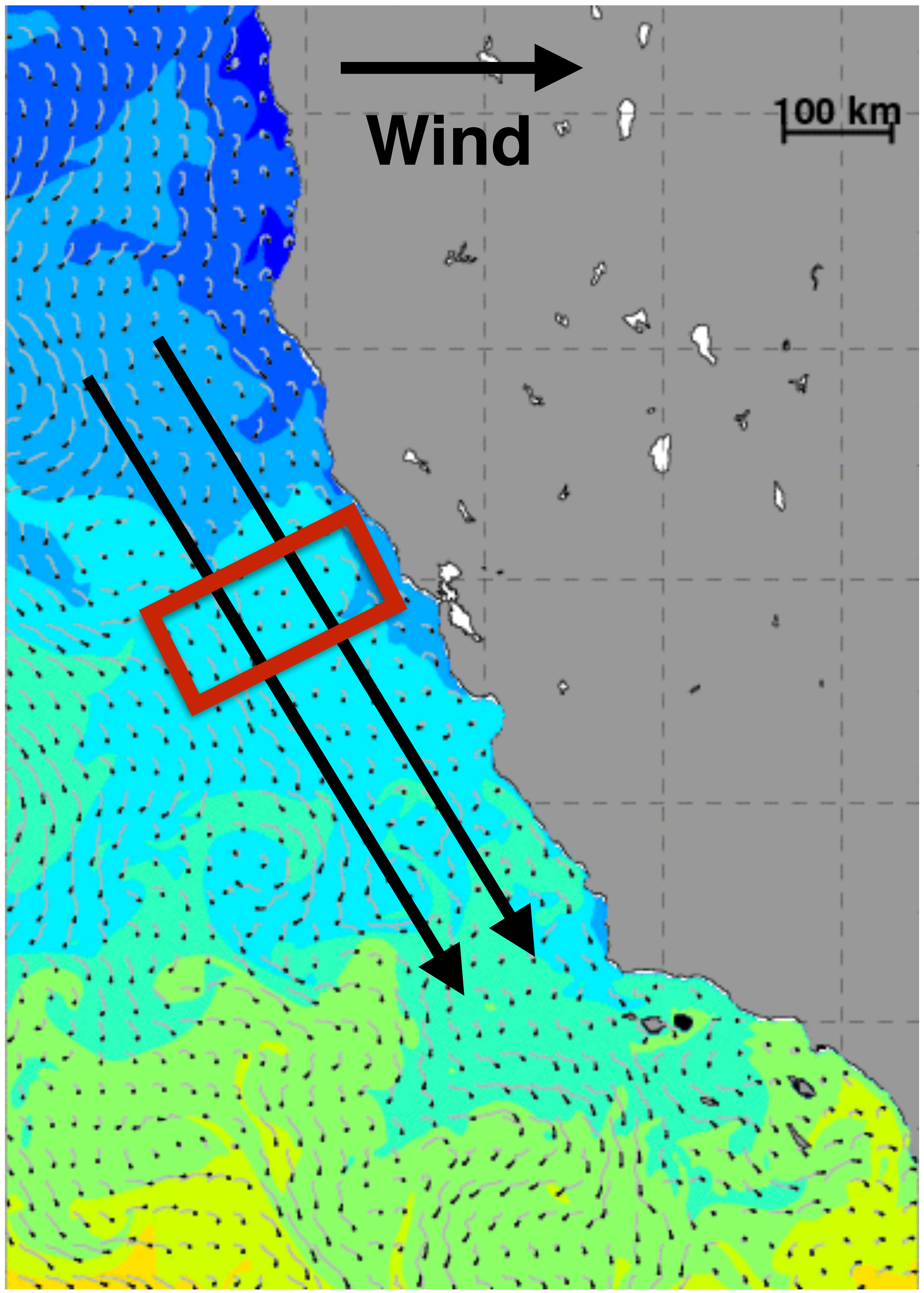
What direction is the Ekman transport?

Ekman transport will be to the right of the wind stress, so it is directed offshore

Given the wind stress, what would you need to calculate the volume transport (in units of Sv) for the Ekman current?

$$\psi_{Ek} = \frac{\tau L}{\rho f}$$

Putting everything together: California Current Case Study



What is the vertical velocity (positive or negative) at the coast and why?

Assuming volume is conserved, relate the volumetric fluxes <u>in the cross-shore direction</u> for the area indicated

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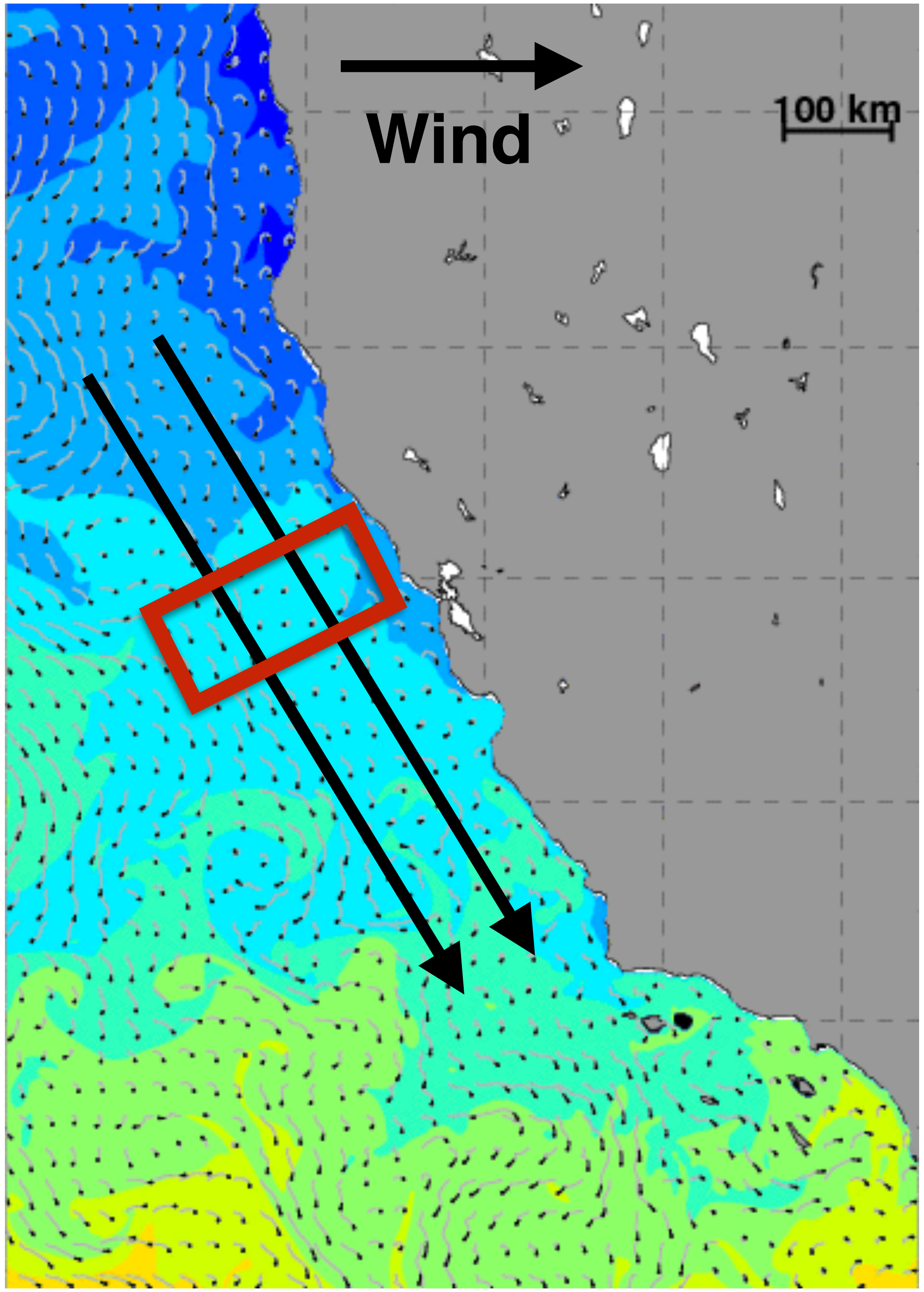


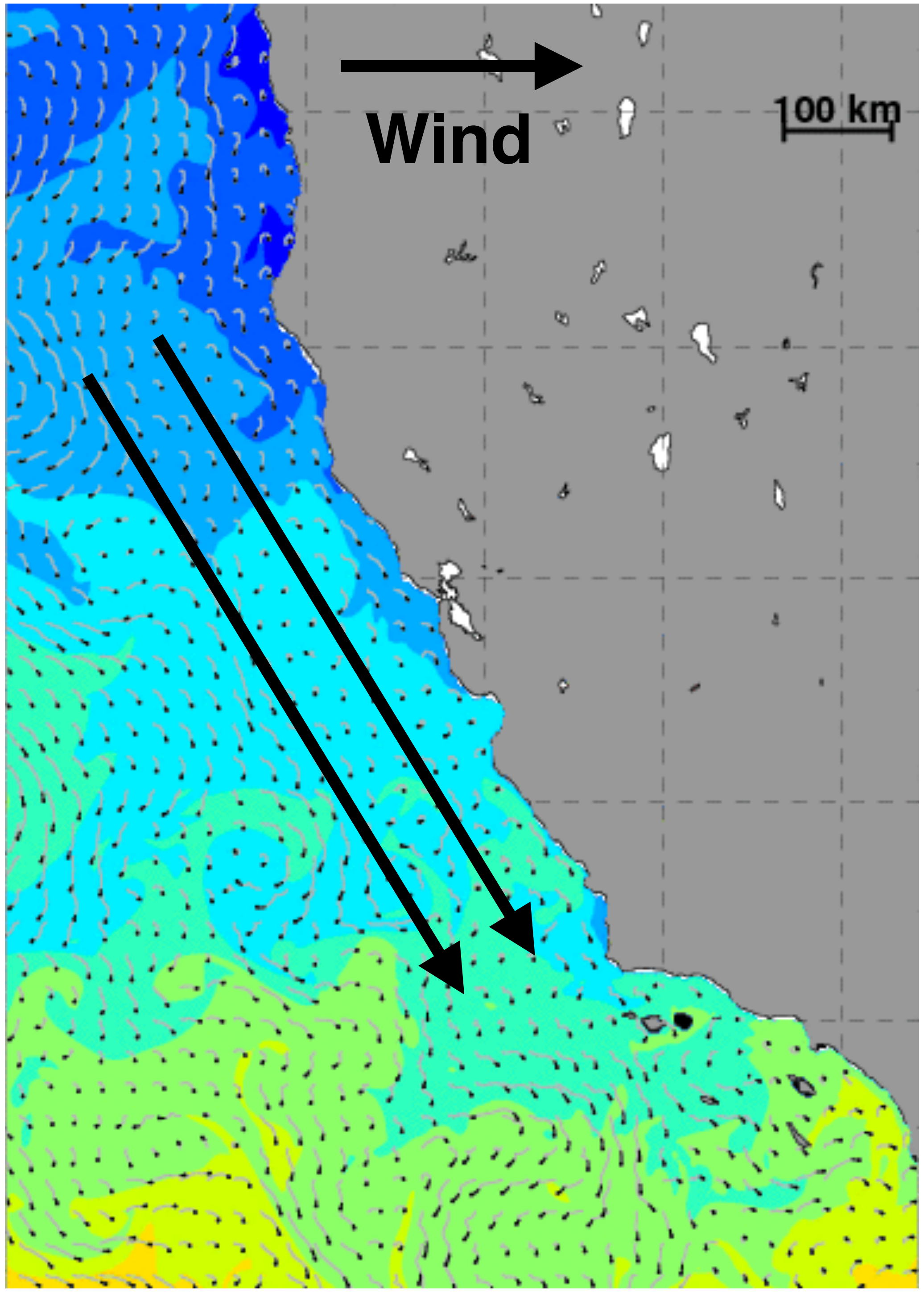
What is the vertical velocity (positive or negative) at the coast and why?

The vertical velocity will be positive (i.e., there is upwelling) due to conservation of volume (water is moving offshore, something has to replace it and since there is a coast it has to replace it from below)

Assuming volume is conserved, relate the volumetric fluxes <u>in the cross-shore direction</u> for the area indicated

$$\psi_{Ek} = \psi_w$$

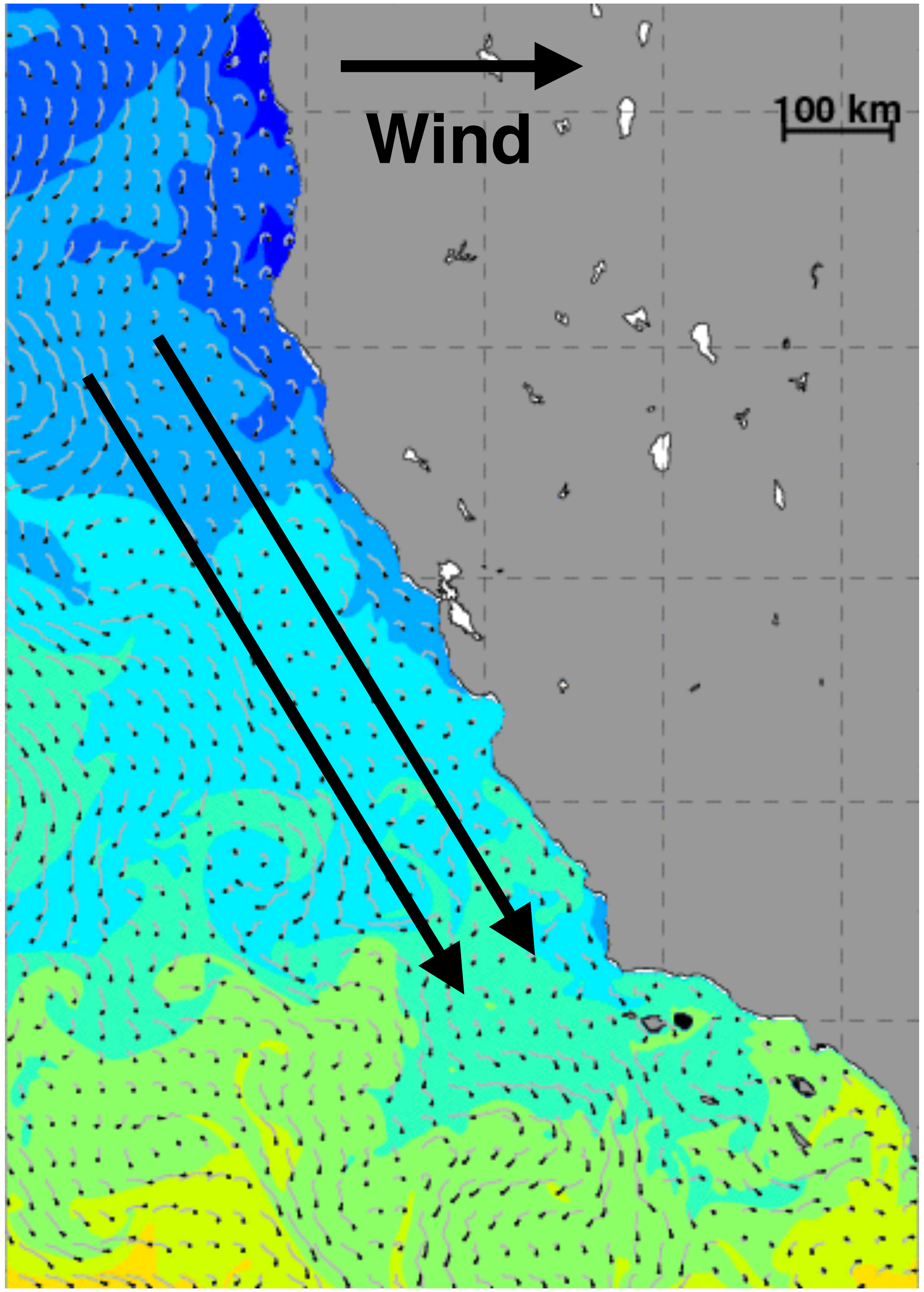
Putting everything together: California Current Case Study



What is the sea surface height profile in the cross-shore?

In what direction does the geostrophic velocity flow?

Putting everything together: California Current Case Study



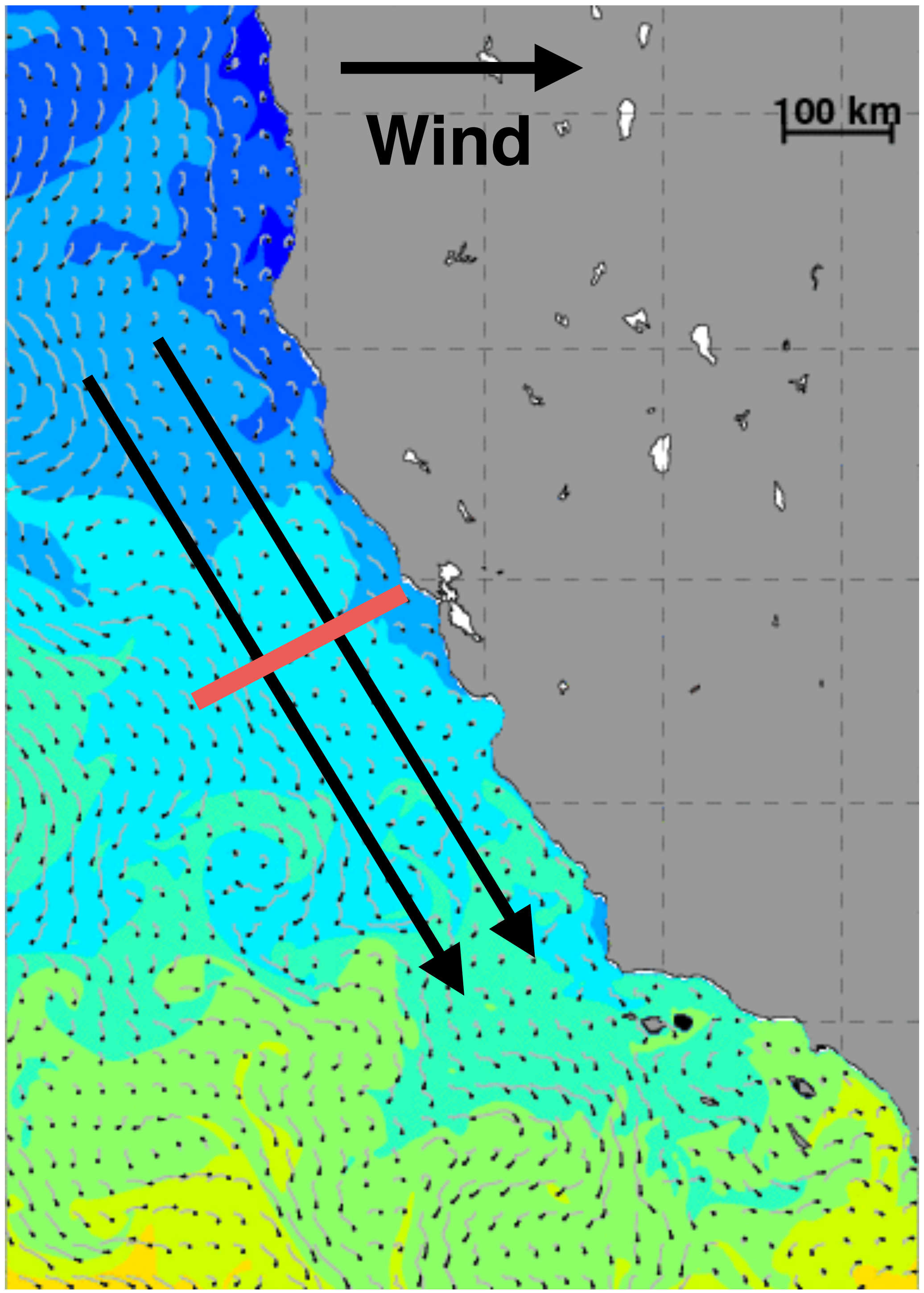
What is the sea surface height profile in the cross-shore?

Ekman transport offshore is causing a pile up of water offshore, so there is higher sea surface in the offshore relative to nearshore(by the coast)

In what direction does the geostrophic velocity flow?

The geostrophic velocity will flow to the right of the pressure gradient force, which due to the sea surface height is directed offshore —-> onshore, so the geostrophic velocity flows towards the equator (i.e., down coast, in the same direction as the wind)

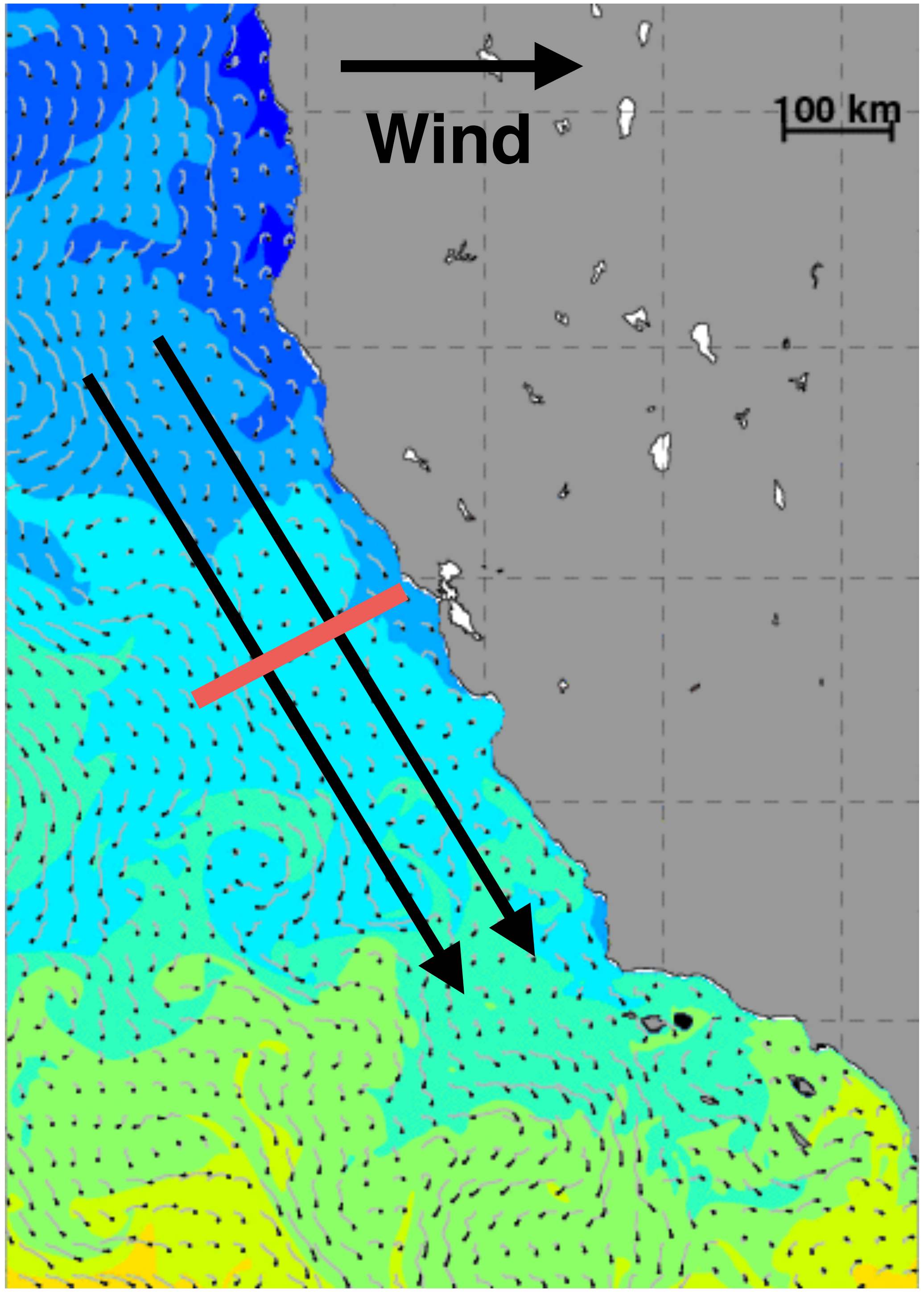
Putting everything together: California Current Case Study



Write an expression for the geostrophic velocity (as a function of the sea surface height)

Assume you know the width (W) and depth (H) that the geostrophic velocity is flowing through, write an expression for the volume transport through the cross-section shown

Putting everything together: California Current Case Study



Write an expression for the geostrophic velocity (as a function of the sea surface height)

$$v = \frac{1}{\rho_0 f}\frac{\partial p}{\partial x}$$

$$p = \rho_0 g(\eta - z)$$

$$\Delta p = \rho_0 g \Delta \eta$$

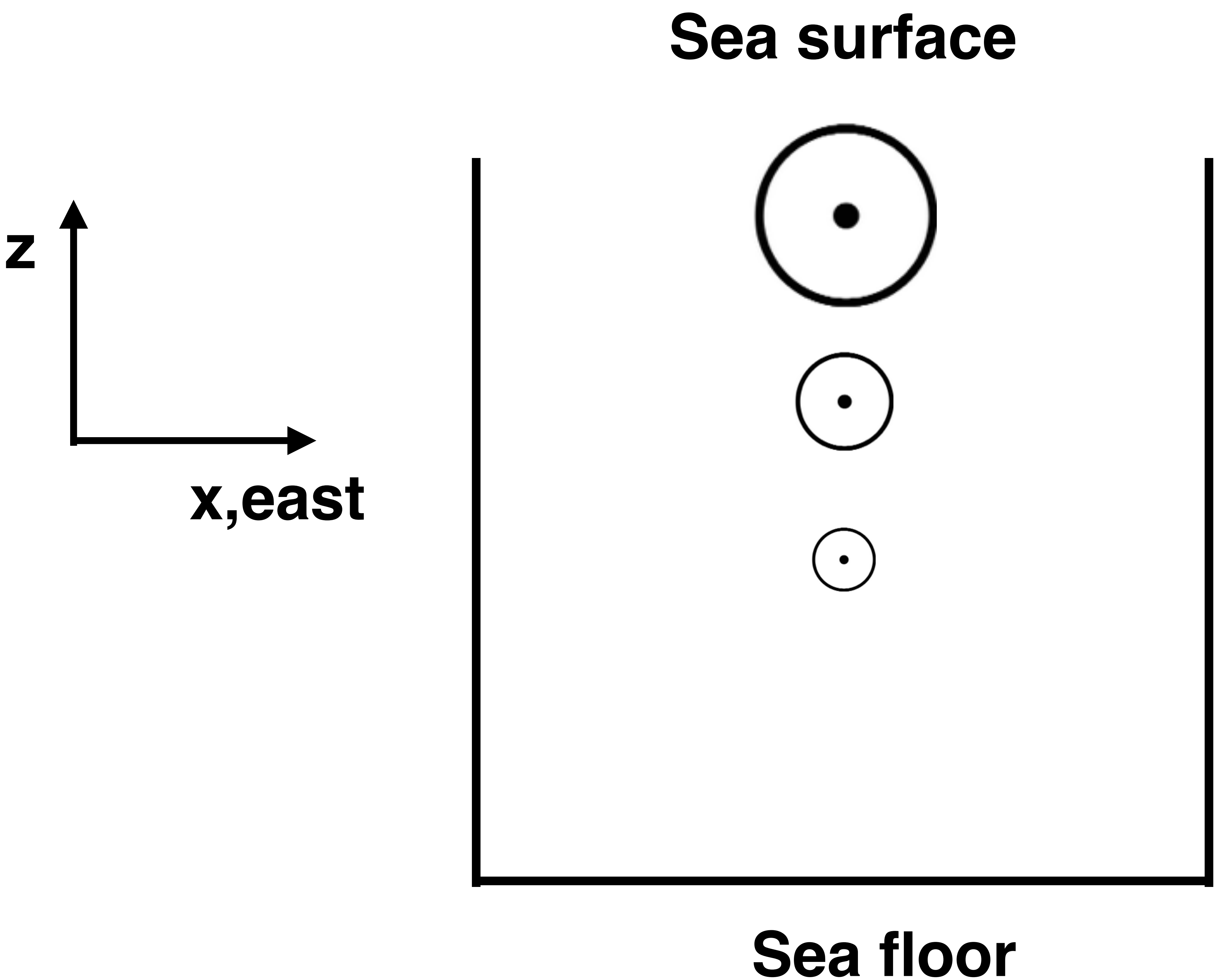
$$\frac{\partial p}{\partial x} = \rho_0 g \frac{\partial \eta}{\partial x}$$

$$v = \frac{g}{f}\frac{\partial \eta}{\partial x}$$

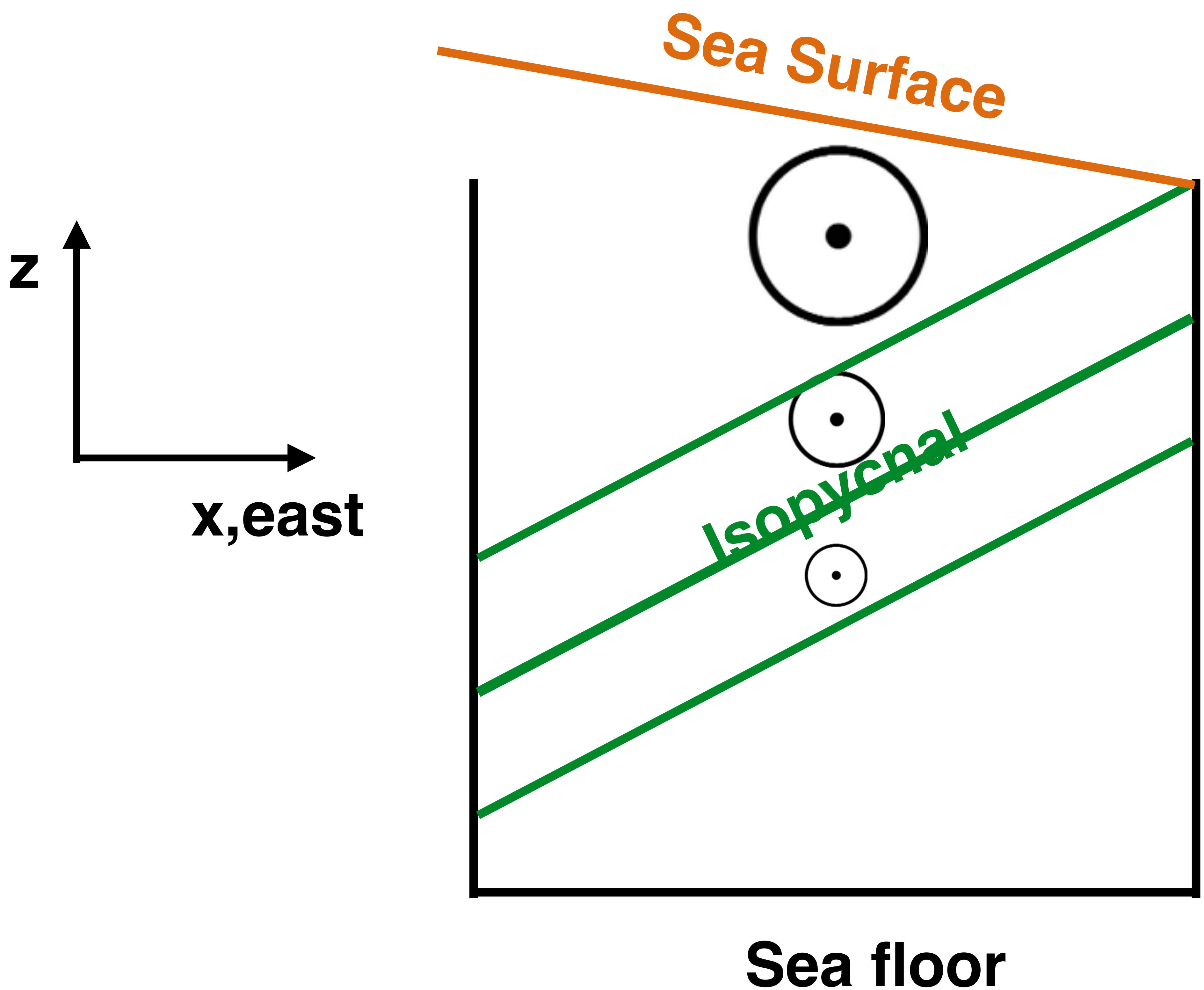
Assume you know the width (W) and depth (H) that the geostrophic velocity is flowing through, write an expression for the volume transport through the cross-section shown

$$\psi_g = vWH$$

If the geostrophic velocity is vertically sheared in the CA current (as shown below), draw the isopycnal structure (and the sea surface structure). Does this isopycnal structure make sense with the vertical velocity at the coast (why or why not)?



If the geostrophic velocity is vertically sheared in the CA current (as shown below), draw the isopycnal structure (and the sea surface structure). Does this isopycnal structure make sense with the vertical velocity at the coast (why or why not)?



We know the sea surface height profile is higher in the offshore due to the Ekman transport causing a pile up of water there (also if you were just given this geostrophic flow in this direction you could deduce it).

You are told the geostrophic velocity decreases with depth. A rule of thumb is that if the geostrophic velocity is decreasing with depth, the isopycnal tilt will oppose the sea surface tilt (this happens in every gyre).

You could also work this out from thermal wind, but you always want to make sure you have your coordinates set up correctly (or else you will get the wrong answer)

Finally, you could have deduced this intuitively by knowing that the vertical velocity is bringing cold water up at the coast (right side of the box) and so it brings up the isopycnals at that side)

Is the equatoward geostrophic flow barotropic or baroclinic?

If the equatoward geostrophic flow is contained within the top 300m of the ocean, in what direction and how much poleward flow must there be if the sea-floor is at 2000m

If I also tell you that this geostrophic flow is subject to instabilities (both barotropic and baroclinic) what other type of phenomena would you expect to find in the California current due to these instabilities?

From a broad-scale perspective, what sign of relative vorticity does the CA current generate along the coastal boundary?

Is the equatoward geostrophic flow barotropic or baroclinic?

Baroclinic: the velocity varies with depth and the isopycnals are not parallel with pressure (depth) contours

If the equatoward geostrophic flow is contained within the top 300m of the ocean, in what direction and how much poleward flow must there be if the sea-floor is at 2000m

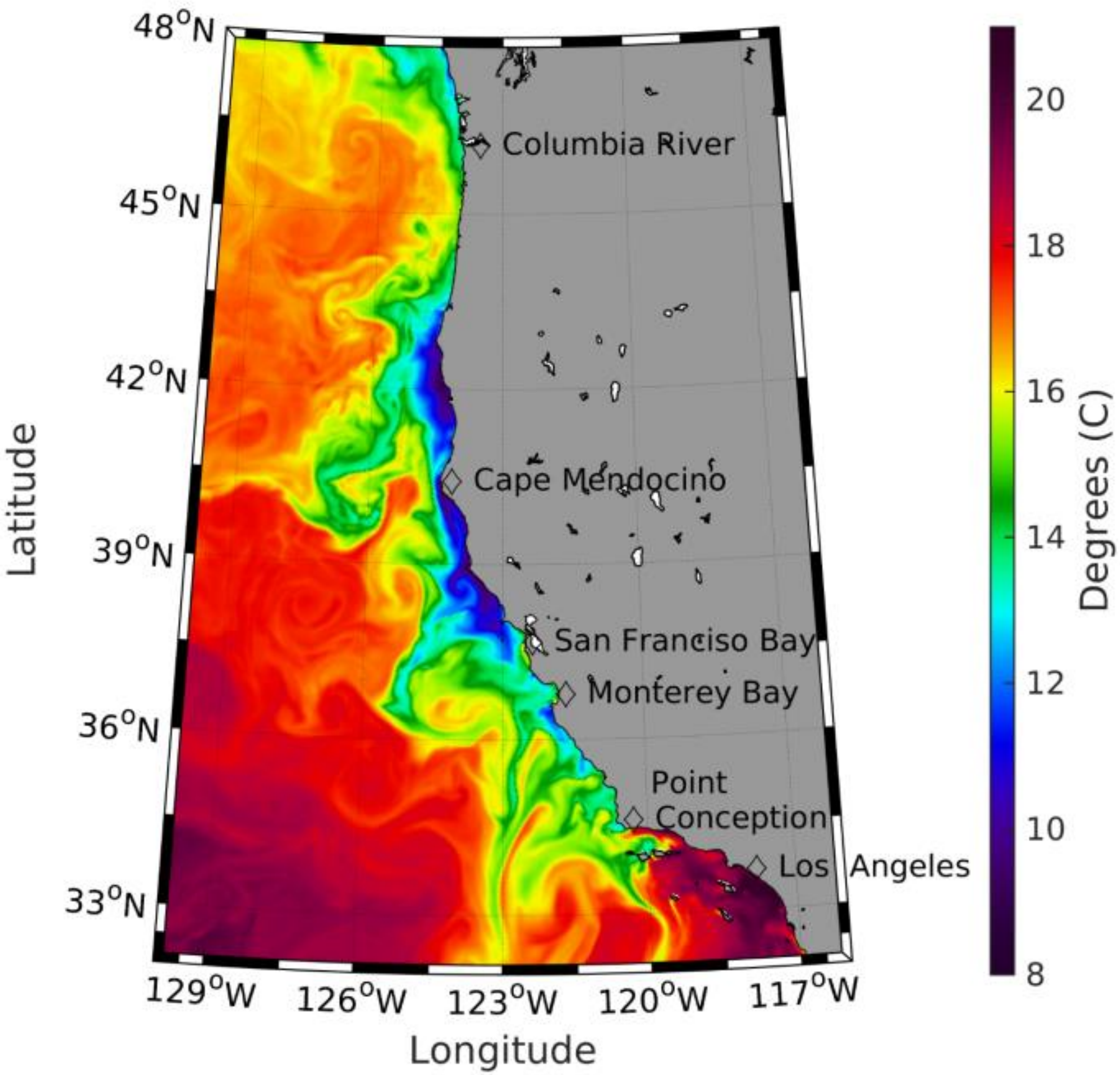
The poleward flow would equal the geostrophic flow via conservation of volume. It would be much slower than the surface flow b/c it is the same volume flowing through a larger area

If I also tell you that this geostrophic flow is subject to instabilities (both barotropic and baroclinic) what other type of phenomena would you expect to find in the California current due to these instabilities?

Mesoscale eddies…these are formed via flow instabilities and play an integral role in maintaining the dynamics of the CA current system

From a broad-scale perspective, what sign of relative vorticity does the CA current generate along the coastal boundary?

Positive relative vorticity. The equatorward flow is slowed down near the coast and this creates a positive relative vorticity (draw a picture to convince yourself)



With all those steps…you should be able to mostly explain the dominant patterns of sea surface temperature (SST) in the figure to the left.

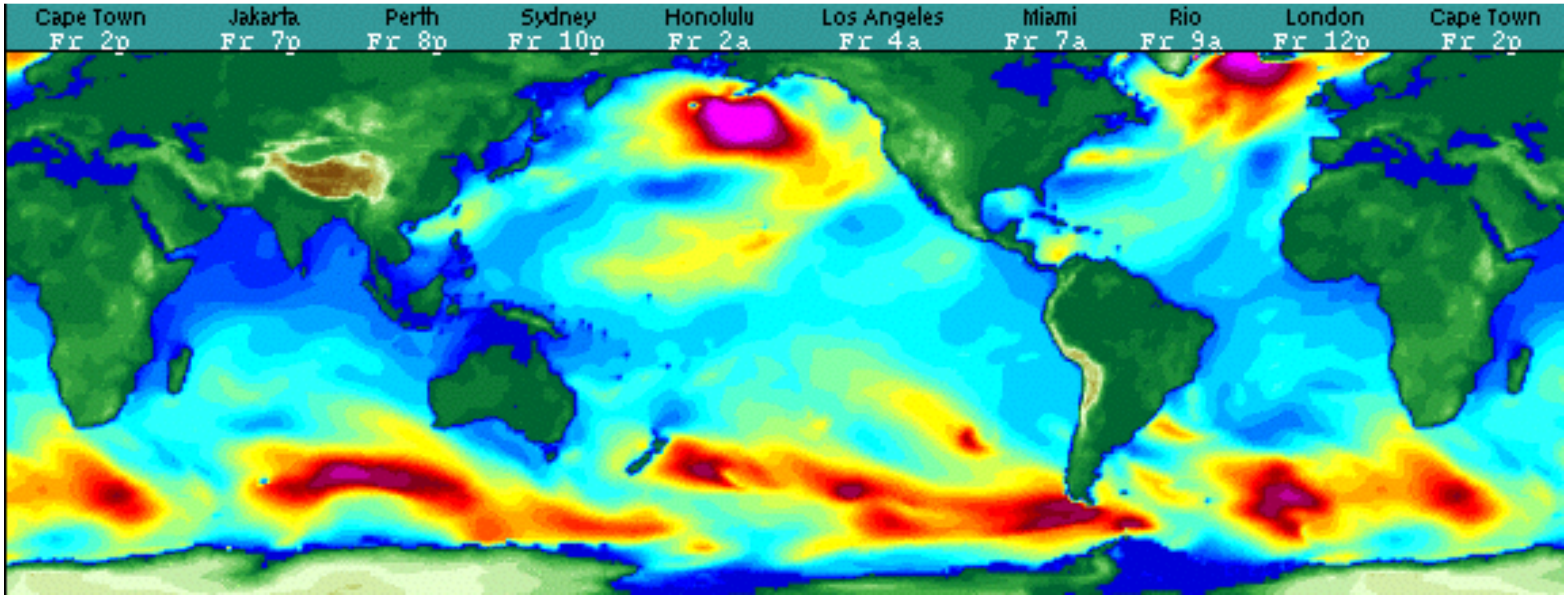
Essentially, you can explain (fundamentally) why there is cold water near the coast and why there is a lot of <u>variability</u> in the SST spatial structure.

In the Northern Hemisphere winter, storms are generated to the north of California. In the Southern Hemisphere winter (North Hemi summer), storms are generated to the south of California.

Where will the swells (surface gravity waves) that hit California generally come from for the summer and winter (North Hemi)?

Using these pieces of information, write an equation for the doppler shifting of surface gravity waves in the North Hemi summer and winter by the geostrophic component California current (assuming it has a constant velocity of (V) and is constantly flowing towards the equator)

Swell Forecast (Surfline)



In the Northern Hemisphere winter, storms are generated to the north of California. In the Southern Hemisphere winter (North Hemi summer), storms are generated to the south of California.

Where will the swells (surface gravity waves) that hit California generally come from for the summer and winter (North Hemi)?

Summer swells will come from the south

Winter swells will come from the north

Using these pieces of information, write an equation for the doppler shifting of surface gravity waves in the North Hemi summer and winter by the geostrophic component California current (assuming it has a constant velocity of (V) and is constantly flowing towards the equator)

Summer

$$C_p = \sqrt{gH} - V$$

Winter

$$C_p = \sqrt{gH} + V$$

*****Not said in question, but assume these are SHALLOW water surface gravity waves**

Gyres

If you know that surface Ekman flow is divergent at the center of a gyre (North Hemi):

1) **Sketch the Ekman current in a (x,y) view along with the geostrophic wind necessary to produce this type of Ekman flow (also give the low-level atmospheric pressure center necessary for the geostrophic wind)**
2) **Sketch the Ekman current, geostrophic current, sea surface and thermo-/pycnocline in a cross-sectional view (y,z) or (x,z)**
3) **Describe the role of potential vorticity in this gyre and what direction (and why) the boundary current must flow**

Extremely tedious question to draw in Keynote (and I don't quite have time to draw it all out)…but we've done this type of problem a bunch of times, so just work it out on your own noting that you are not given the wind stress to start, but rather are given the Ekman flow. This is just another way to practice putting all the gyre pieces together.

If you get asked this type of question on the final, do not just start drawing things from memory. Start with the information you are given (which may not be the atmospheric winds) and work it out from there. For example, you could be given the shape of sea surface and thermocline and asked to work it out from there.

Potential Vorticity

What types of currents have we discussed that are fundamentally driven by potential vorticity conservation (explain what aspect of PV plays a role in each)

The types of currents we've talked about that are driven by PV conservation are the interior transport and western boundary currents in gyres and slope currents in the coastal ocean

The gyre PV flows (interior transport and boundary current) are mainly driven by changes in coriolis parameter (f) and relative vorticity, with the boundary current existing to balance out relative vorticity input by wind.

Slope currents are maintained on the slope due to the depth term (H) in the PV equation. On the slope, if the current gets nudged a bit up or down the slope, H changes a great amount, and thus the PV would change. So slope currents like to stay on the slope b/c they do not want to change their H which would change their PV. ** A change in H (e.g., 100m) greatly outweighs a change in f (e.g., 10^-5 s^-1)

$$q = \frac{f + \zeta}{H}$$

Waves

1) What are the differences between surface and internal waves?

2) Describe the differences between short and long surface waves (mathematically and in words)

Waves

1) What are the differences between surface and internal waves?

Surface waves occur on the surface and are subject to a restoring force of gravity. Internal waves occur on density surfaces and are subject to a buoyant restoring force (reduced gravity).

Surface waves are generated by winds. Internal waves are generated by any process that disturbs density surfaces to trigger the buoyant restoring force (e.g., flow over variable topography).

And of course, their dispersion relations (e.g., relation for phase speed and frequency) are different.

Also, the physical consequences of each are different
- surface waves lead to longshore and rip currents
- internal wave breaking leads to mixing and is responsible for closing out the MOC
- both can transport material via stokes drift

2) Describe the differences between short and long surface waves (mathematically and in words)

See my Week 8 discussion slides (slide 8)