AOS 103

Week 4 Discussion

Starting from an atmospheric HIGH pressure center (e.g. for the subtropical Pacific)
North Hemi

1) Deduce/draw/describe the geostrophic wind
2) Deduce/draw/describe the Ekman currents
3) Deduce/draw/describe the geostrophic current (and its vertical variation)
4) Deduce/draw/describe the boundary current

*You should be drawing horizontal maps of the wind and Ekman currents and then the shape of the sea surface and thermocline in a cross-section along those maps (which will include the geostrophic currents)

*START BY LABELING A COORDINATE SYSTEM FOR YOUR GYRE

Starting from an atmospheric LOW pressure center North Hemi

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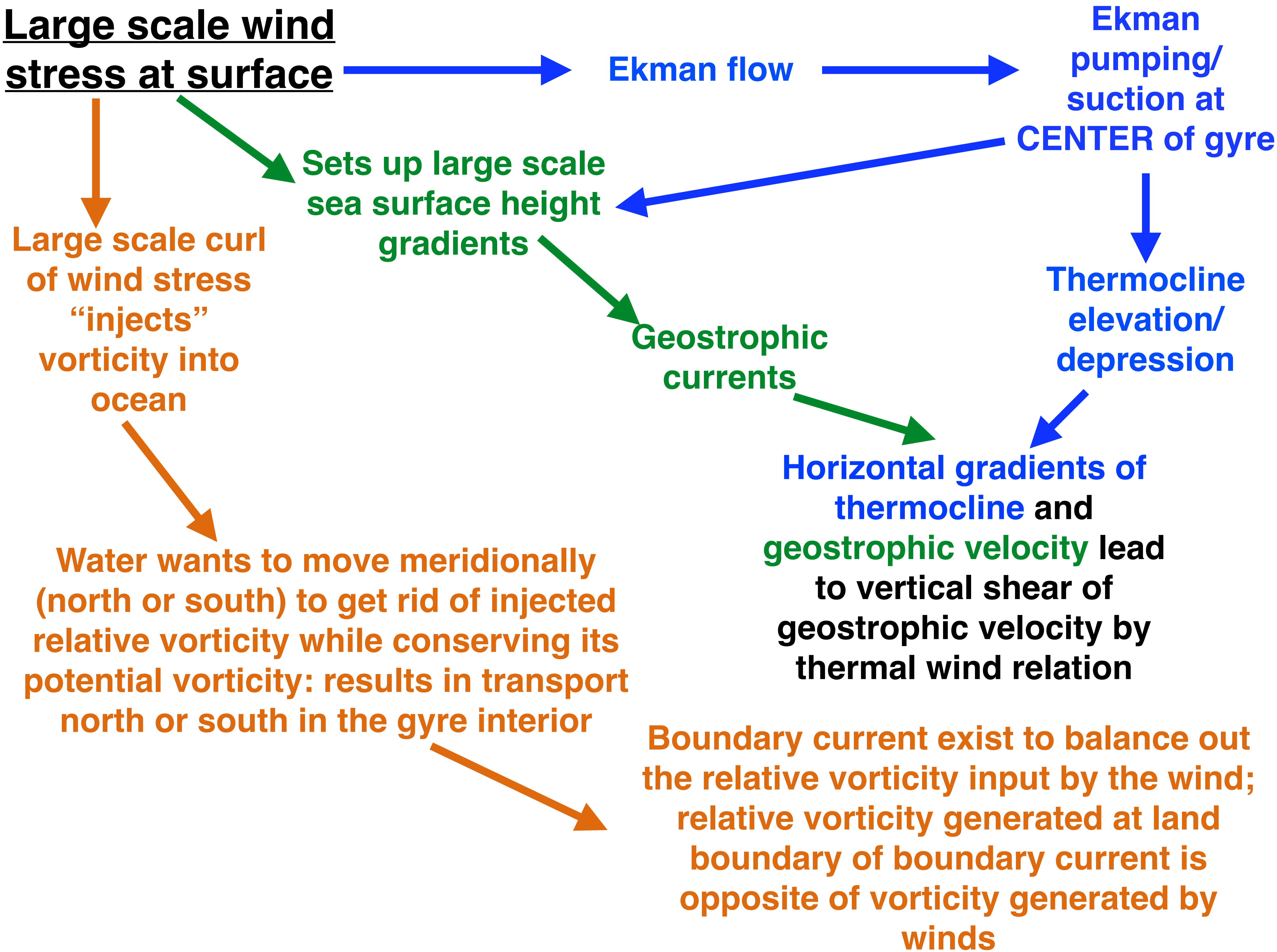
Gyres

There are 3 main types of dynamics going on in gyres that can all be traced back to the wind stress (in conjunction with Coriolis force):

1) **Ekman dynamics (Ekman flow/transport and Ekman pumping/suction)**
2) **Geostrophic currents due to sea surface height gradients**
3) **North/south transport in center of gyre and at land boundaries due to potential vorticity conservation**


Large scale wind stress at surface
Ekman flow
Ekman pumping/ suction at CENTER of gyre
Sets up large scale sea surface height gradients
Large scale curl of wind stress “injects” vorticity into ocean
Geostrophic currents
Thermocline elevation/ depression
Horizontal gradients of thermocline and geostrophic velocity lead to vertical shear of geostrophic velocity by thermal wind relation
Water wants to move meridionally (north or south) to get rid of injected relative vorticity while conserving its potential vorticity: results in transport north or south in the gyre interior
Boundary current exist to balance out the relative vorticity input by the wind; relative vorticity generated at land boundary of boundary current is opposite of vorticity generated by winds

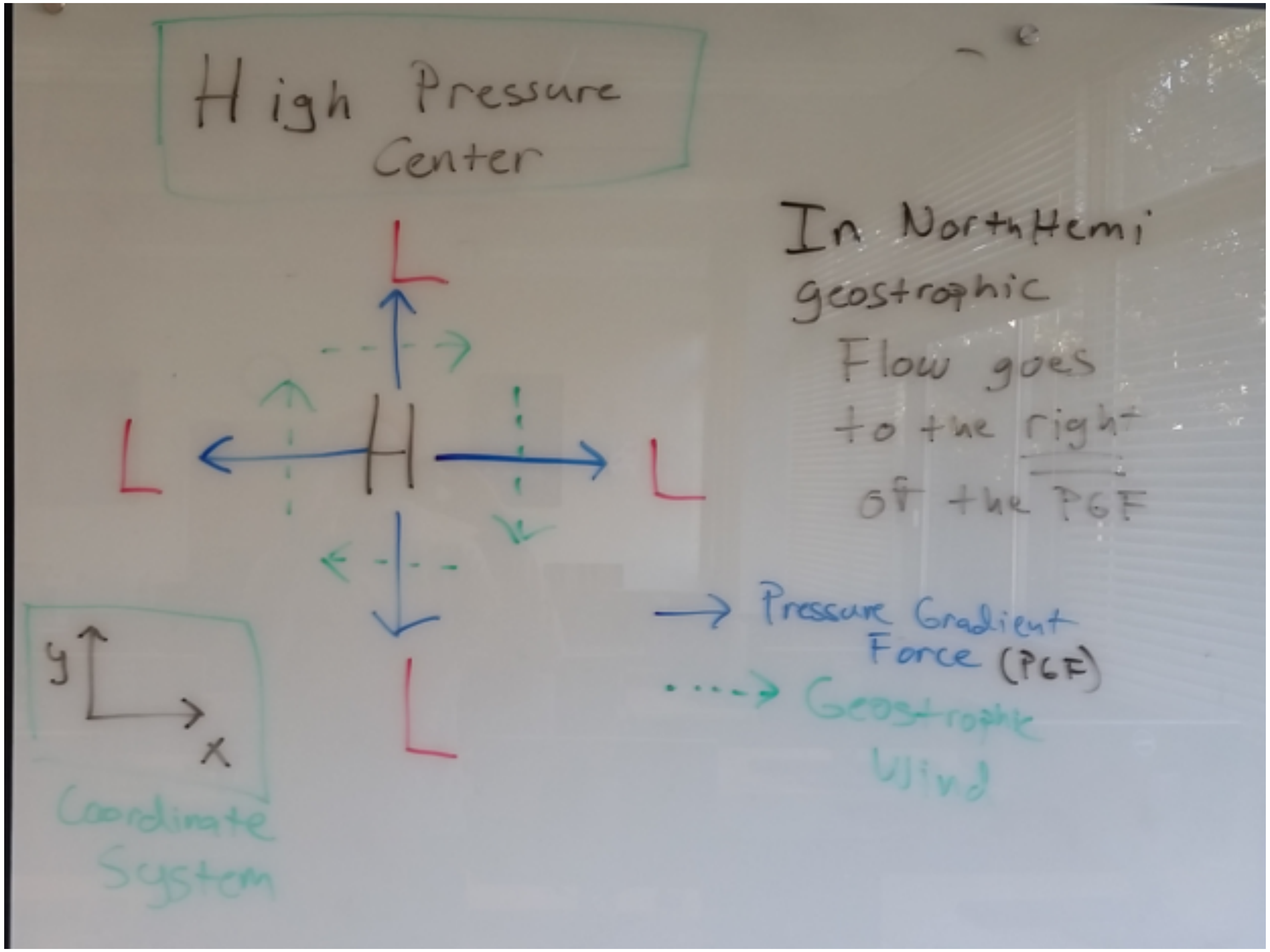
For any gyre:

- **Start with the large scale atmospheric pressure**
- **Deduce the geostrophic atmospheric wind from this pressure**
- **Use the wind pattern to infer Ekman transport (it will go into our out of the gyre radially)**
- **Use the direction of Ekman transport to infer whether there is upwelling (suction) or downwelling (pumping) at the center of the gyre**
    - **Essentially answer this question: is there convergence or divergence of water at the center of the gyre?**
- **Use this behavior at the center of the gyre to infer what the thermocline and sea surface height are doing**
- **Use the sea surface height to infer which way the surface pressure gradient forces want to push water**
- **Use these pressure gradient forces to infer a geostrophic current**
- **The horizontal variation of the thermocline combined with a geostrophic current will mean that the geostrophic current will have vertical shear (increase or decrease) with depth due to the thermal wind balance**
- **The final piece of the gyre story is the boundary current…figure out the sign of vorticity that the wind is inputting to the gyre and what type of boundary current would be needed to balance that out**

Working through this example…

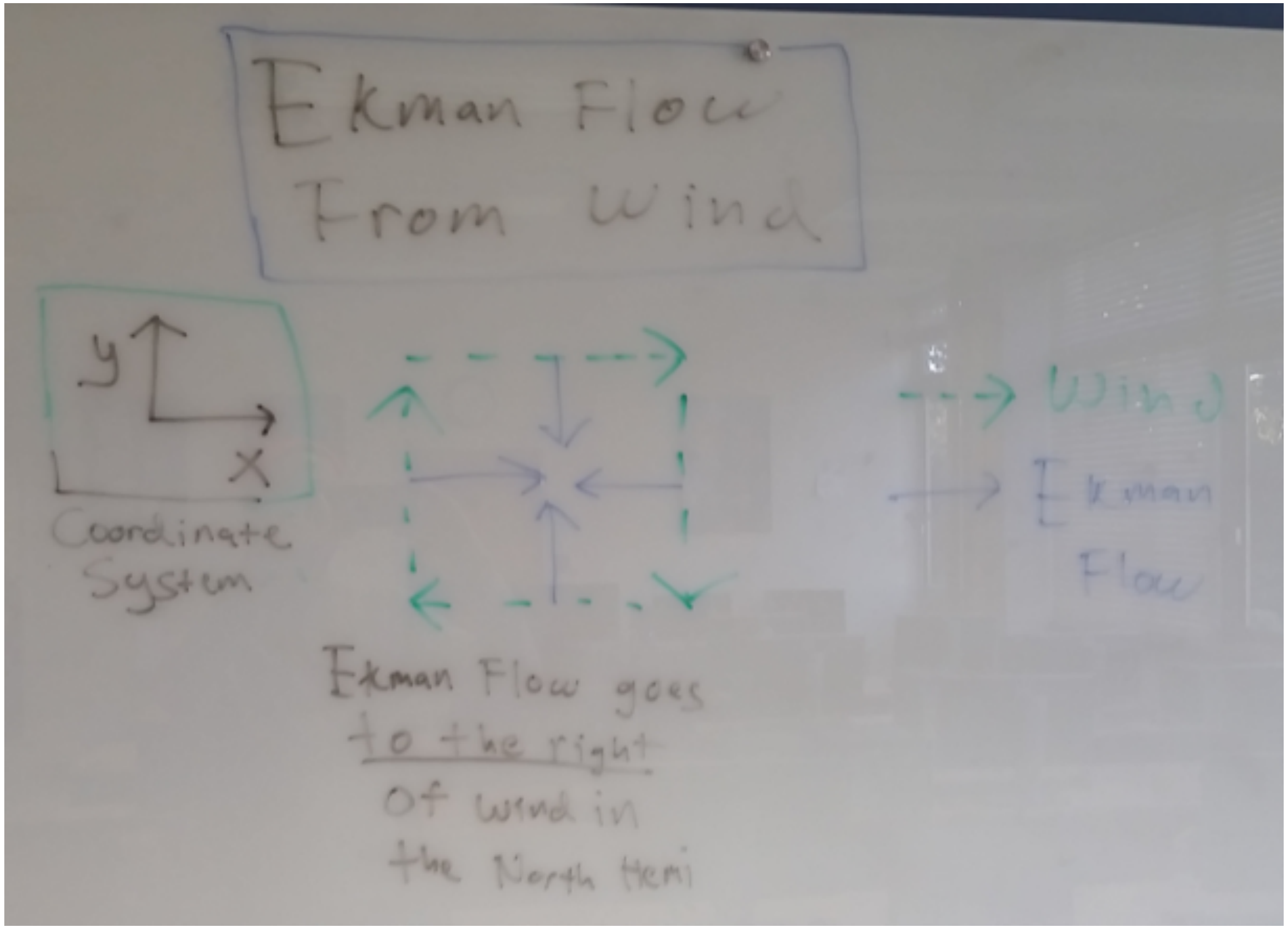
Starting from an atmospheric HIGH pressure center (e.g. for the subtropical Pacific in Northern Hemisphere

1) Deduce/draw/describe the geostrophic wind



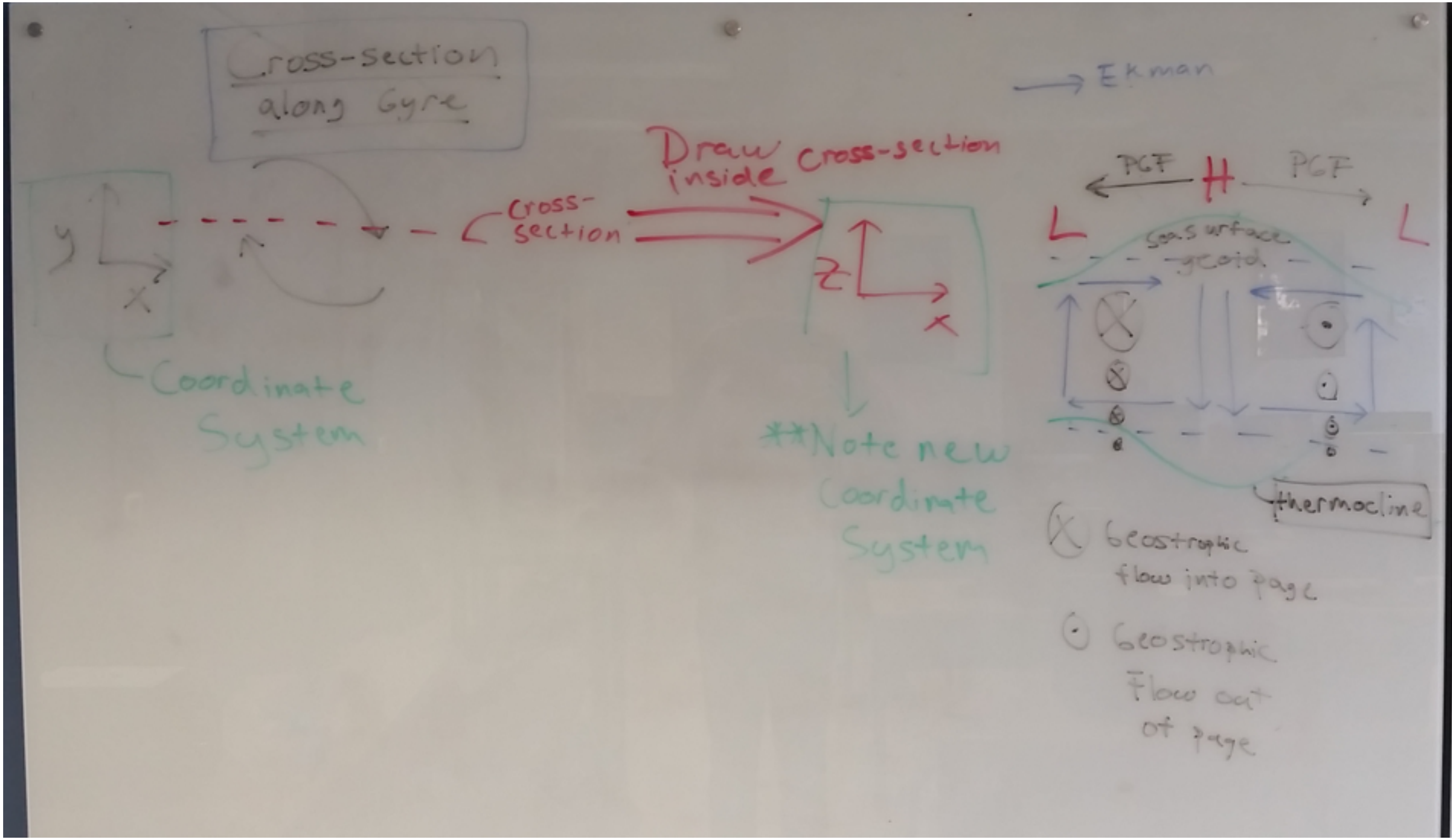
- **Pressure gradient force points from high to low pressure**
- **Geostrophic wind (driven by pressure gradients and coriolis (rotation) forces) flows to the RIGHT of the pressure gradient force (for the NH, for SH it flows to the LEFT)**

2) Deduce/draw/describe the Ekman currents



- The wind causes a surface current in the ocean
- This is the Ekman current, which is driven by both the wind and the rotation of the Earth
- It flows to the RIGHT of the wind direction in the NH (North Hemi) and to the LEFT of the wind direction in the SH

2) **Deduce/draw/describe the geostrophic current (and its vertical variation)**



Consequences of Ekman flow

-Ekman surface flow causes a convergence at the center of the gyre.

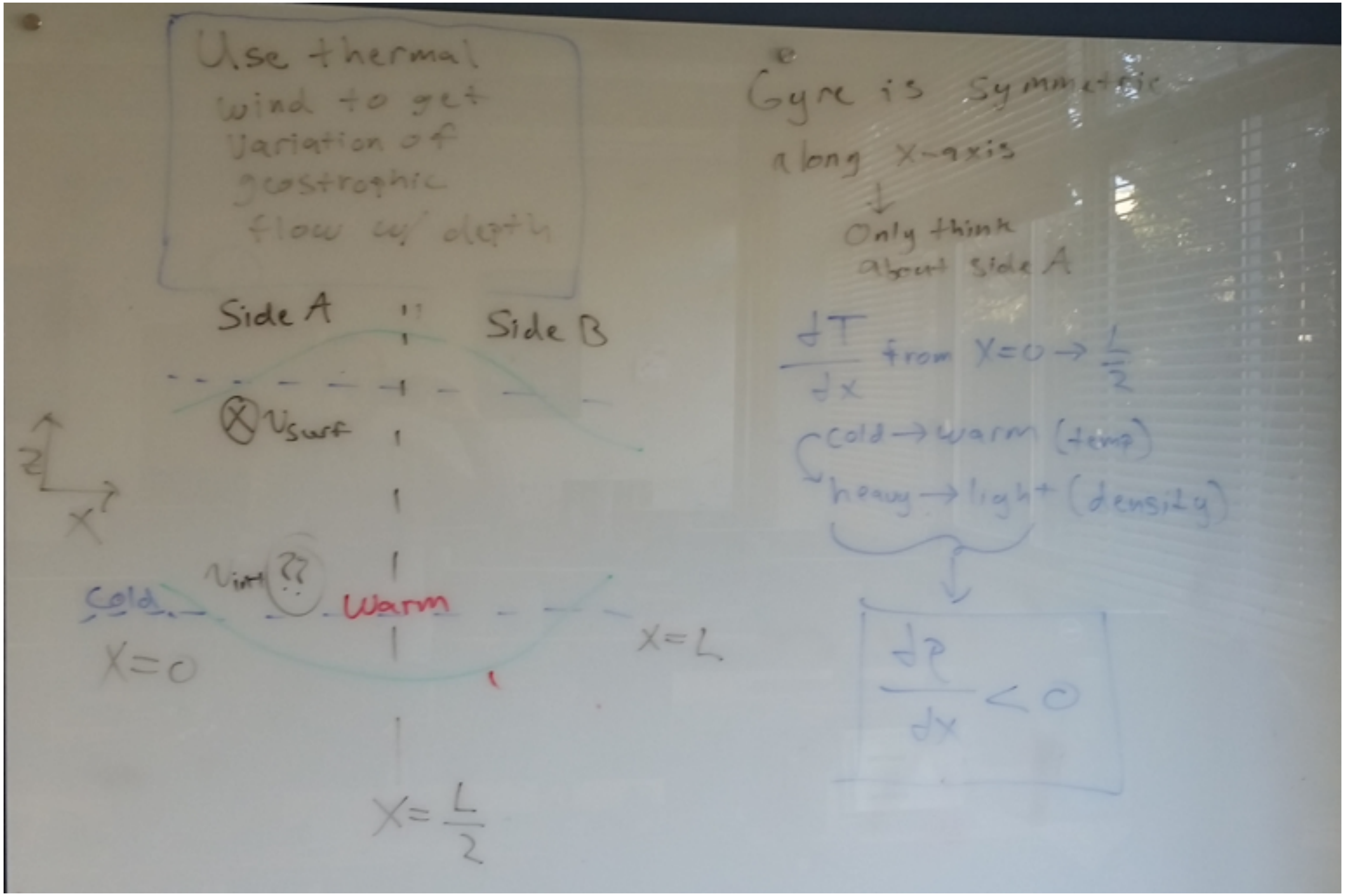
- there is Ekman downwelling because of the convergence (via conservation of volume)
- The Ekman downwelling (sometimes called "pumping") depresses the thermocline
- The convergence at the center of the gyre raises the sea surface at the center (via conservation of volume)

Ekman flow causes a sea surface height gradient —-> which is a pressure gradient

- The raised sea surface in the center of the gyre leads to a pressure gradient force pointing out from the center towards the sides of the gyre
- There will be a resulting geostrophic current due to this pressure gradient that goes to the RIGHT of each PGF on either side of the gyre. This will result in geostrophic flow into the page on the left(relative to the drawings) side of the cross-section and flow out of the page on the right

But now we need to say something about how this geostrophic flow varies with depth (it is drawn on the last slide, but no explanation has been given yet)

2) Deduce/draw/describe the geostrophic current (and its vertical variation)



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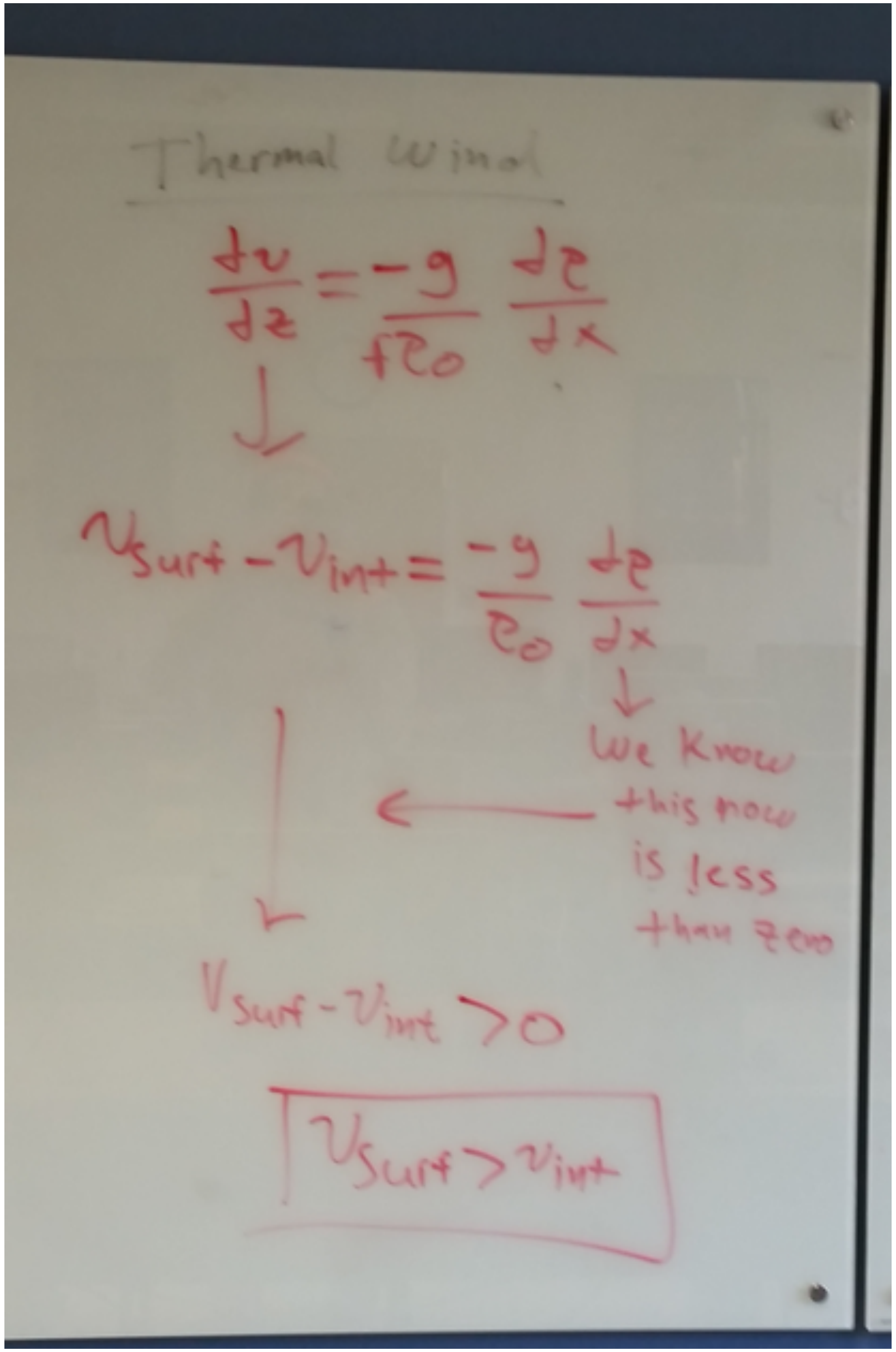
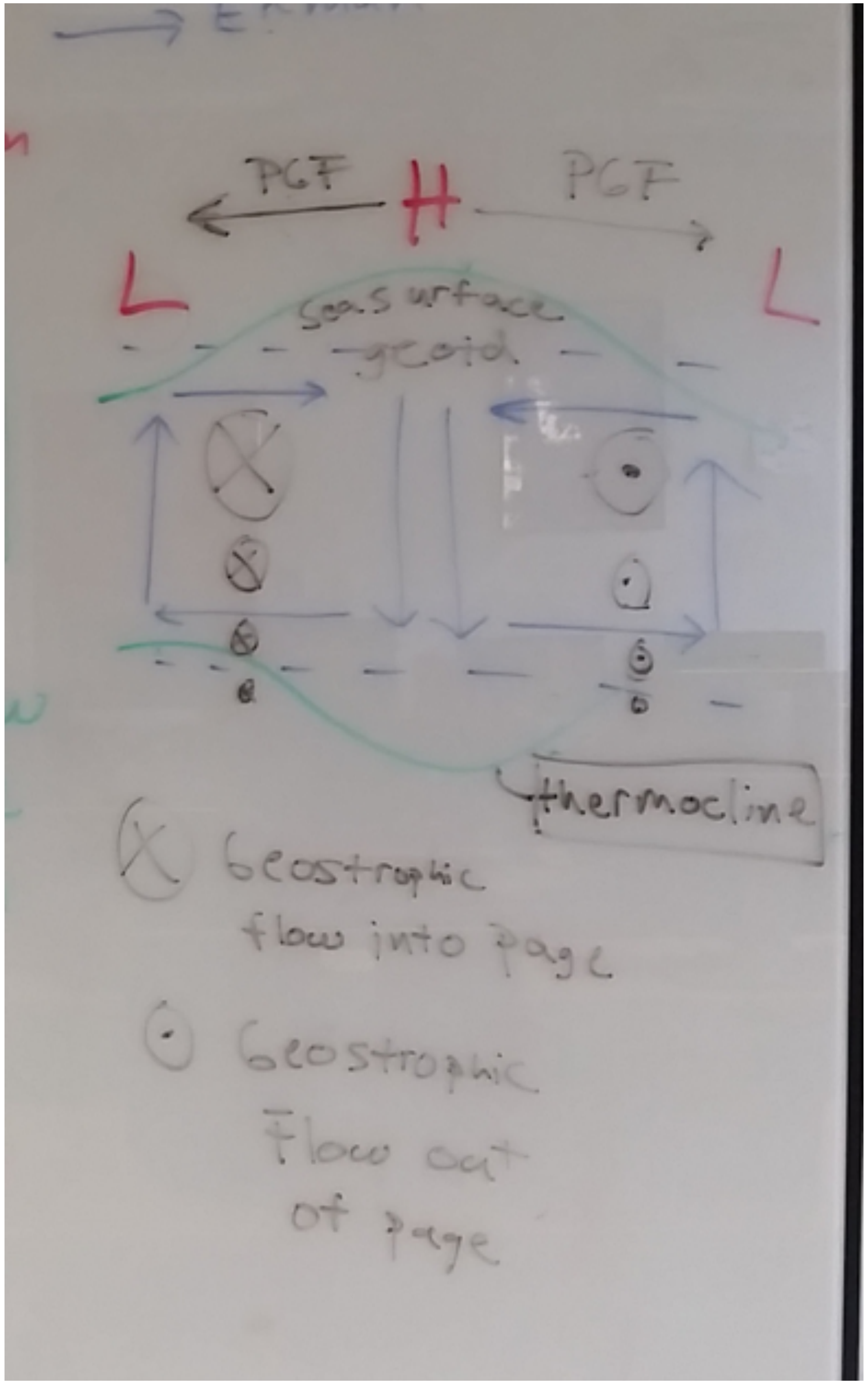




- Once we know that v_surf>v_int, we can draw decreasing geostrophic velocity with depth (i.e., smaller circles)

Full explanation on next page

Vertical variation of geostrophic velocity

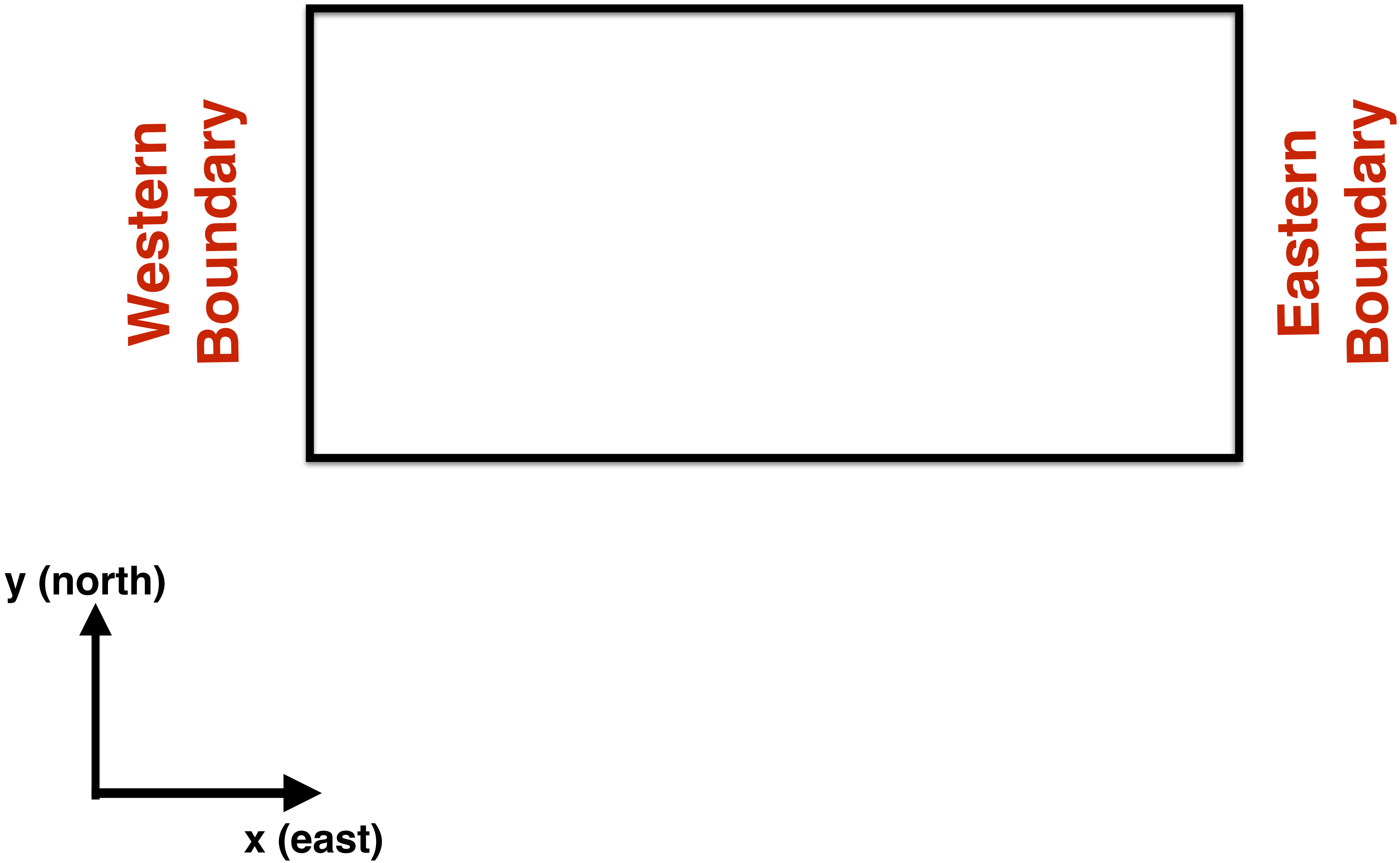
-The basic relation you want to get to is what are the relative magnitudes of the surface geostrophic flow relative to the interior (i.e., deeper) geostrophic flow
-Thermal wind balance tells us that this difference (dv/dz) is proportional to the horizontal density gradient
-We can infer the horizontal density gradient from the shape of the thermocline

We also have an intuition that the gyre is symmetric about the center, so we only need to work this out for one side (i.e., if velocity decreases in magnitude with depth on one side, it will do so similarly on the other side)

We consider “Side A” on the cross-section from 3 slides ago:
-If we go along a straight horizontal line along the bottom (denoted in the figures by the x-axis) we see that we go from a cold place to a warm place from the left side of the cross-section to the center
-We know this b/c we know that water is colder below the thermocline (solid green line) and warmer above the thermocline
-Colder water is heavier (we know this b/c of what the equation of state tells us)
-Warmer water is lighter (again, equation of state tells us this)
-So, our horizontal density gradient is (in words): heavy to light—-> this implies that the horizontal gradient is negative (think if you were to plot density as a function of x…it would be a line with a negative slope—-> negative slope = negative gradient(derivative))
-Now we know the sign of our density gradient and can use that information within the thermal wind equations to make a statement about the relative sizes of the surface velocity (v_surf) and interior velocity (v_int)
-The relation we get is that the v_surf > v_int , AND knowing that v_surf >0, this means that v_int will be a smaller, POSITIVE number than v_surf.
-One assumption we do make here is that velocity does not change sign with depth
-If you worked out the same relation for “Side B”, you would see that v_surf<v_int, but v_surf<0, and velocity does not change sign with depth, so the interior velocity would decrease in magnitude as well (i.e., smaller negative numbers…e.g., v_surf= -10, v_int= -5–-> -10 < -5)

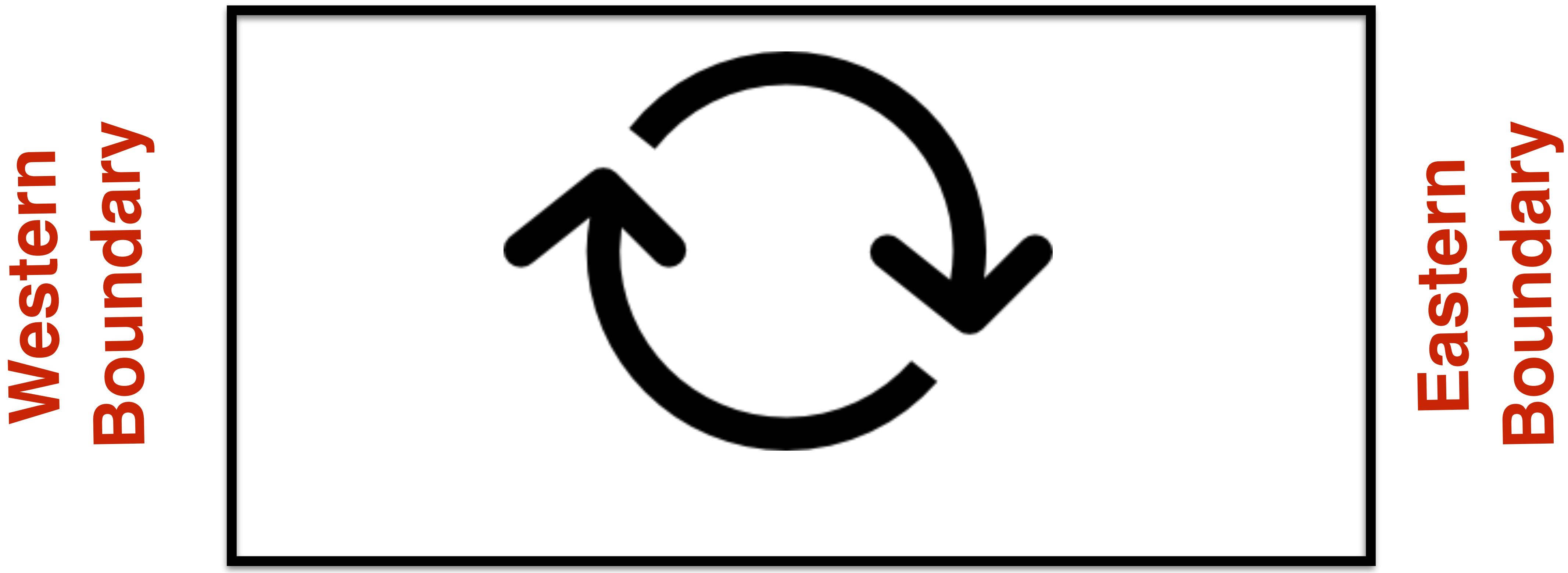
4) Deduce/draw/describe the boundary current

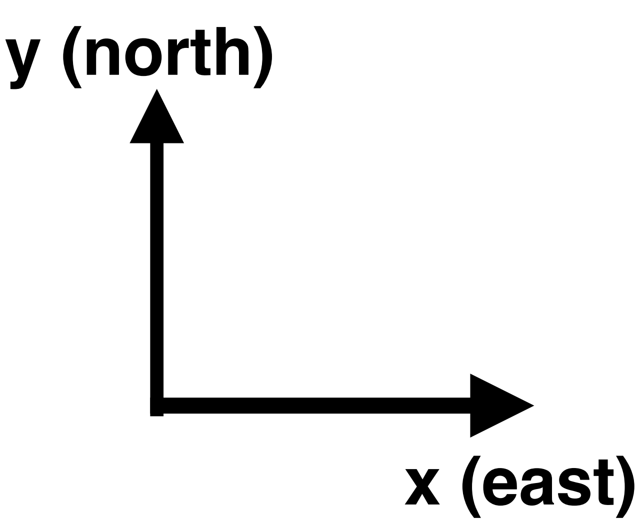
Think of this box as our subtropical gyre in the NH, that all started with wind causing Ekman flow



4) Deduce/draw/describe the boundary current

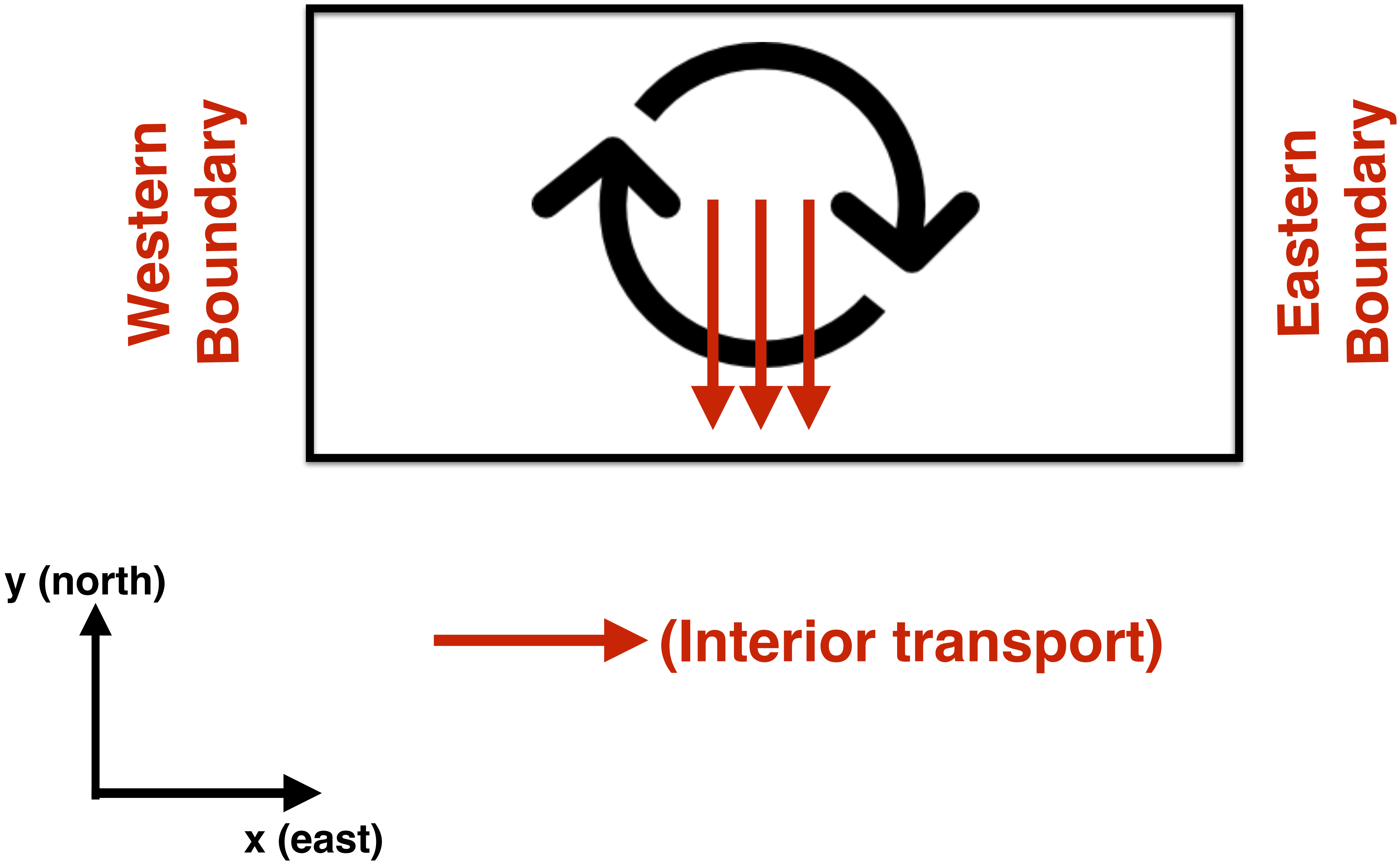
Surface wind inputs NEGATIVE relative vorticity (right hand rule applied to the wind has your thumb going into the page—-> that means the relative vorticity is negative)





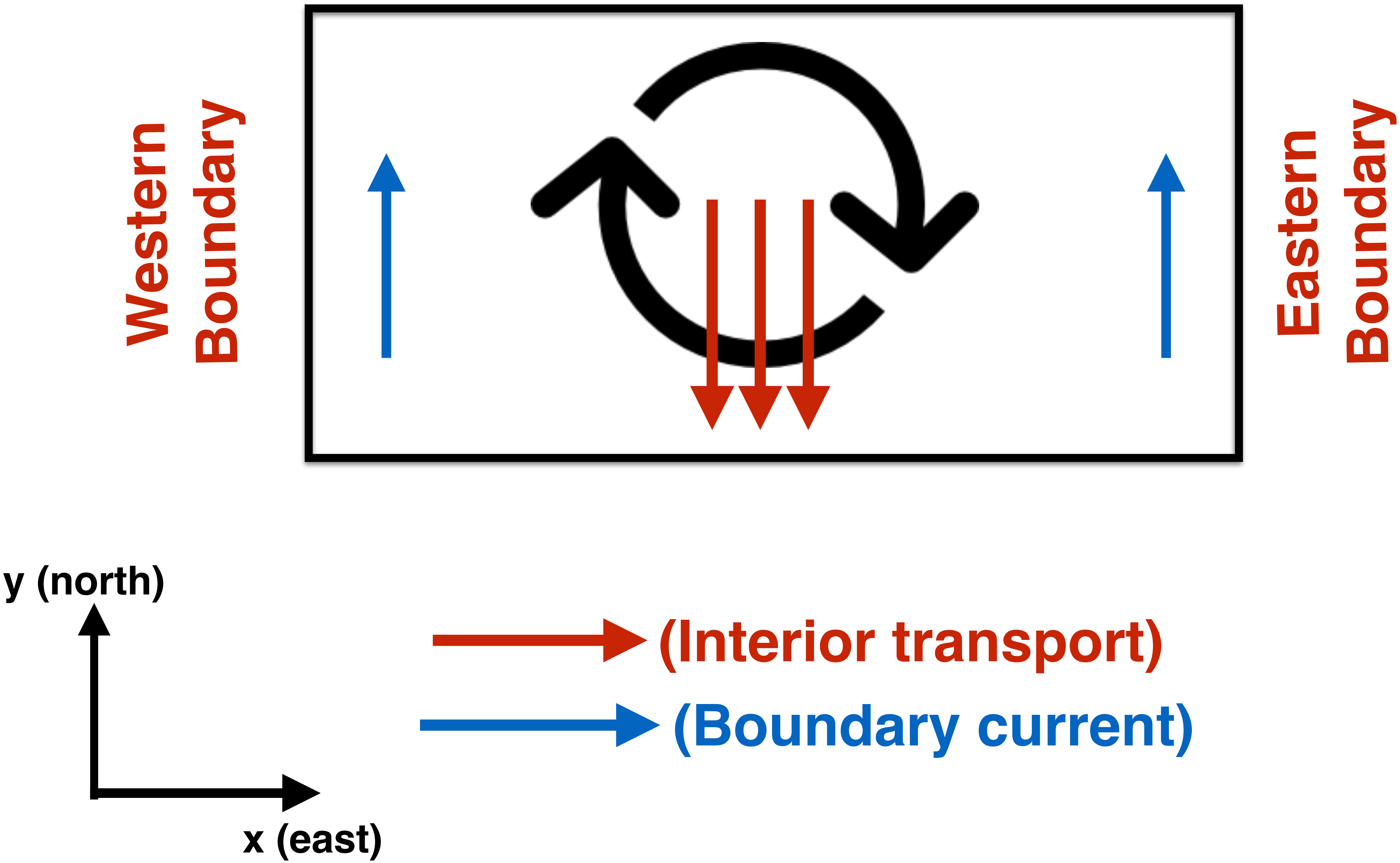
4) **Deduce/draw/describe the boundary current**

Water columns will want to move SOUTH (equatorward) in the interior of the gyre in order to reduce their PV (q ~ f/H)…this is b/c we can assume that the wind is changing the PV to make it smaller and so water columns can reduce their PV by moving south (where f is smaller)



4) Deduce/draw/describe the boundary current

This gyre "box" obeys all the same conservation laws we have talked about…so if water in the interior is flowing south(equatorward) in the middle of the box, to conserve mass (and volume) there must be a return flow going north(poleward) at one of the sides…BUT, *which side does this happen on (eastern or western boundary)??*



4) Deduce/draw/describe the boundary current

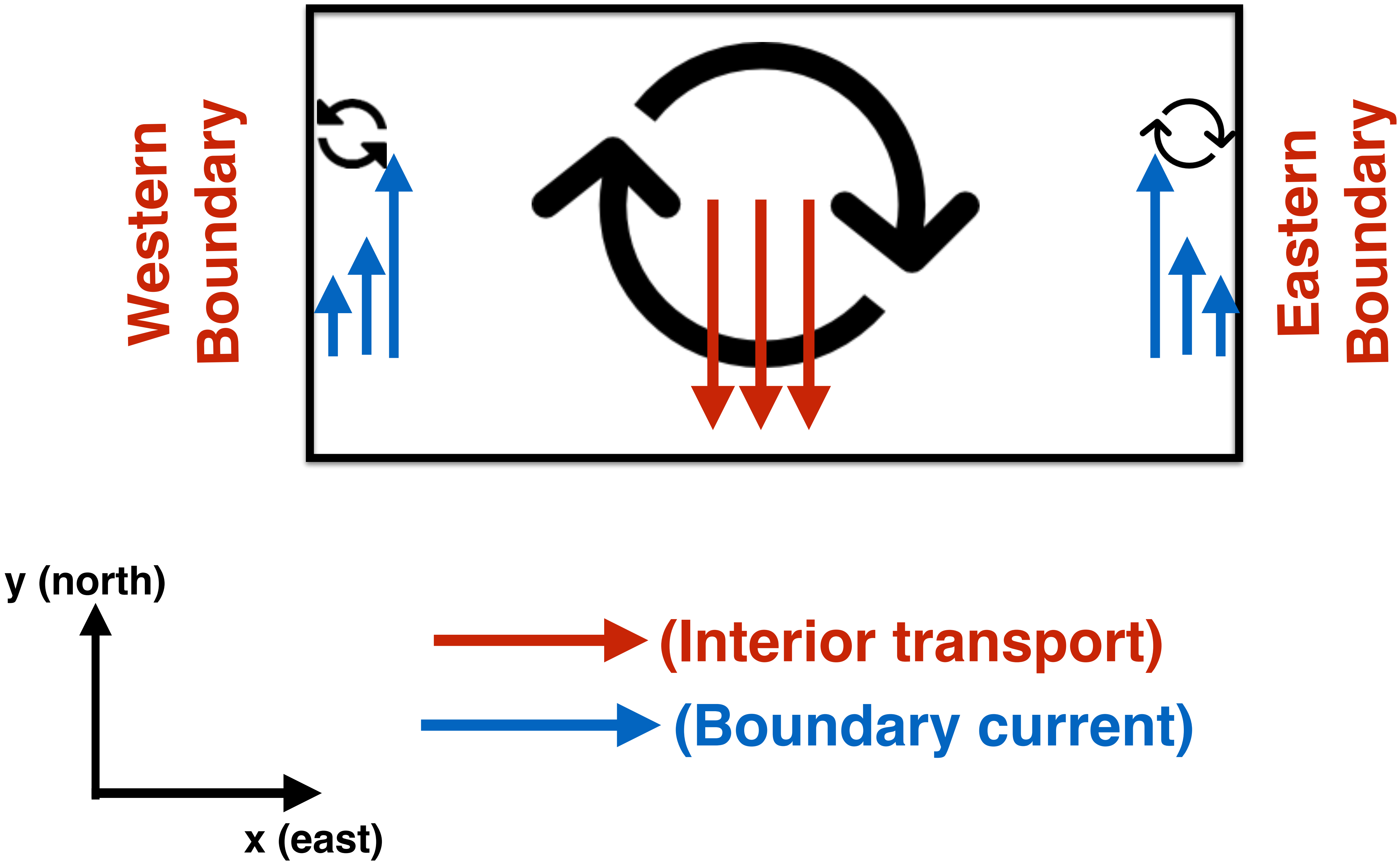
-Not only does the gyre need to conserve its volume (mass), it also needs to balance out the NEGATIVE input of vorticity by the wind

-Each of the flows along the boundary will produce vorticity b/c the friction at the boundaries causes flows to slow down as they get closer to the boundary

-So there is a SHEAR at each of the boundaries

-On the eastern boundary this shear would create NEGATIVE vorticity

-On the western boundary this shear would create POSITIVE vorticity



4) Deduce/draw/describe the boundary current

To balance out the negative vorticity input by the wind, the boundary current must create(supply) positive vorticity.

The western boundary current supplies this positive vorticity

It exists to 1) conserve mass and 2) balance out the vorticity input by the wind