Introduction to Atmospheric Circulation (continued)

Start rotating table with ice
(try again)

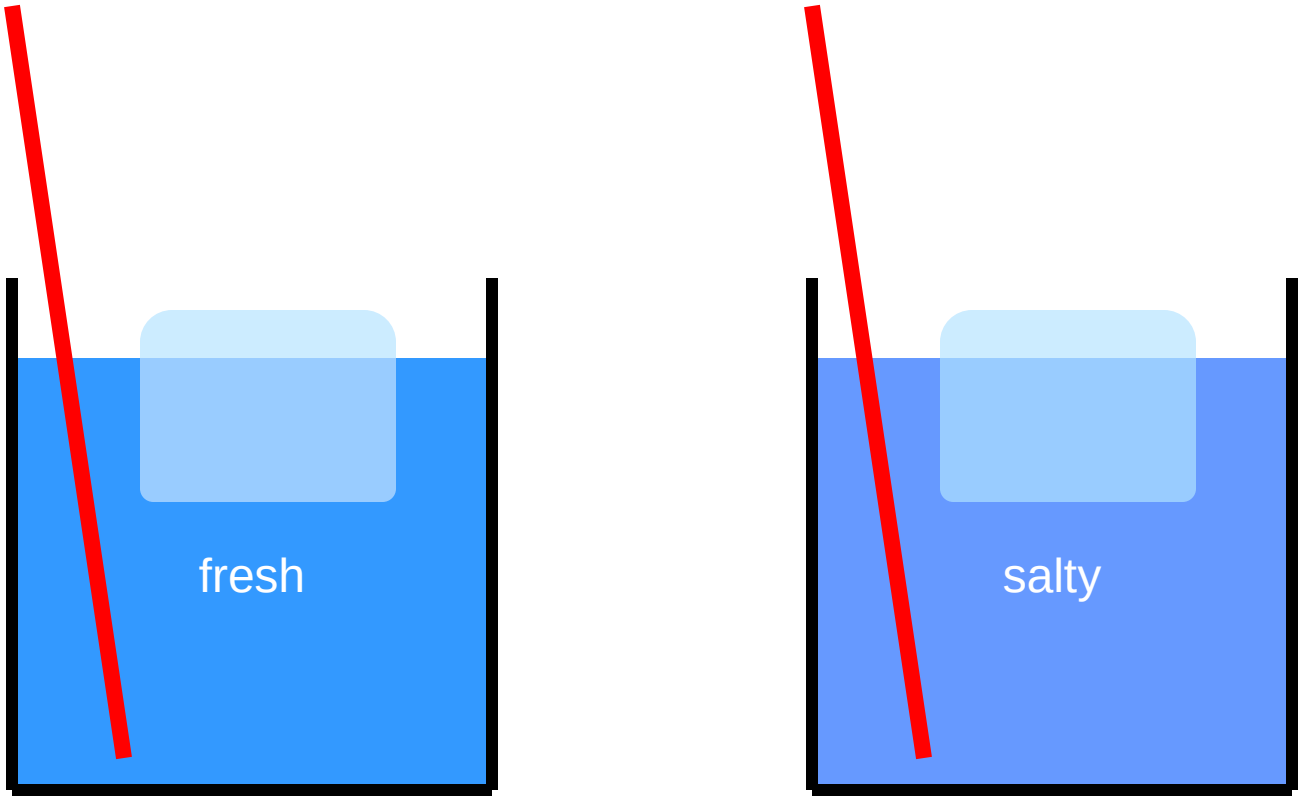
Start heated bottle experiment (try again)

Scientific Practice

- Observe nature (ice cube melted more slowly in salty water)
- Develop hypothesis (layer of cold, less dense water isolated ice cube from warm, more dense water)
- Carry out experiment
- Confirm** or refute hypothesis

** Hypotheses can never be formally proved to be true

Will Stirring Affect Ice Cube Melting?



Do stirred melting ice cube experiment

What Constrains Motions in Fluids?

(Review)

What Constrains Motions in Fluids?

Buoyancy differences

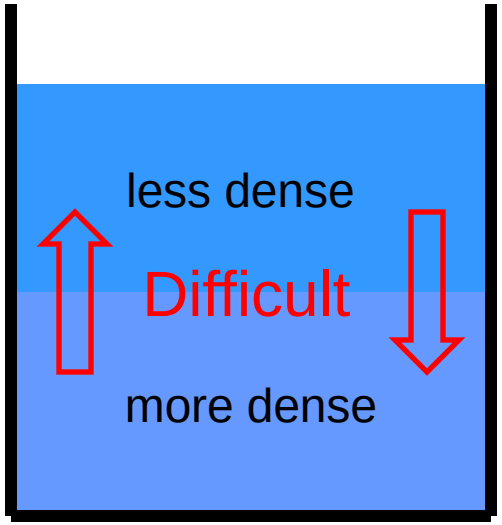
- Difficult for more dense fluid to move up
- Difficult for less dense fluid to move down

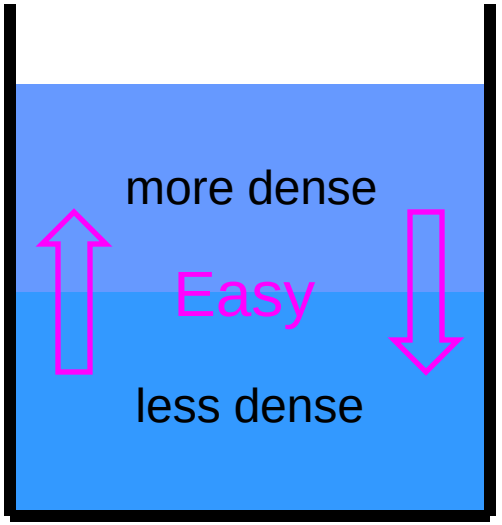
Angular momentum differences

- Difficult for fluid with more angular momentum to move to region of less angular momentum
- Difficult for fluid with less angular momentum to move to region of more angular momentum

Buoyancy Constraint on Fluid Motion

- Easy to move less dense fluid up and more dense fluid down
- Difficult to move less dense fluid down and more dense fluid up

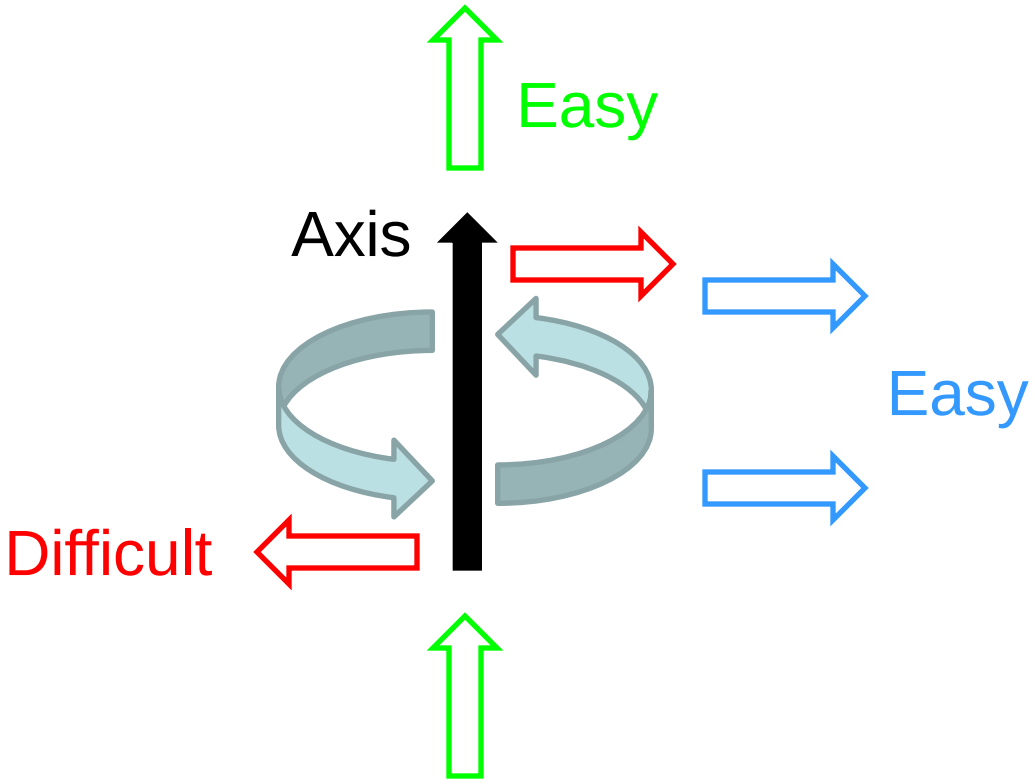




How Does Rotation Affect Motion?

Fluid wants to keep same angular momentum

→ *spinning around axis in same direction at same speed*



Rotating Tank

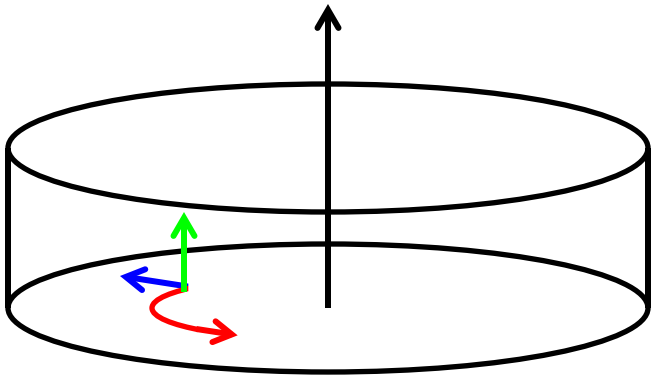
for “solid body” rotation, Ω is the same everywhere

Angular momentum is same for

- Azimuthal direction (around the circle)
- Vertical direction

Angular momentum is different for

- Radial direction



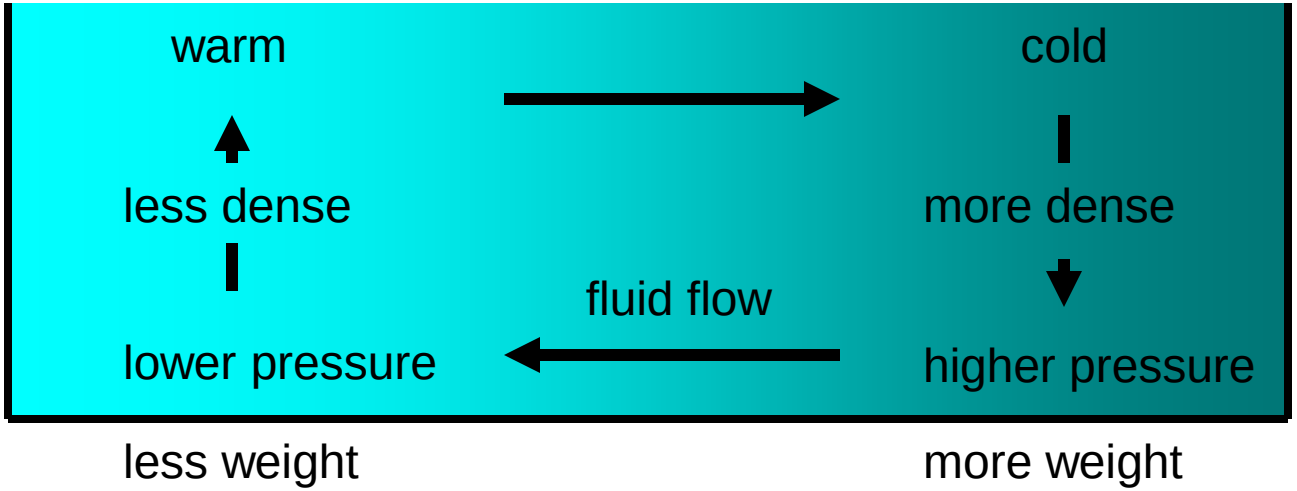
Motion without Rotation

Group discussion

- What motion will occur?
- Why?

Motion without Rotation

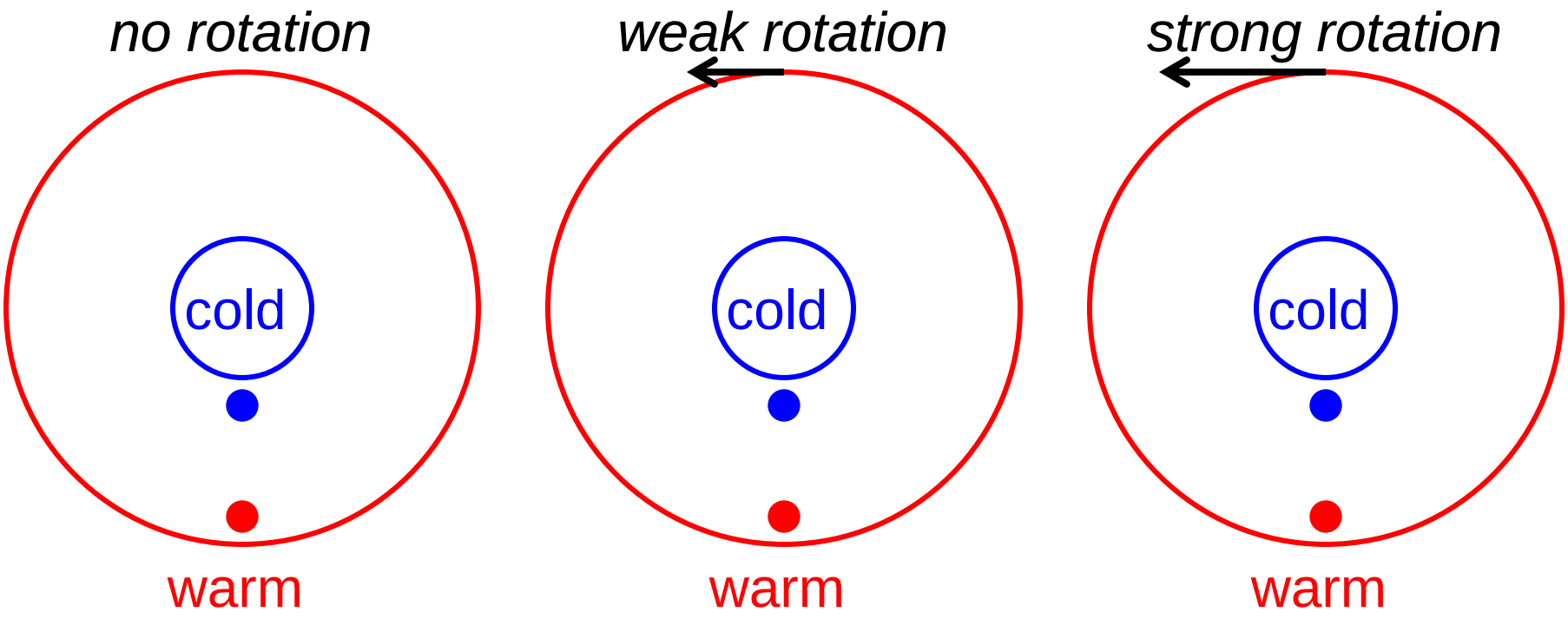
- Warm air and warm water rise, cold air and cold water sink
- Fluid flows from high pressure to low pressure



Motion with Rotation

Group discussion

- Show how fluid starting at the blue spot and red spot moves (rotating reference frame, conserving ang. mom.)



Conservation of Angular Momentum

If no torque (force in direction of rotation),
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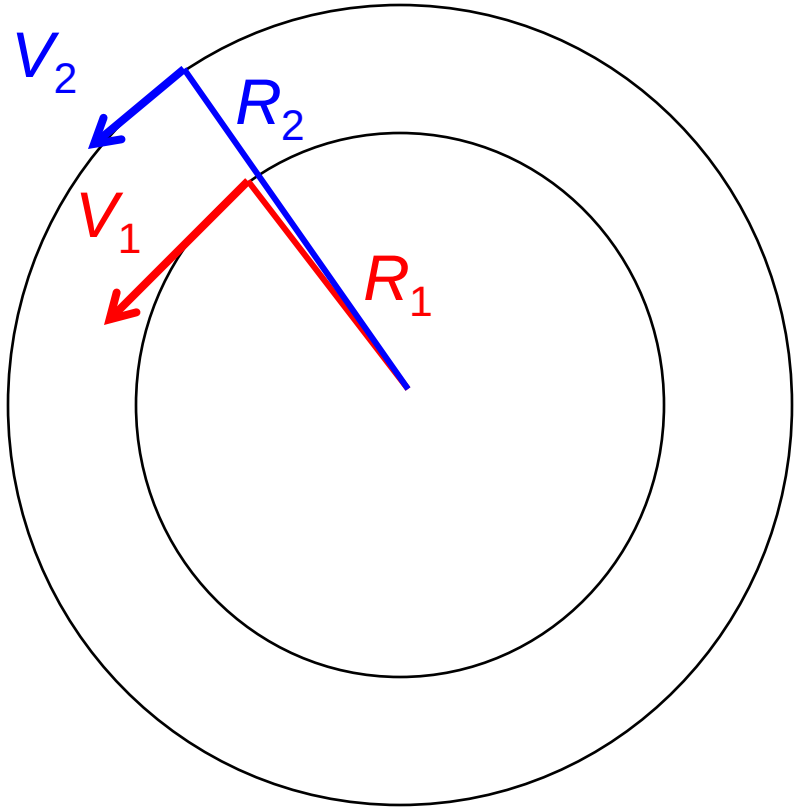
$R_1 V_1 = R_2 V_2$

$R_1 < R_2$

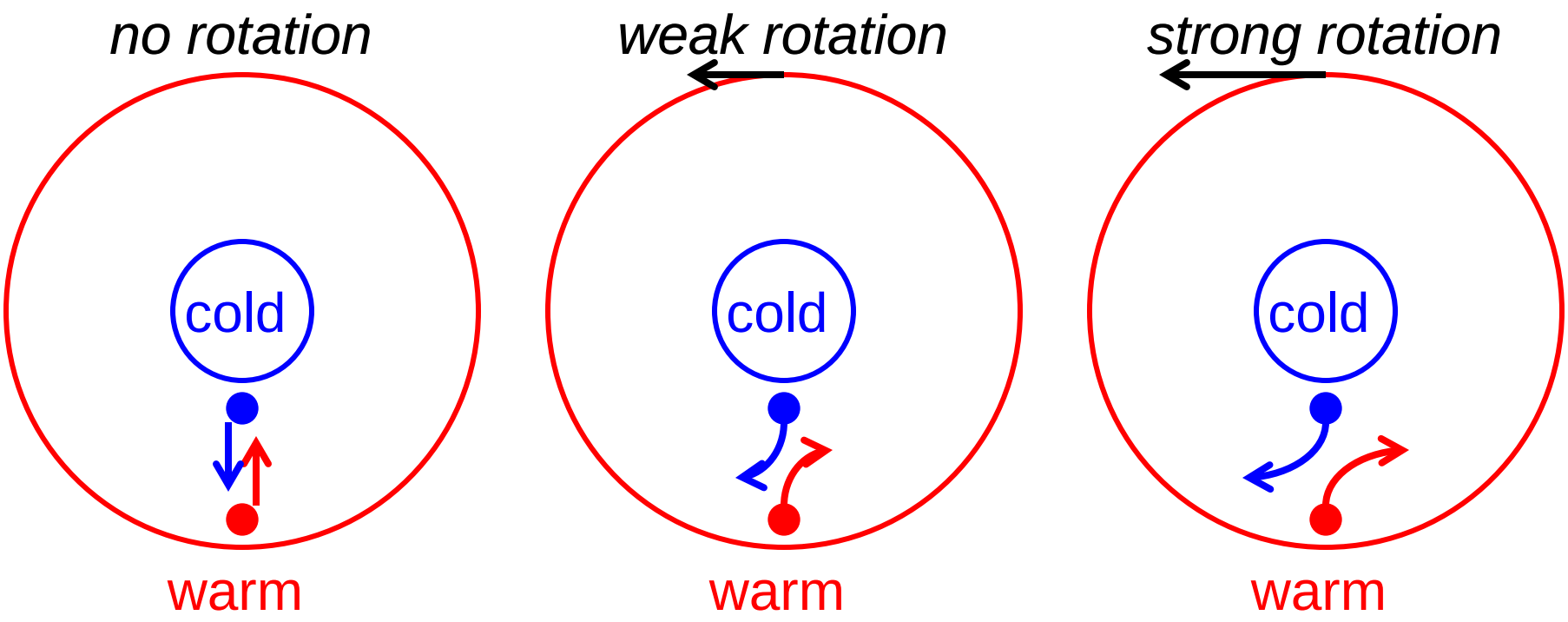
$V_1 > V_2$



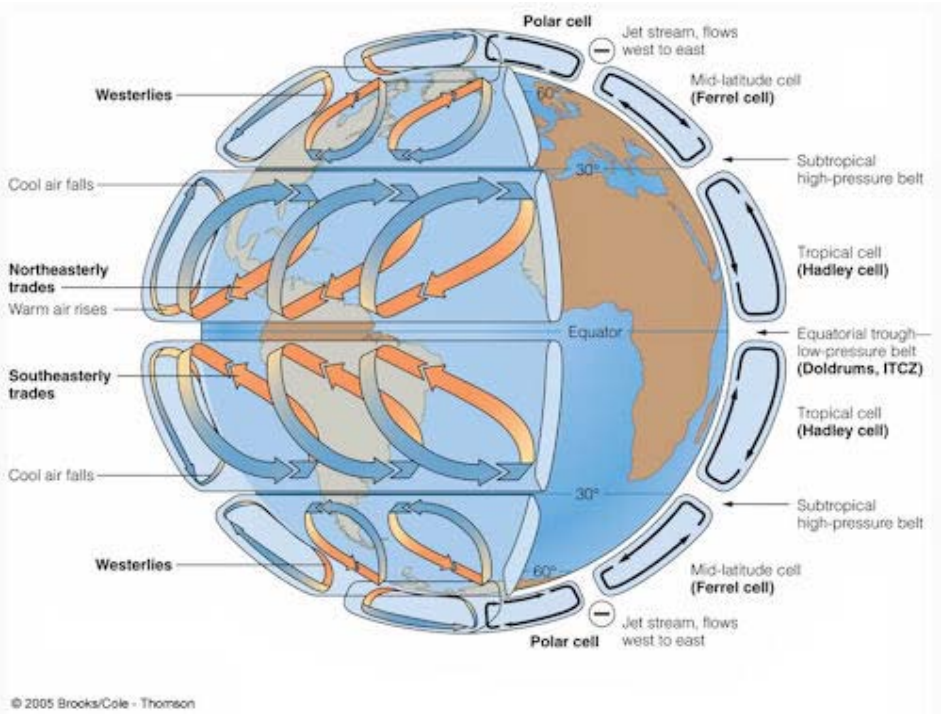
Motion with Rotation

Conservation of angular momentum requires

- Rotation faster than reference frame for inward motion
- Rotation slower than reference frame for outward motion



Hadley Circulation and Trade Winds



Examine rotating table

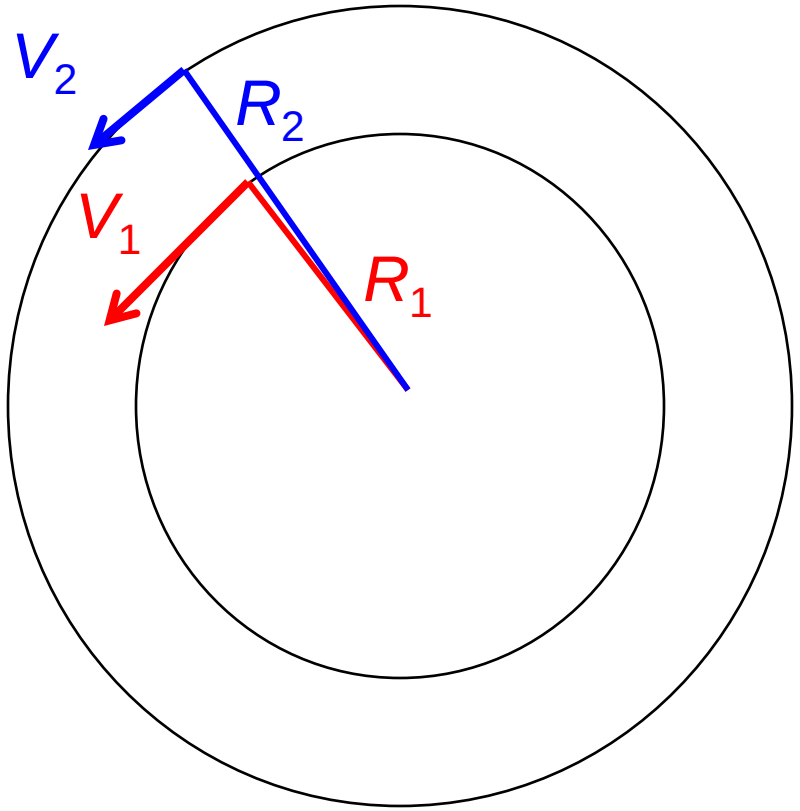
Increase rotation on rotating table

Is Momentum Always Conserved?

Imagine that air at the equator is rotating at the same rate as the Earth.

Imagine that this air moves to the North Pole while conserving angular momentum.

What is the speed of the wind relative to the Earth?



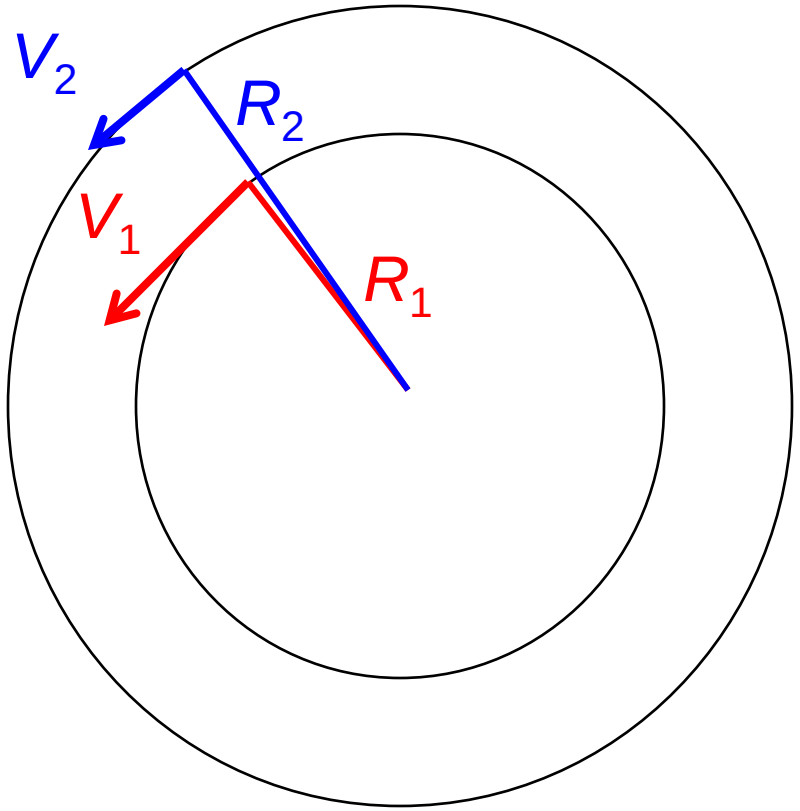
Is Momentum Always Conserved?

Imagine that air at the equator is rotating at the same rate as the Earth.

Imagine that this air moves to the North Pole while conserving angular momentum.

What is the speed of the wind relative to the Earth?

Infinite!



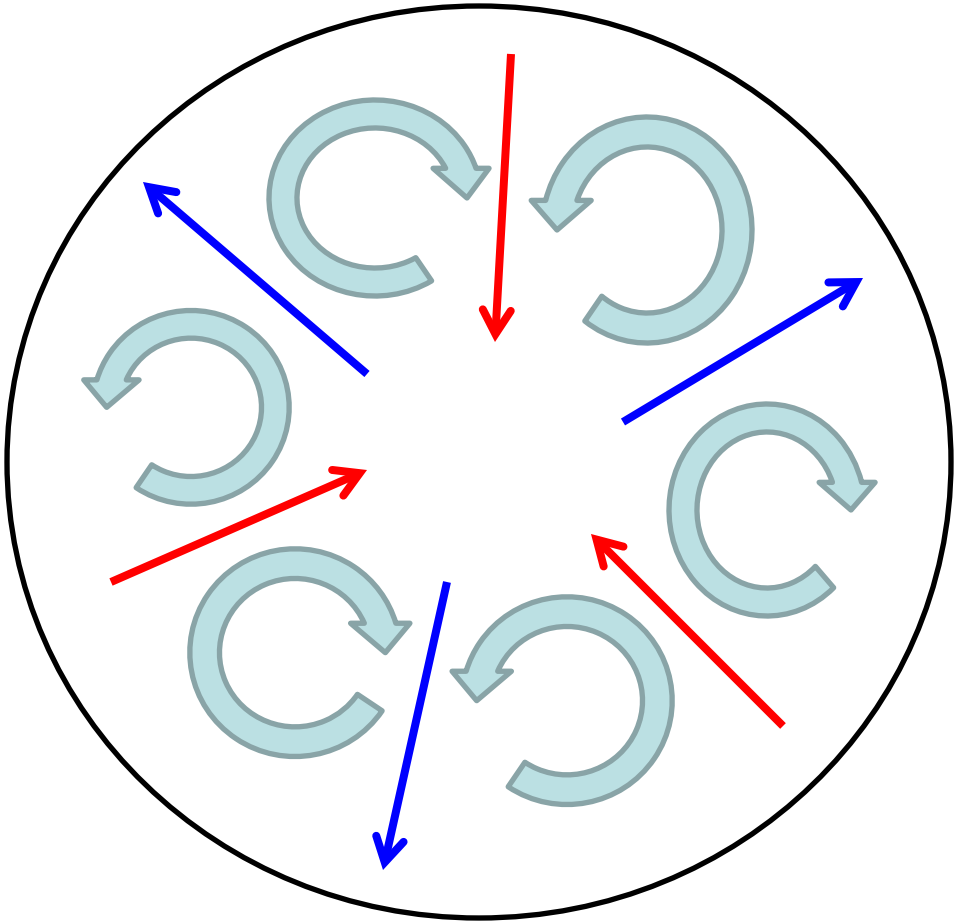
Baroclinic Instability

- Occurs when the warm-cold temperature difference is large and/or rotation rate is large
- Motion is very fast
- Instabilities (waves or eddies) develop
- Momentum is no longer conserved
- These eddies transport heat

Heat Transport by Eddies

Warm goes poleward

Cold goes equatorward

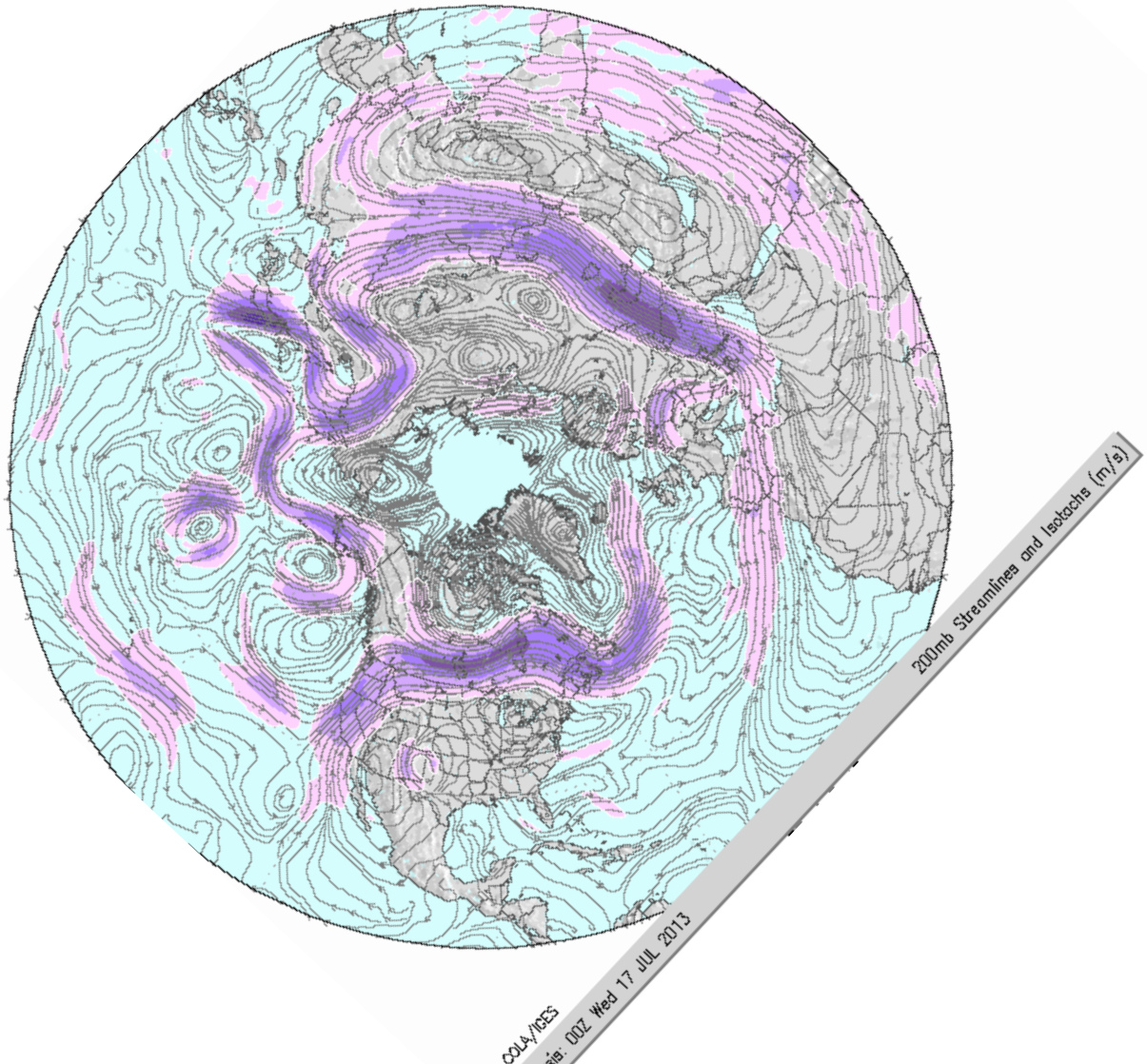


The Jet Stream

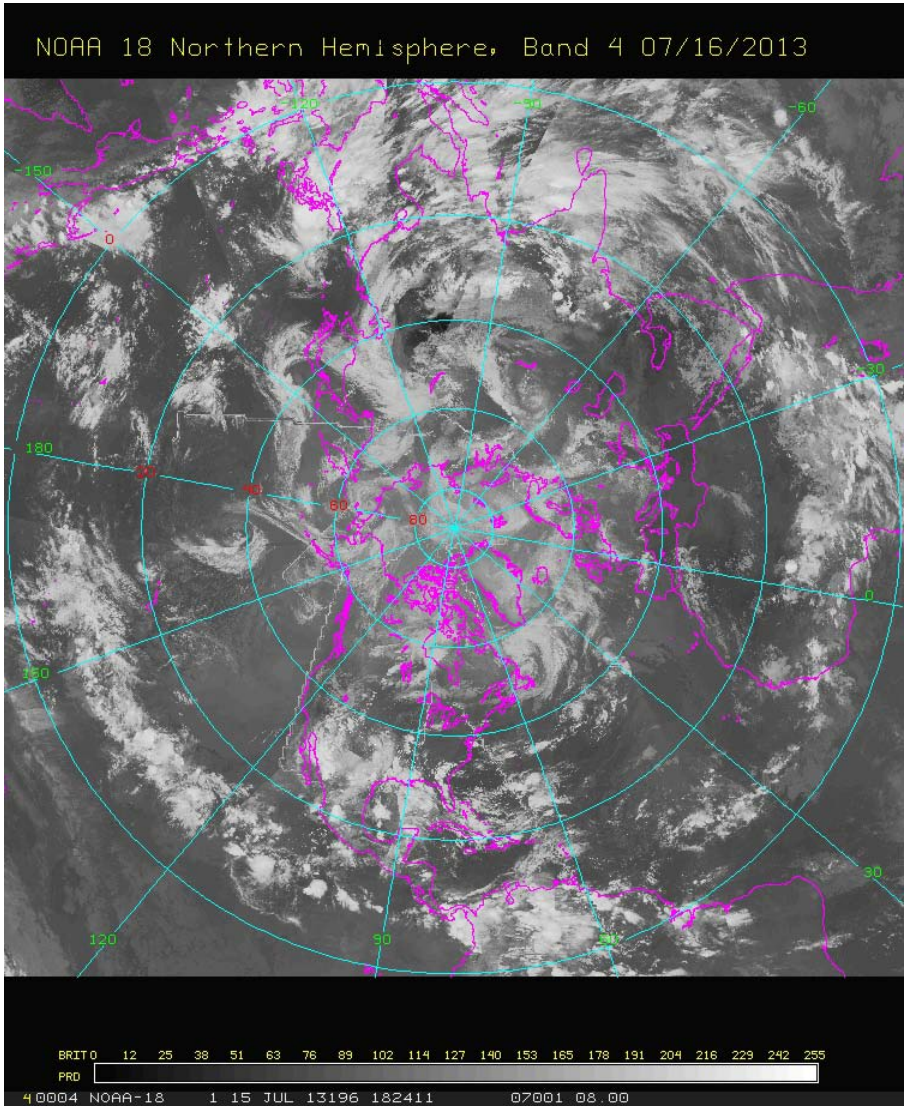
- High above the surface, air moves poleward from the equator
- The wind becomes strongly westerly (from the west) due to conservation of angular momentum
- The jet stream is so fast, that instabilities (waves or eddies) develop
- Momentum is no longer conserved
- These eddies transport heat farther poleward (and produce weather)

Jet stream animation

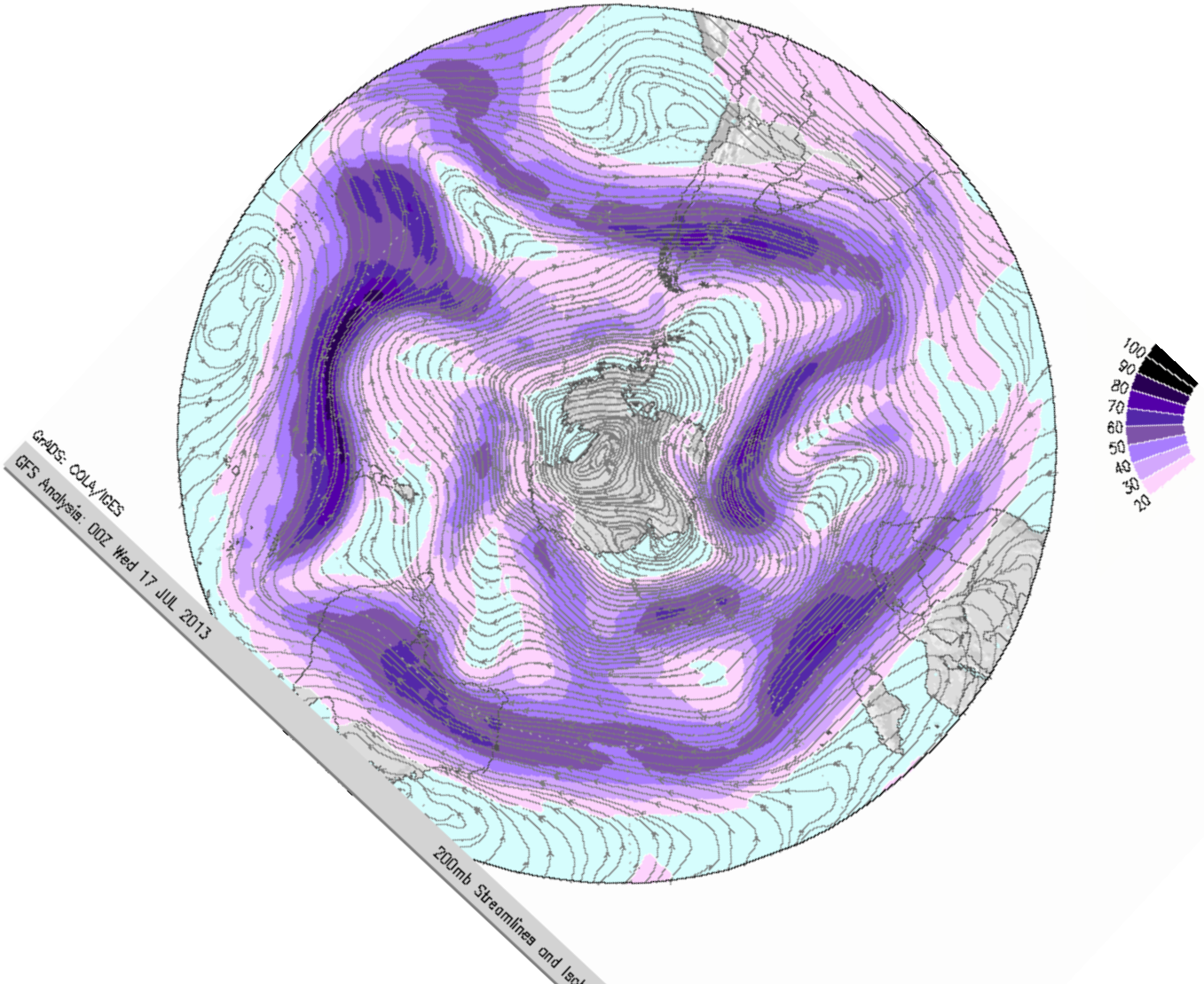
Jet Stream and Clouds



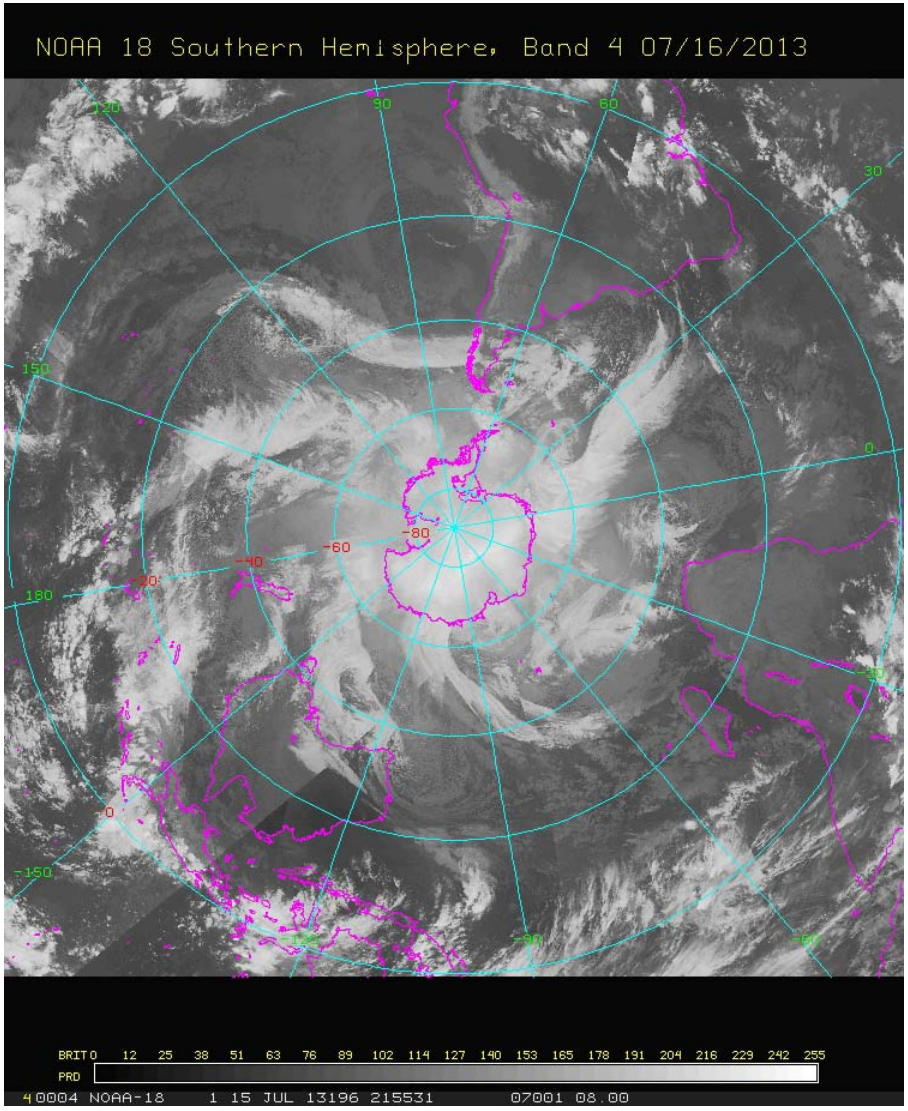
Jet Stream and Clouds



Jet Stream and Clouds



Jet Stream and Clouds



Check heated bottle experiment

Examine rotating table

Break

Introduction to Oceanic Circulation

Wind Driven Circulation

Cold Upwelling

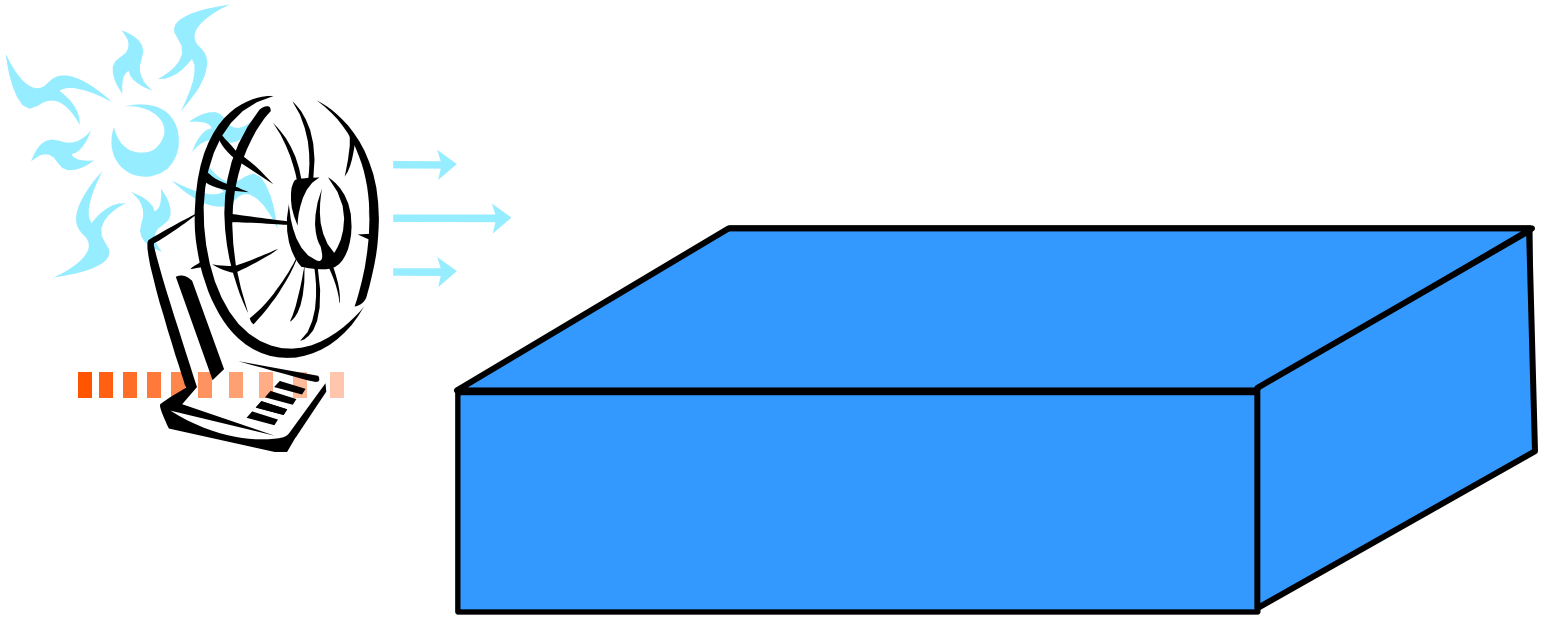
Warm Western Boundary Currents

Start rotating table with fans

How Does Wind Affect Water Motion?

Group Discussion

- How does water move?
- Are there any constraints?

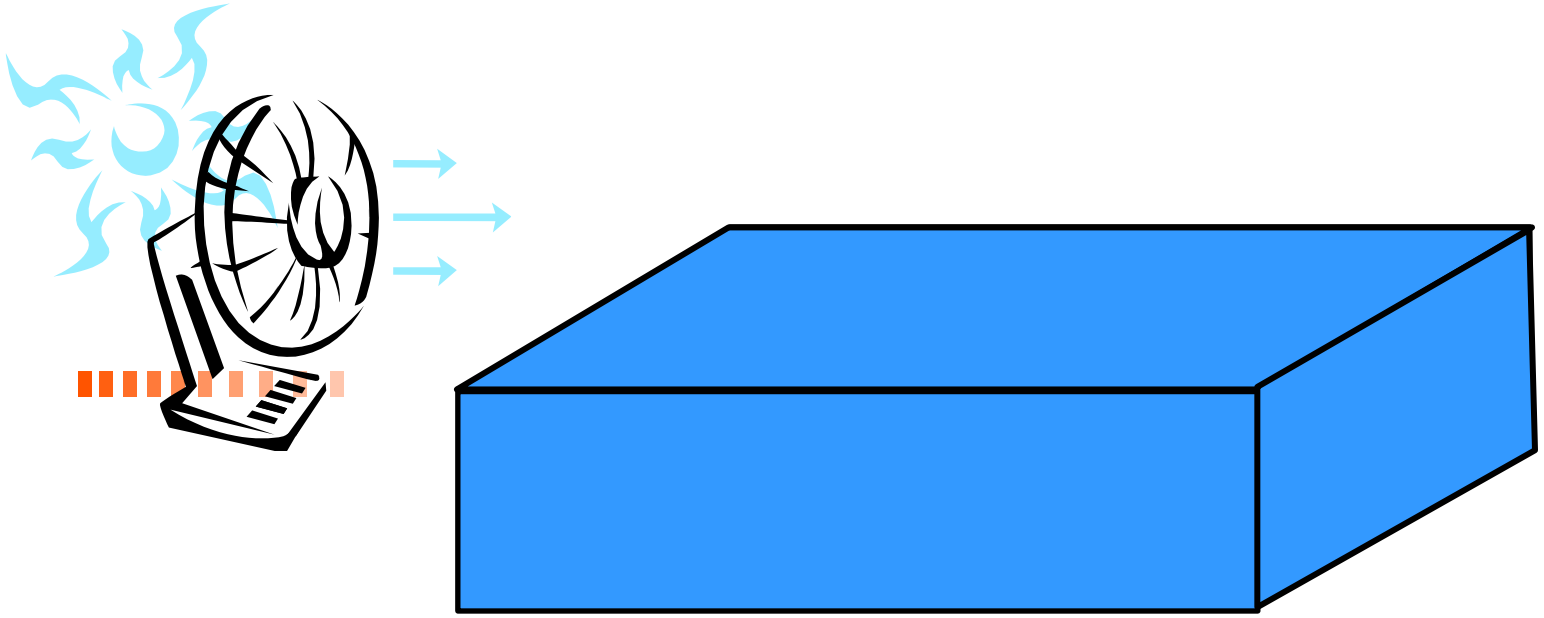


Fans and tubs experiment

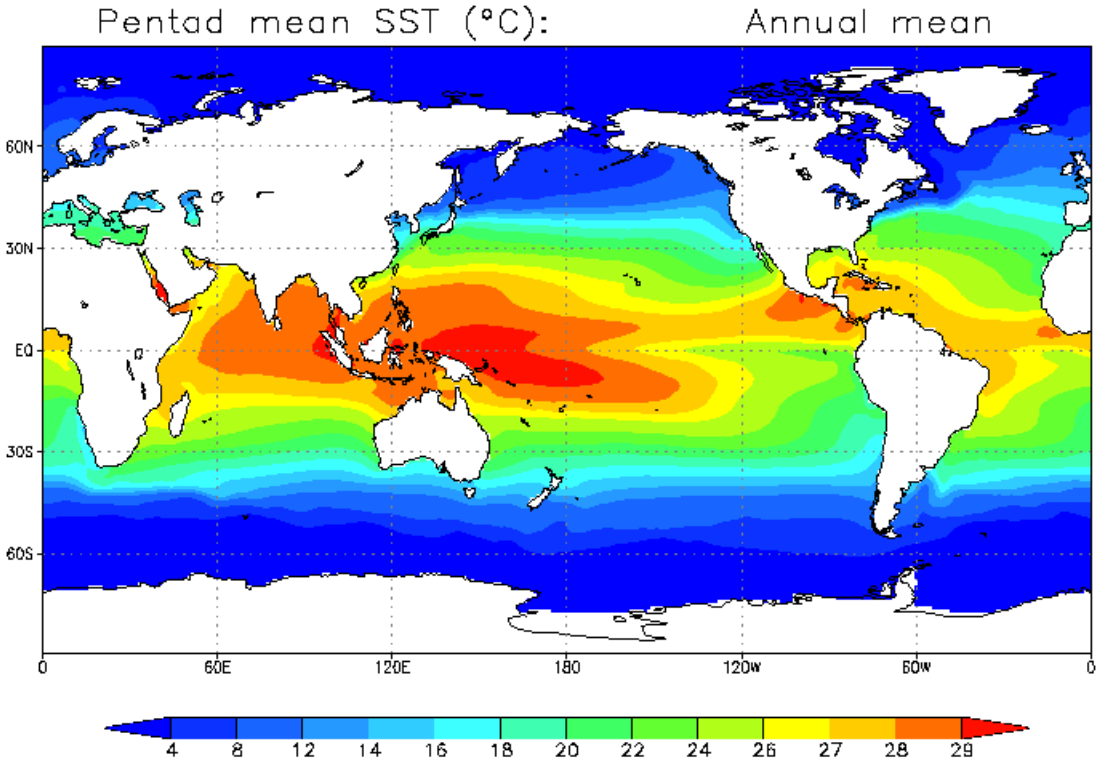
How Does Wind Affect Water Motion?

Group Discussion

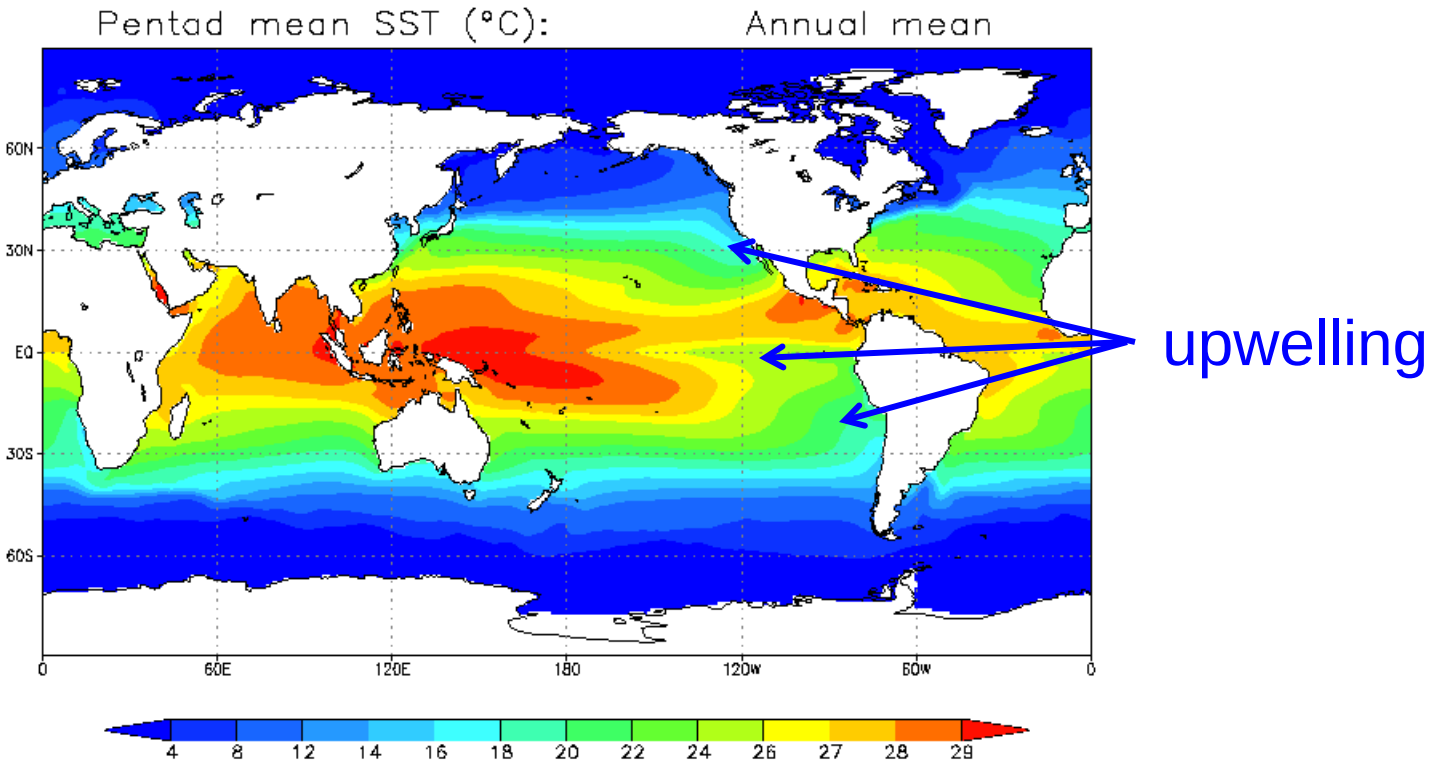
- In what sorts of ways did the water move under different fan orientations?
- Were there any constraints on the motion?



Sea Surface Temperature

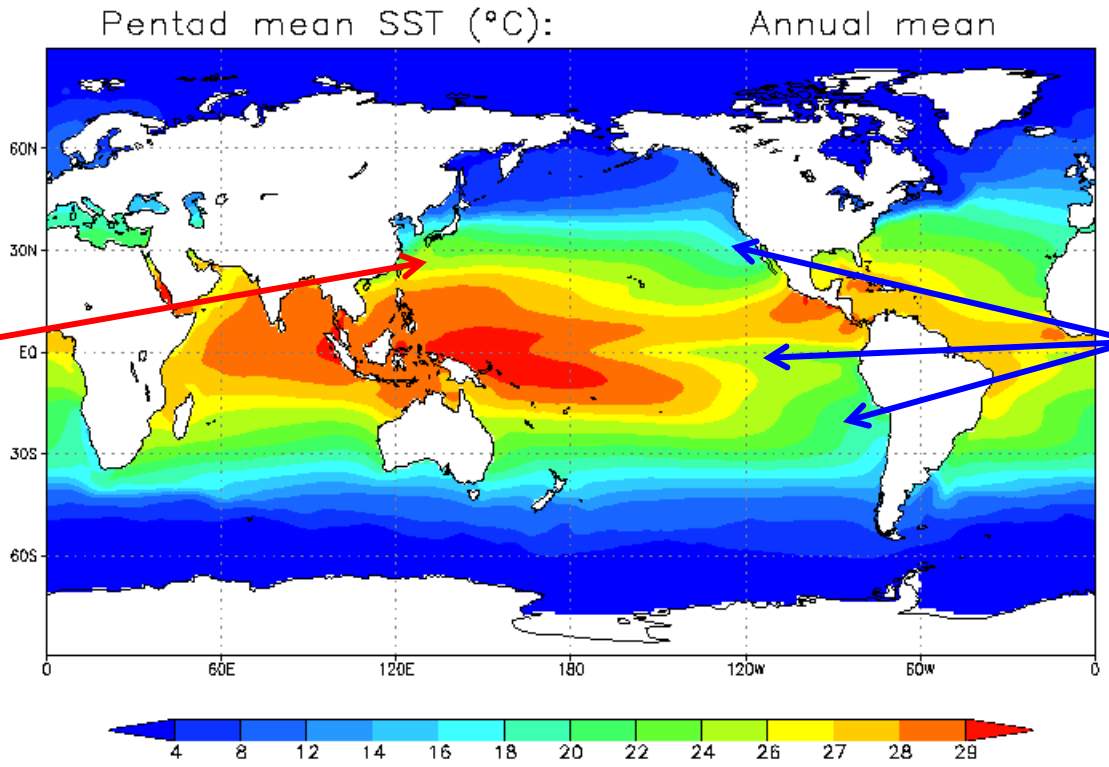


Sea Surface Temperature



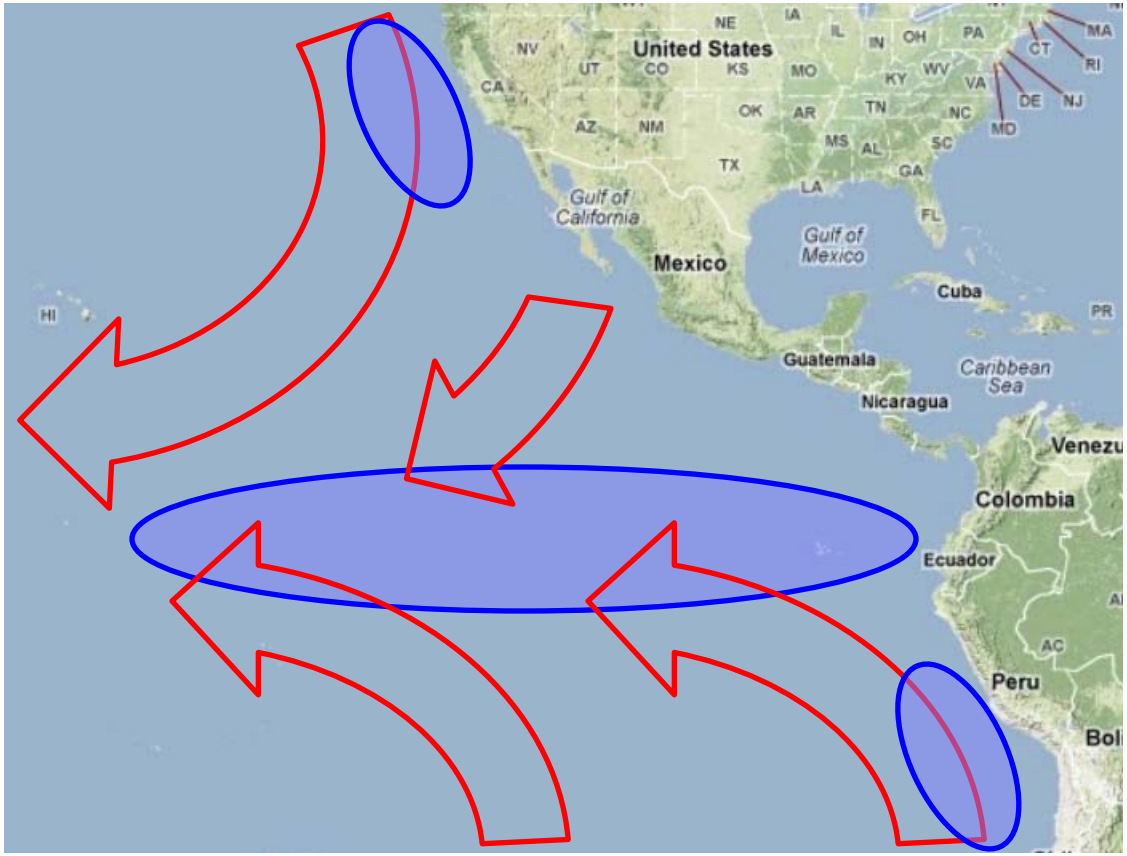
Sea Surface Temperature

western boundary current

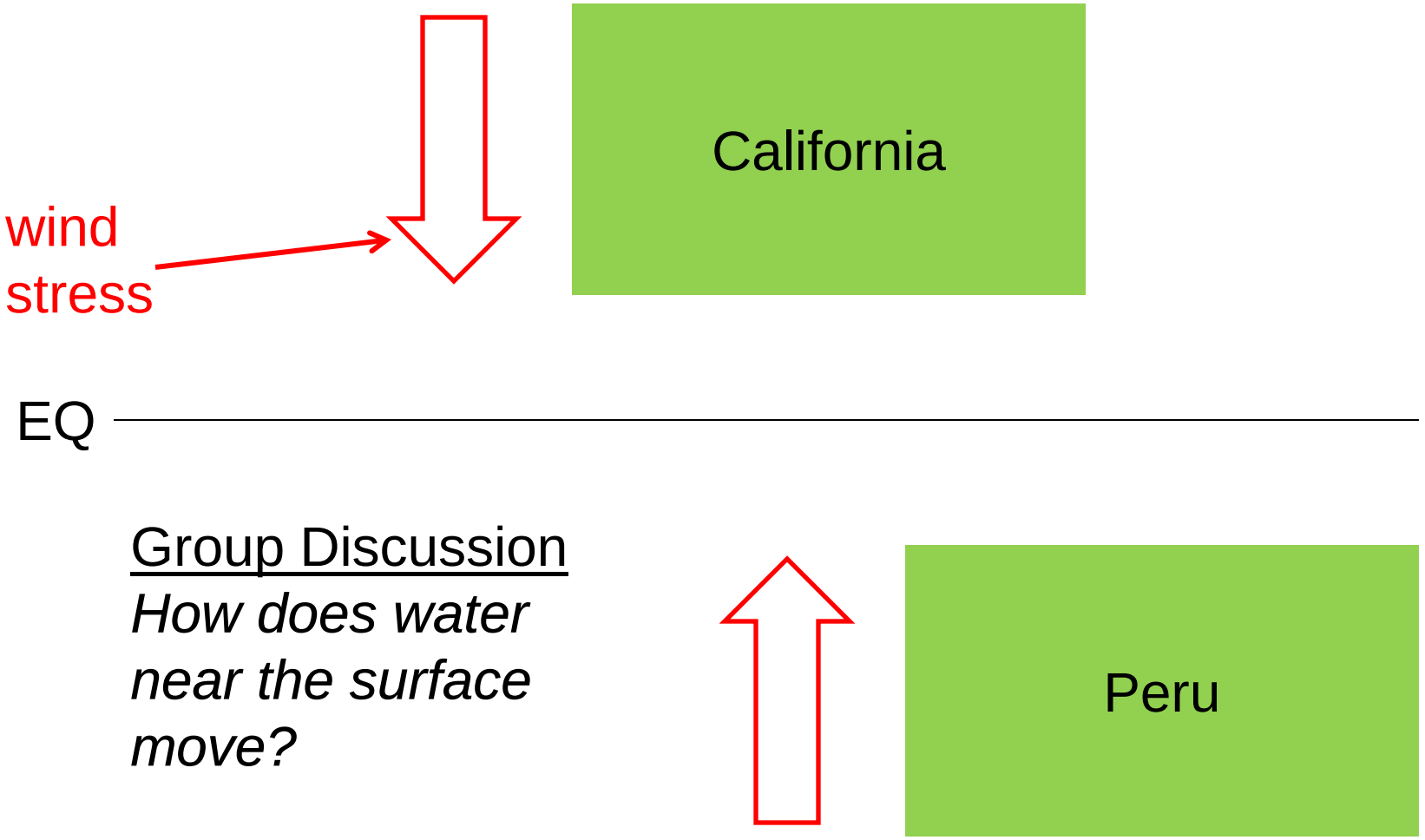


upwelling

Trade Winds and Upwelling



Wind Drags Ocean Surface Equatorward



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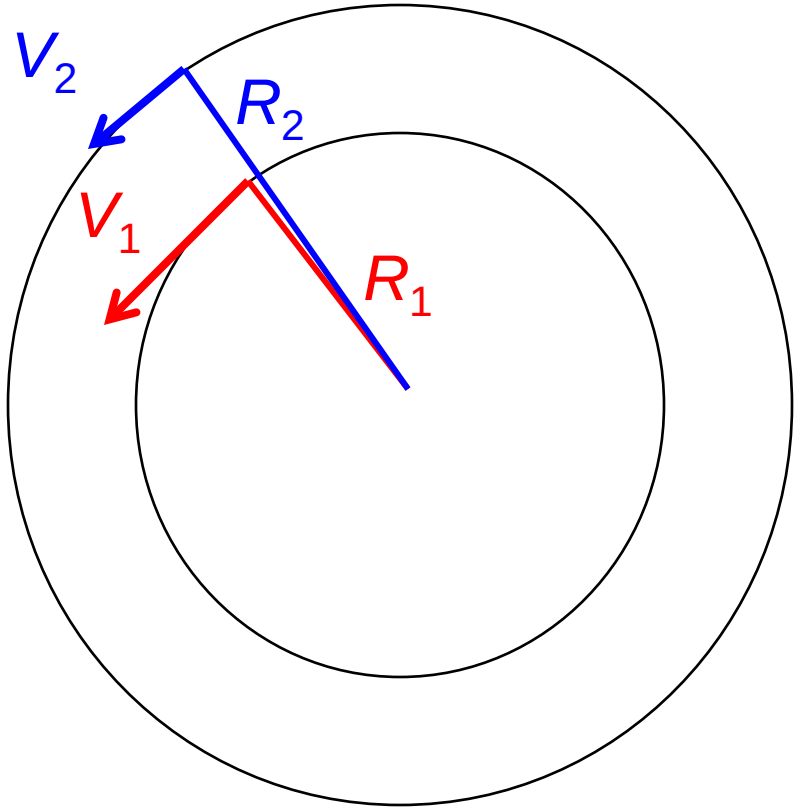
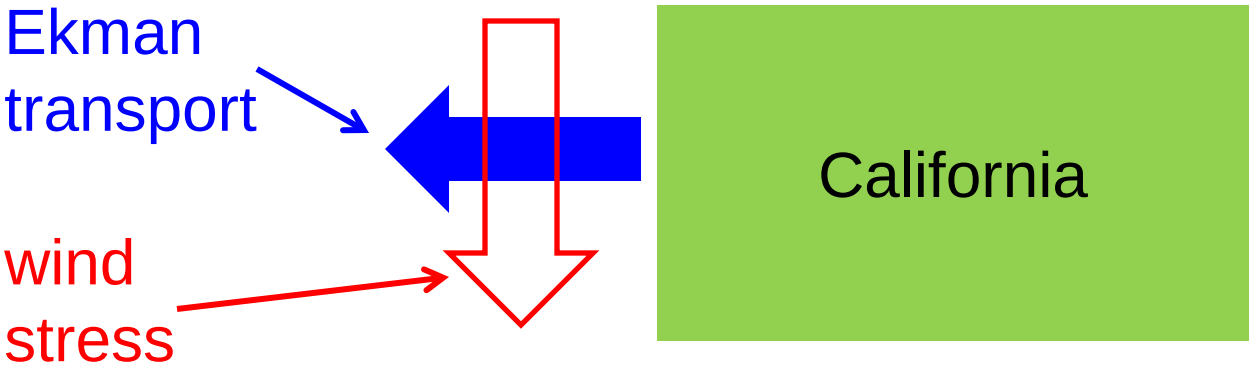


Ocean Surface Moves Westward

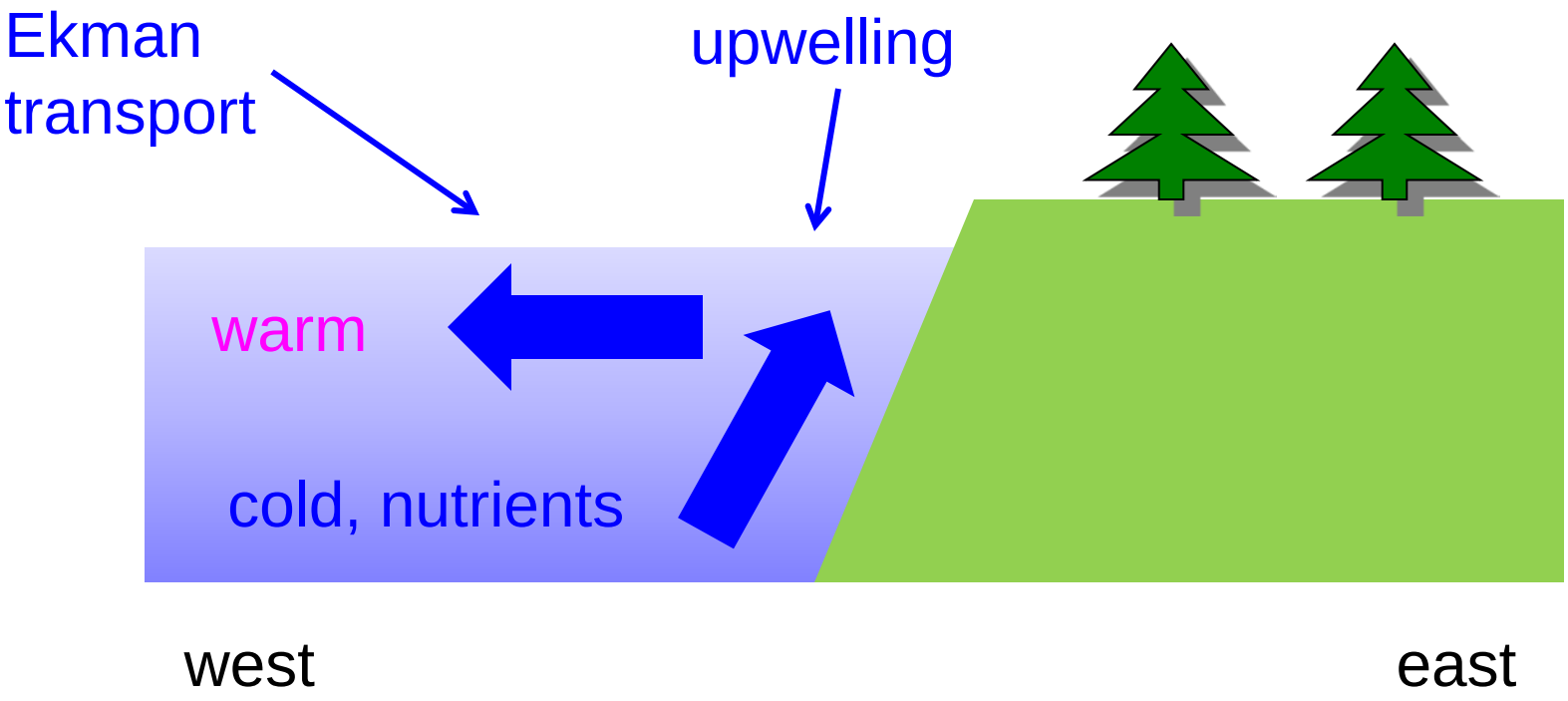


EQ

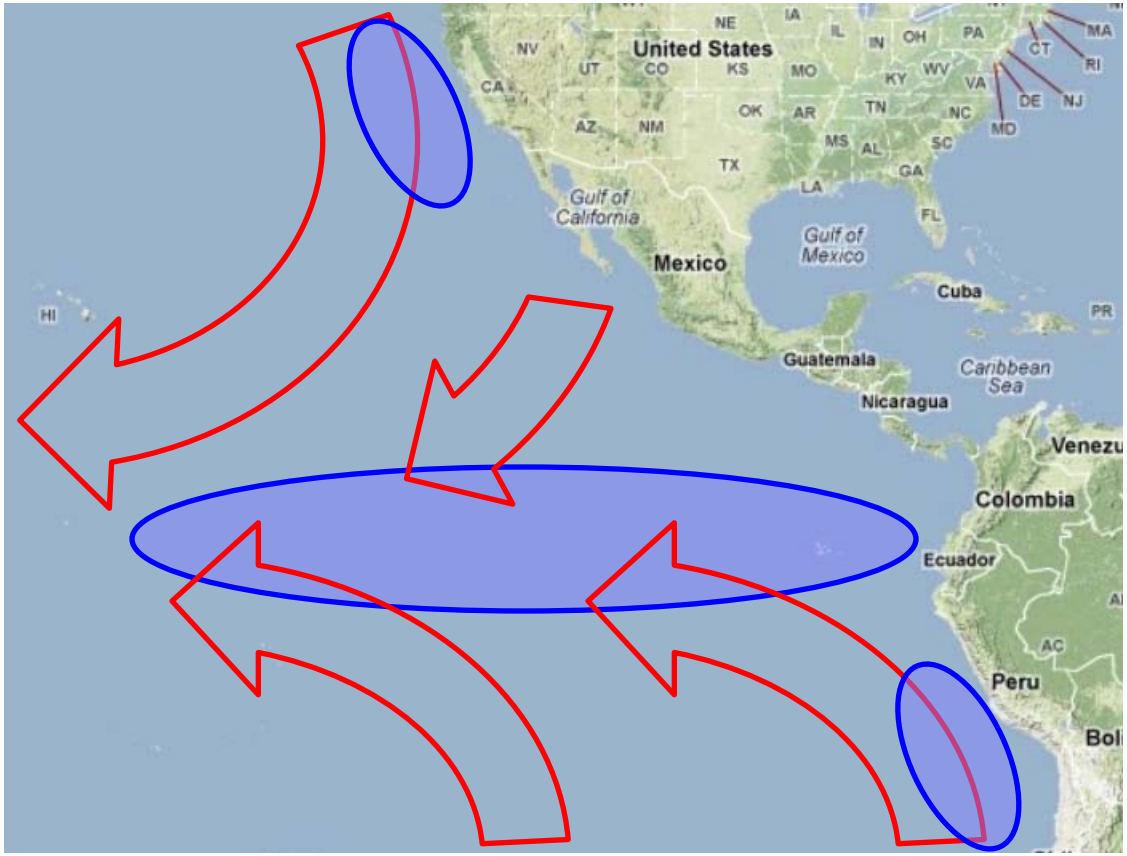
ocean surface rotates
more slowly than the Earth

moves westward relative
to the Earth

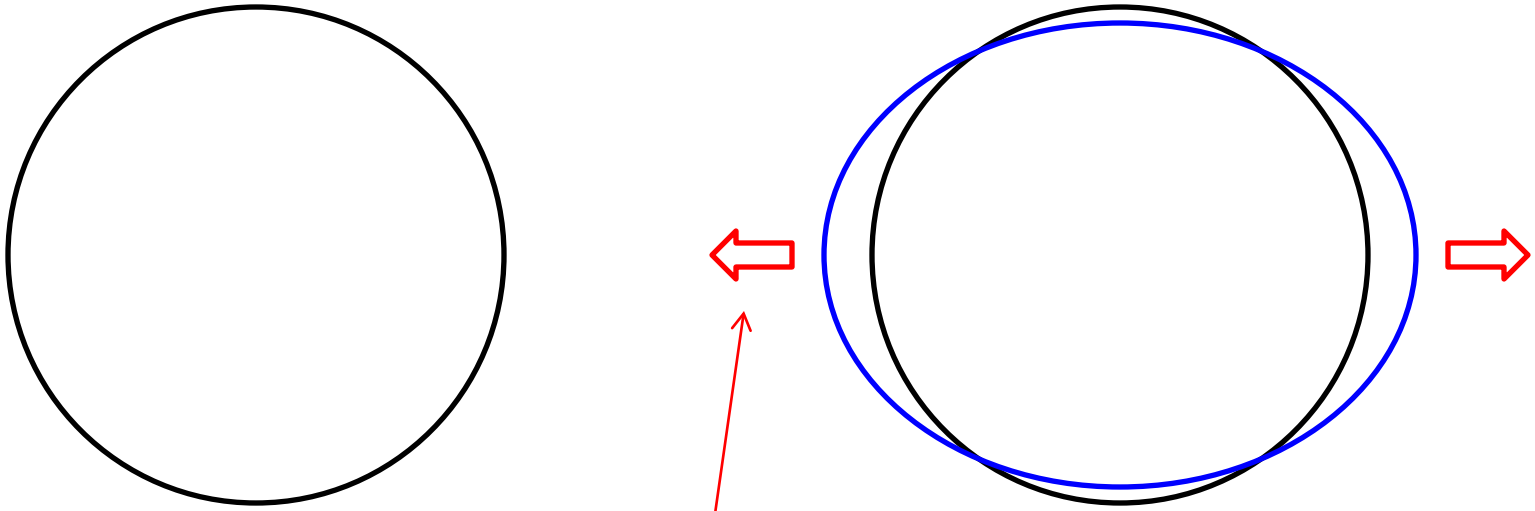
Upwelling Replaces Surface Water



What Happens at the Equator?



Equatorial Bulge from Rotation

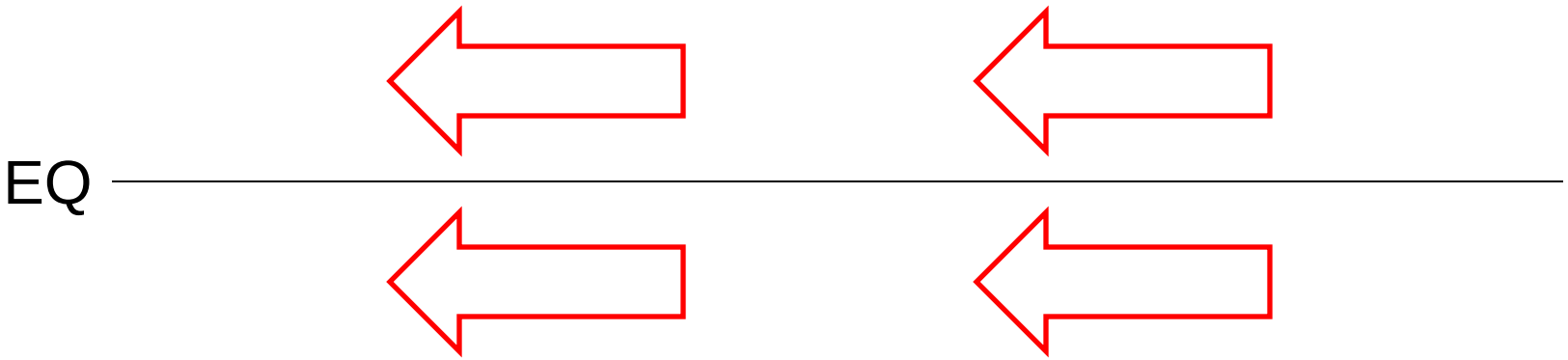


non-rotating earth
is spherical

outward
centrifugal
acceleration

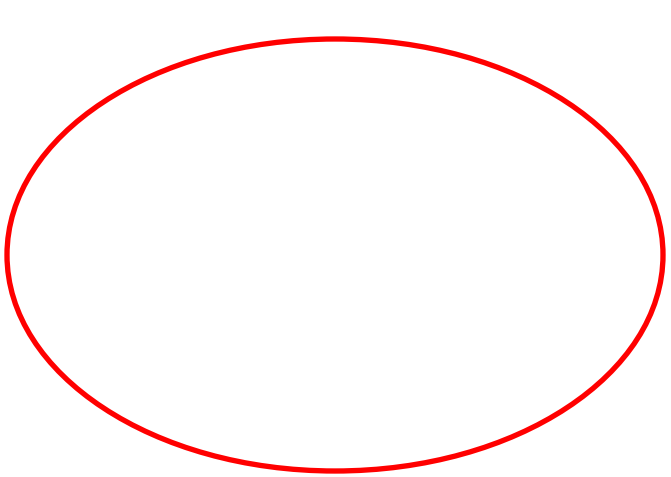
rotating earth
is oblate

Wind Drags Ocean Surface Westward

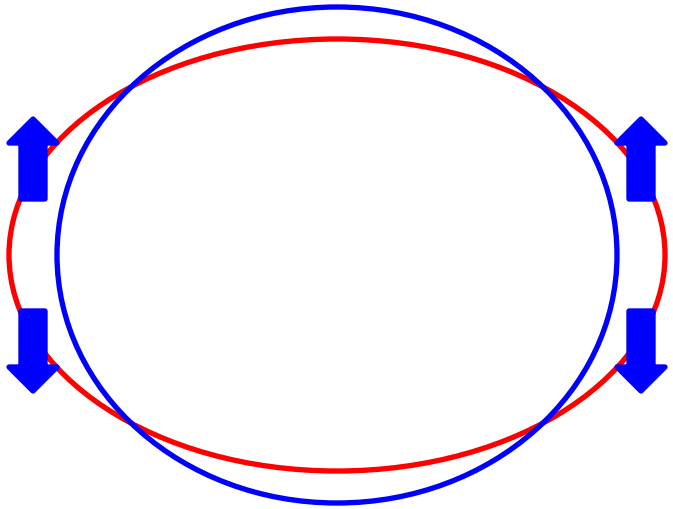


ocean surface rotates
more slowly than the Earth

Equatorial Bulge from Rotation



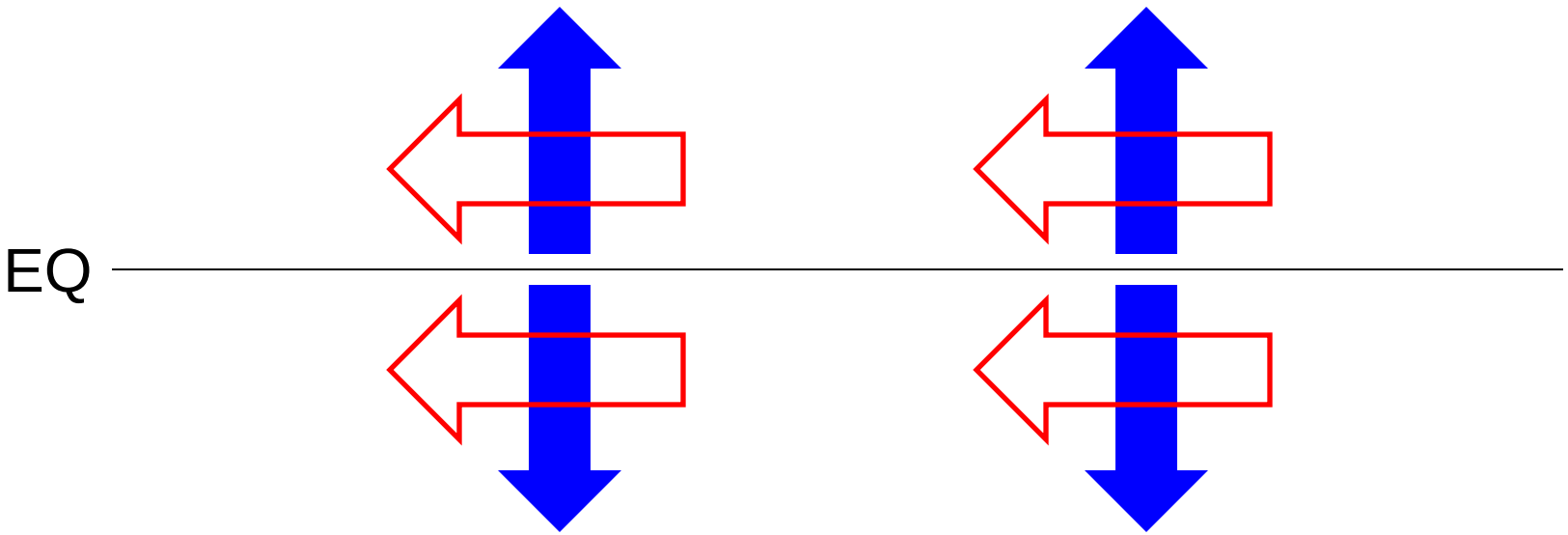
faster rotation
is more oblate



slower rotation
is less oblate

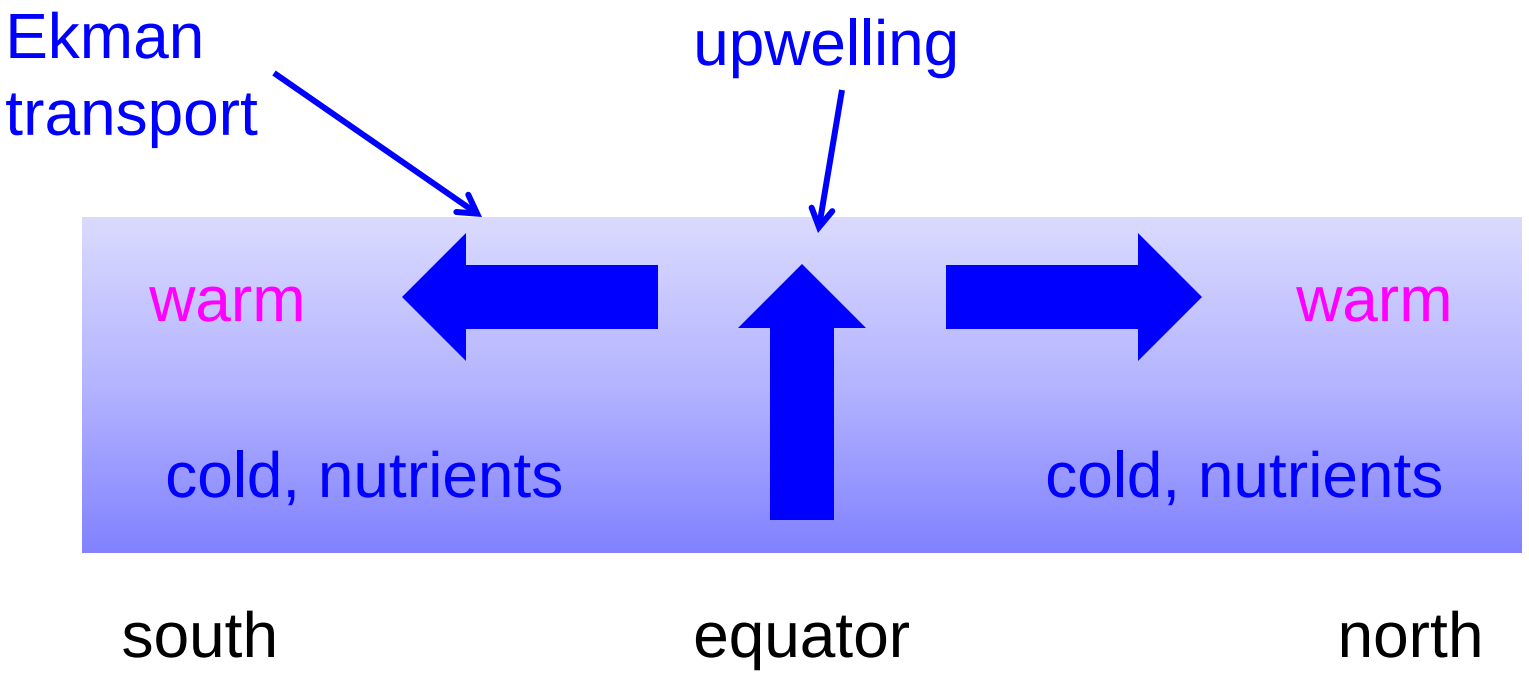
water moves poleward when rotation slows

Wind Drags Ocean Surface Westward



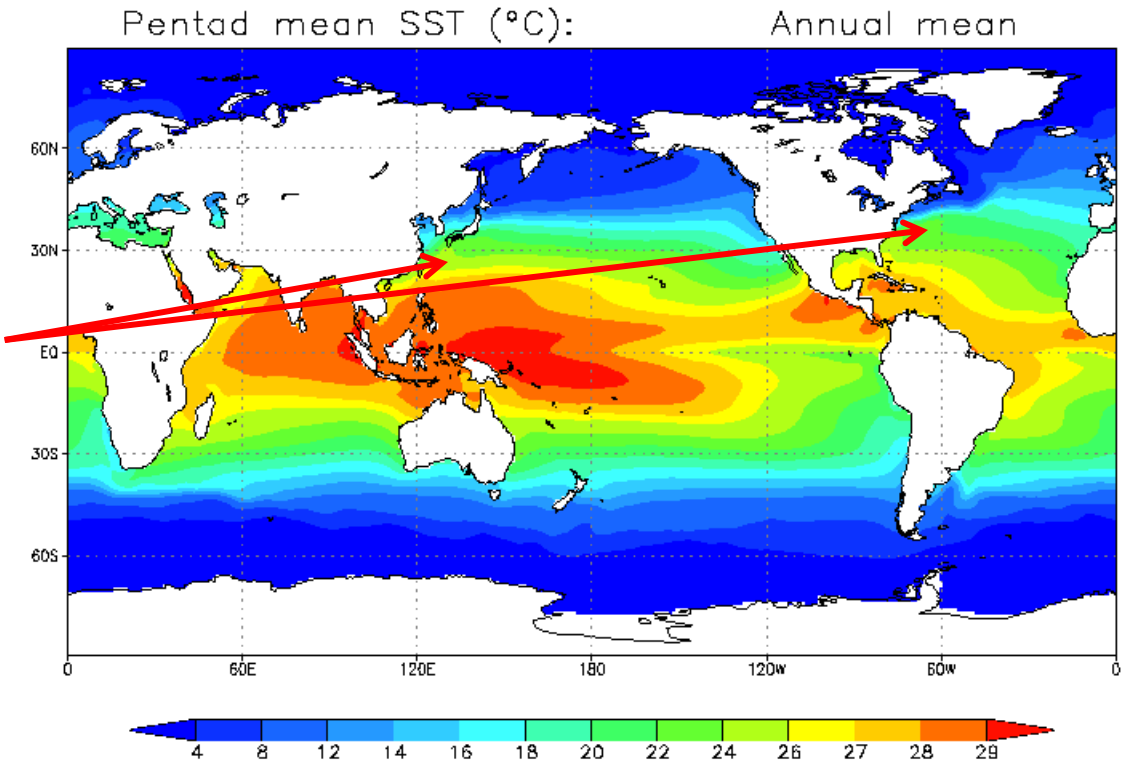
ocean surface moves poleward

Upwelling Replaces Surface Water

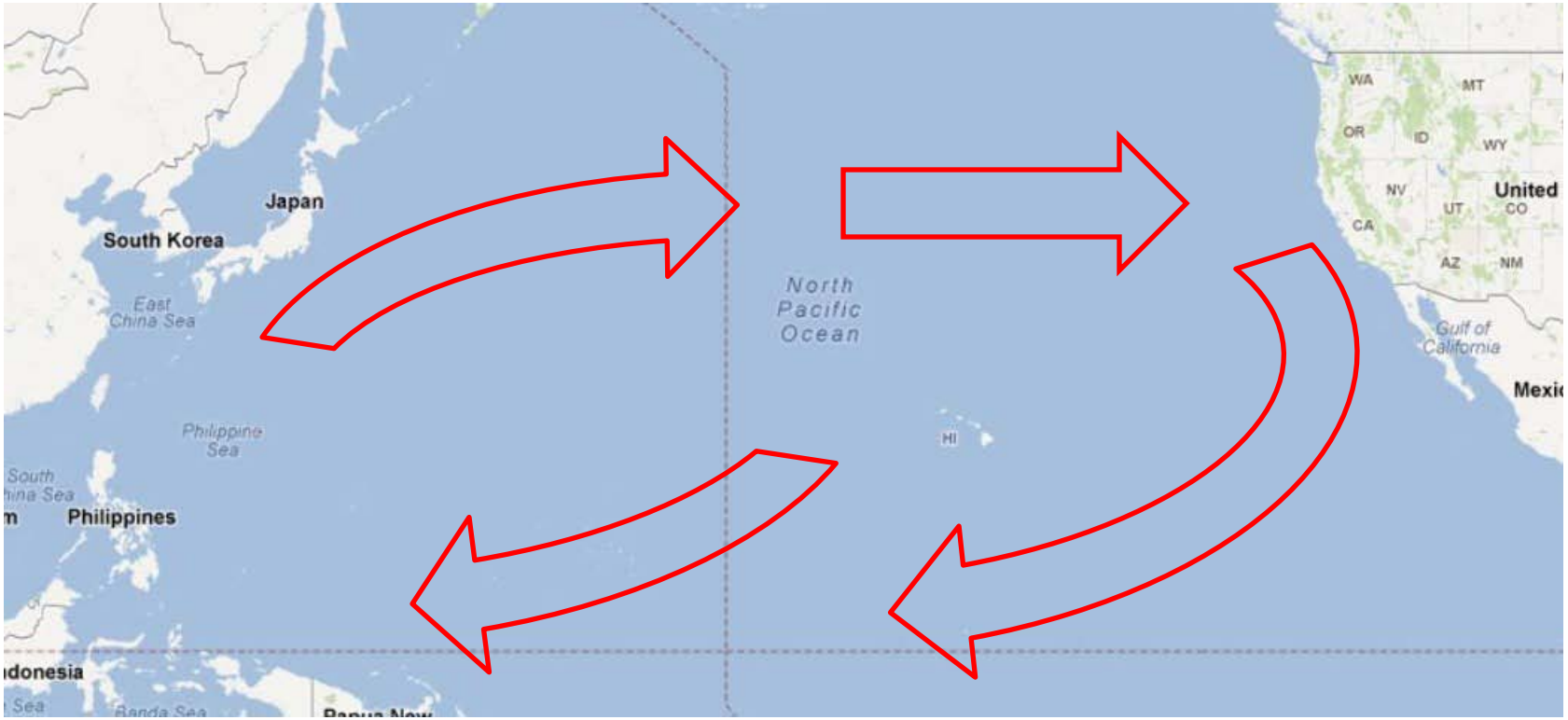


Sea Surface Temperature

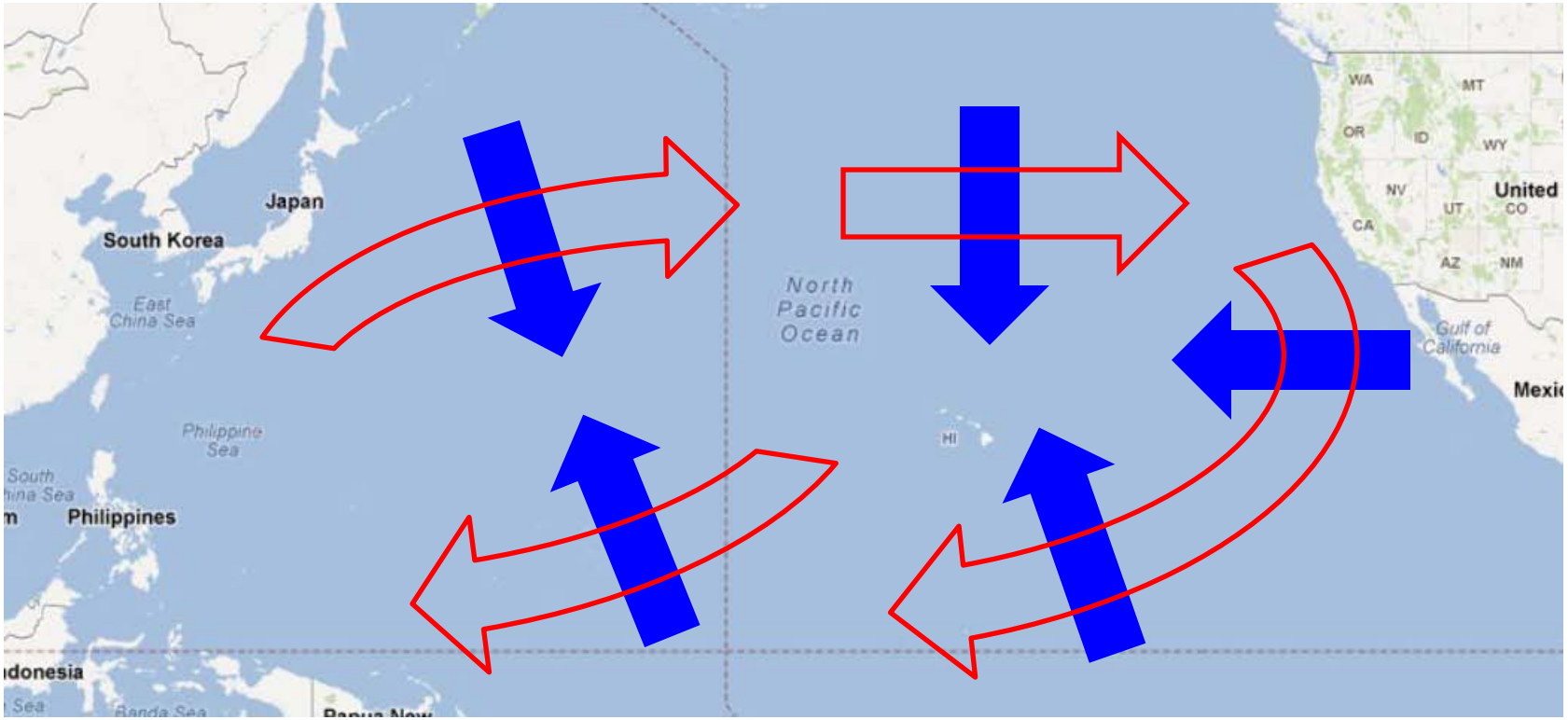
western boundary currents



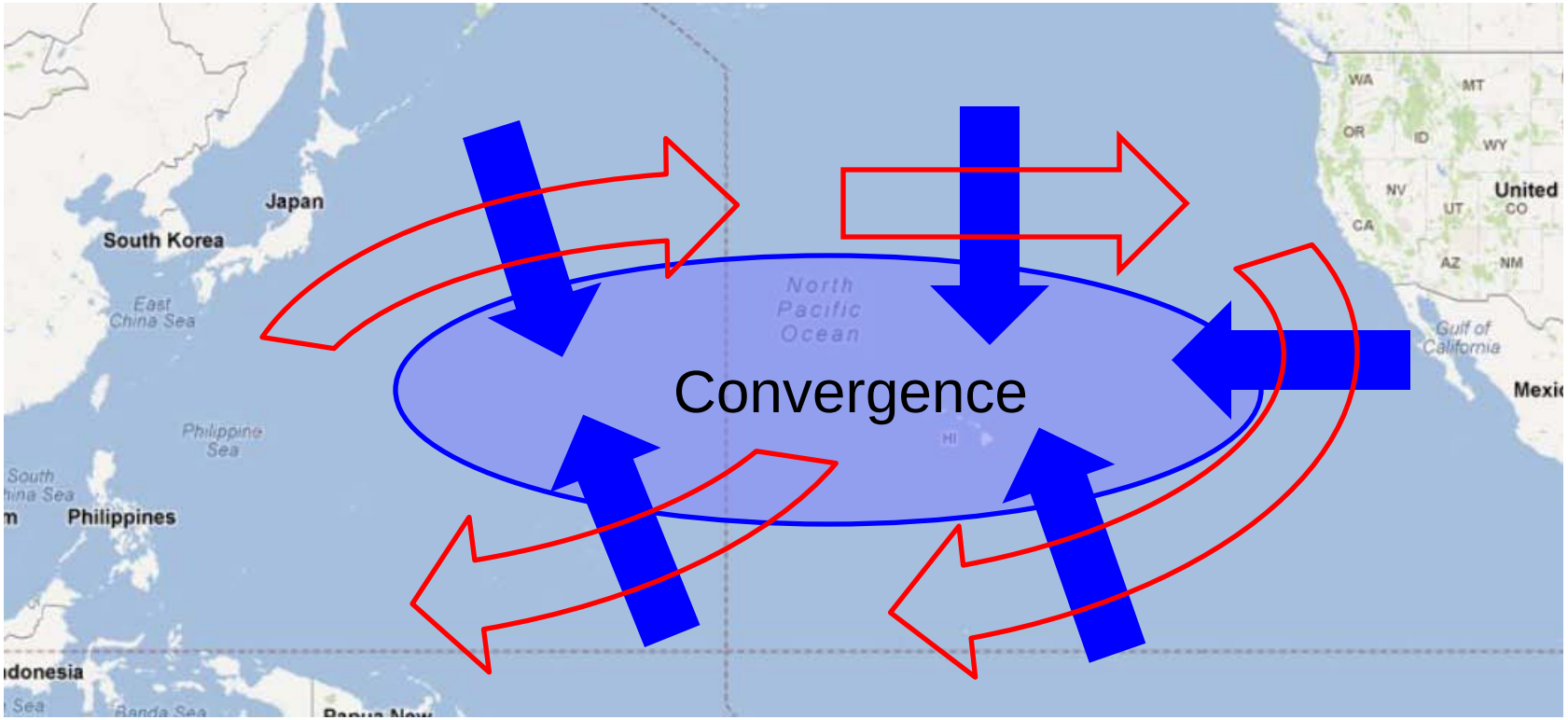
Wind Stress over Subtropical Gyre



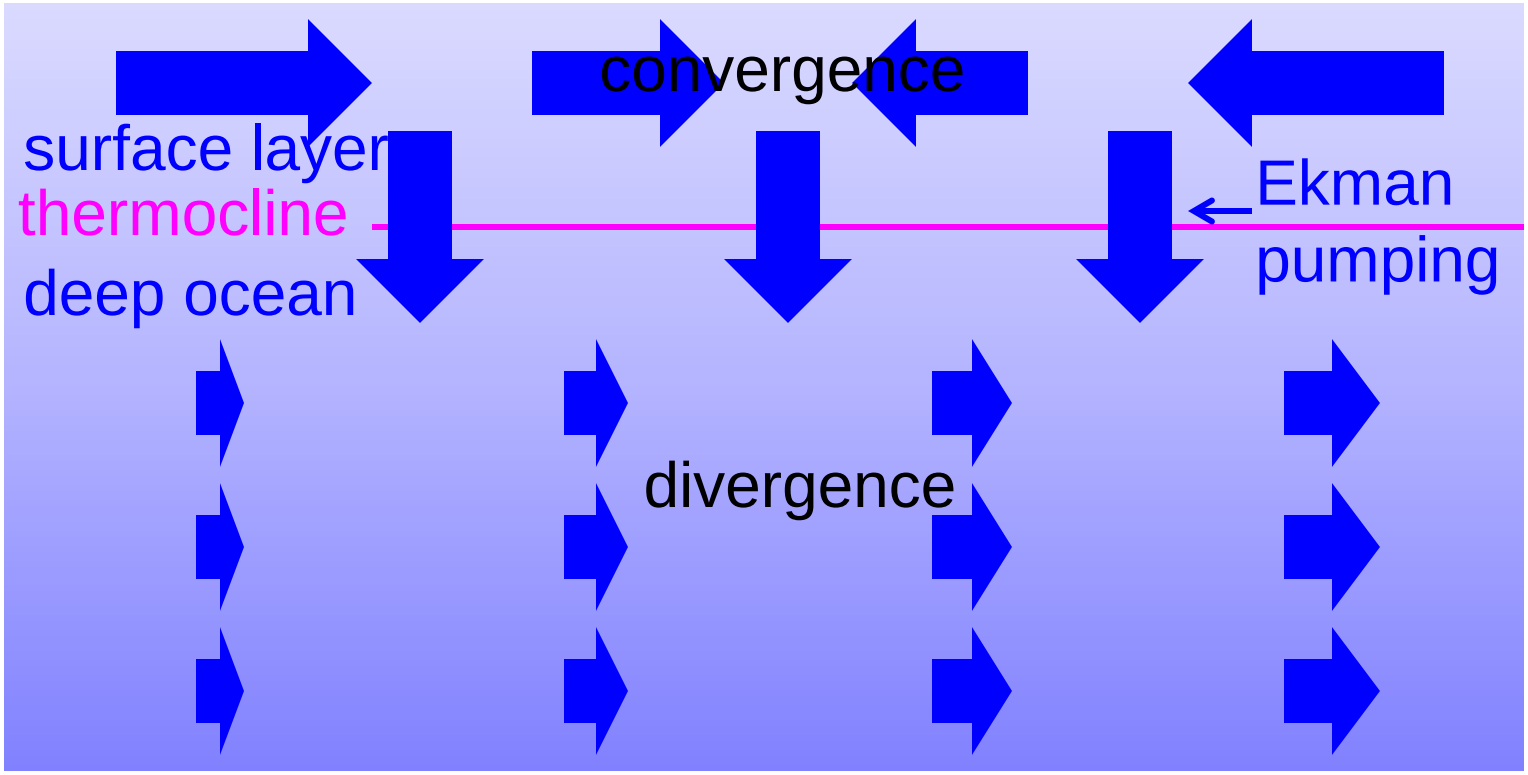
Surface Ocean Movement



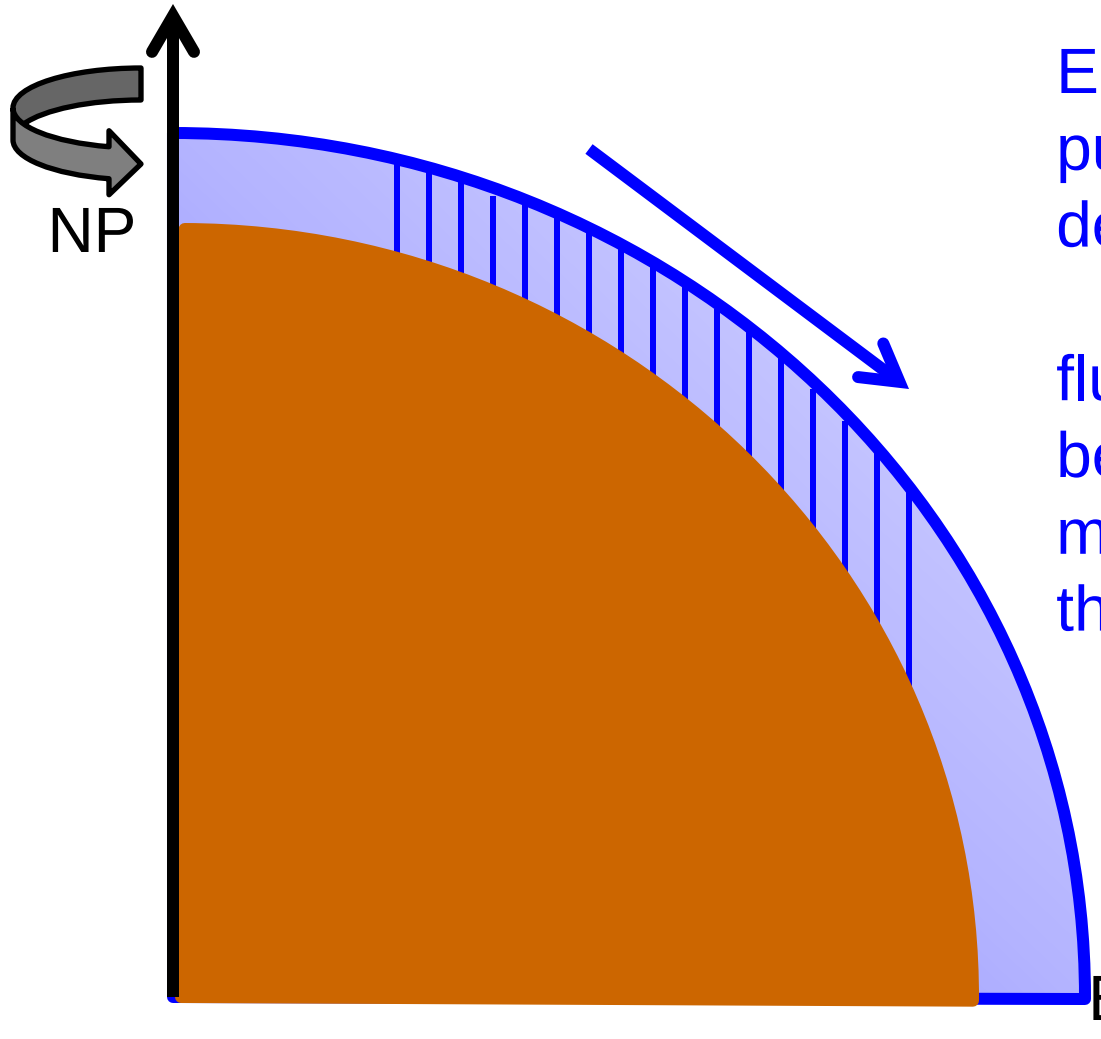
Convergence of Ocean Surface



Ekman Pumping and Sverdrup Transport



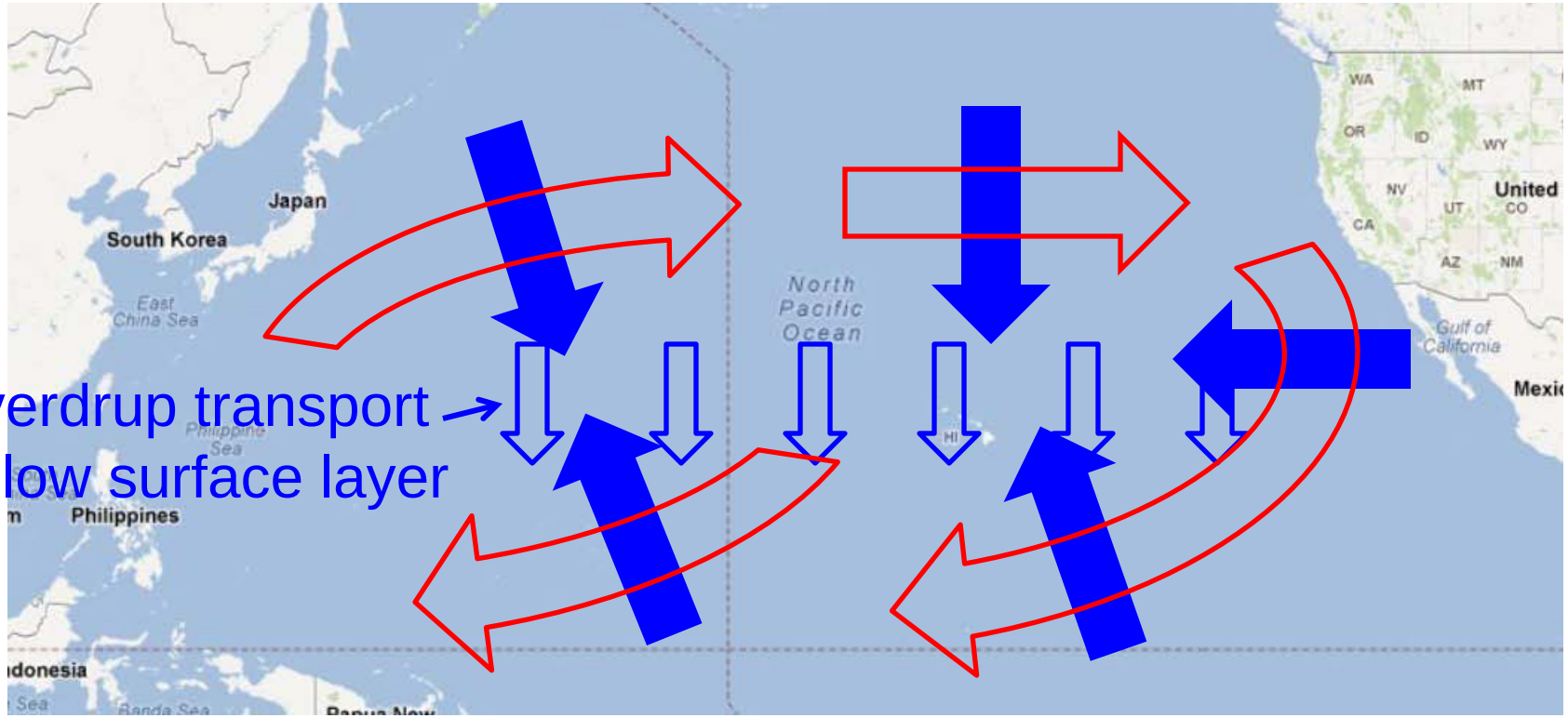
Why is Sverdrup Transport Equatorward?



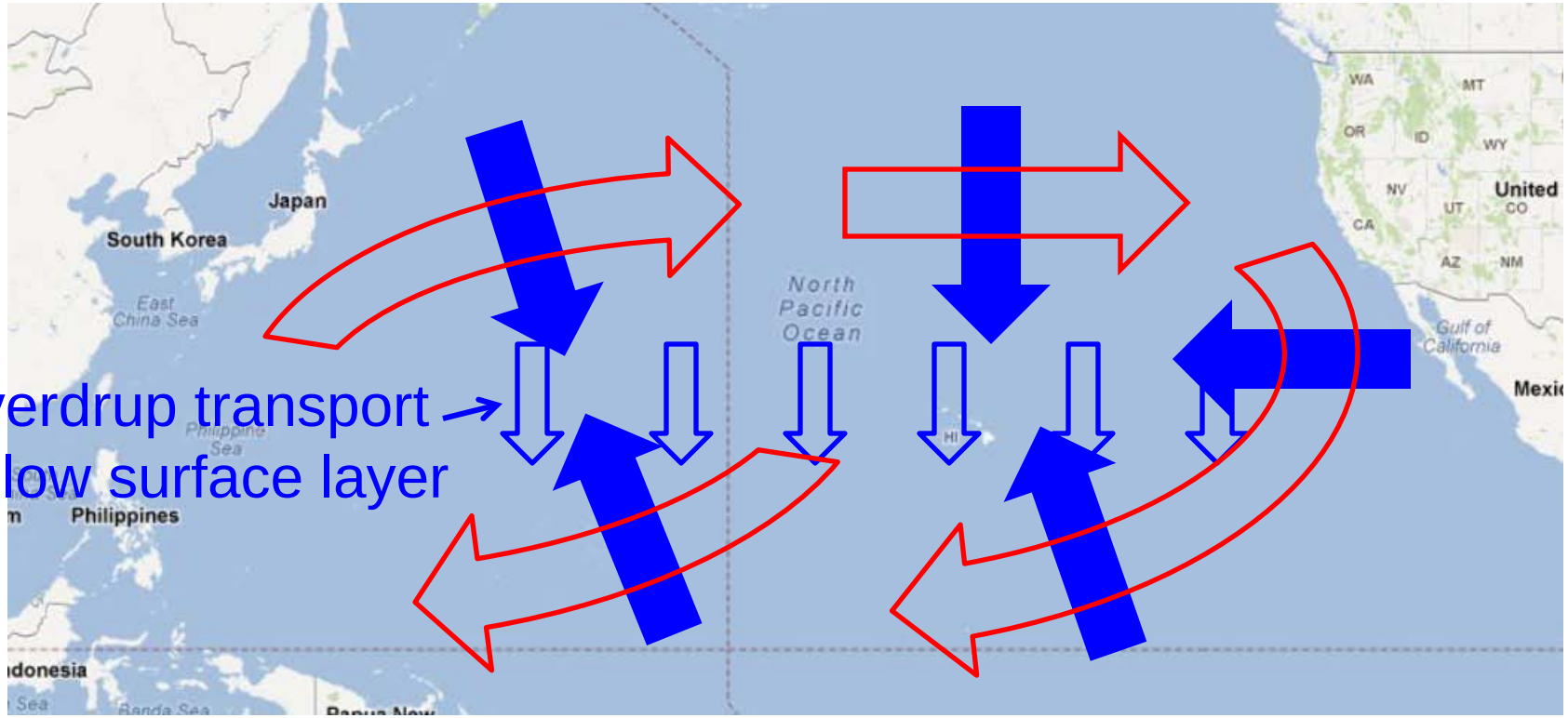
Ekman pumping pushes water into deep ocean

fluid columns can be taller if they move closer to the equator

Deep Ocean Movement



How Does Water Return Poleward?



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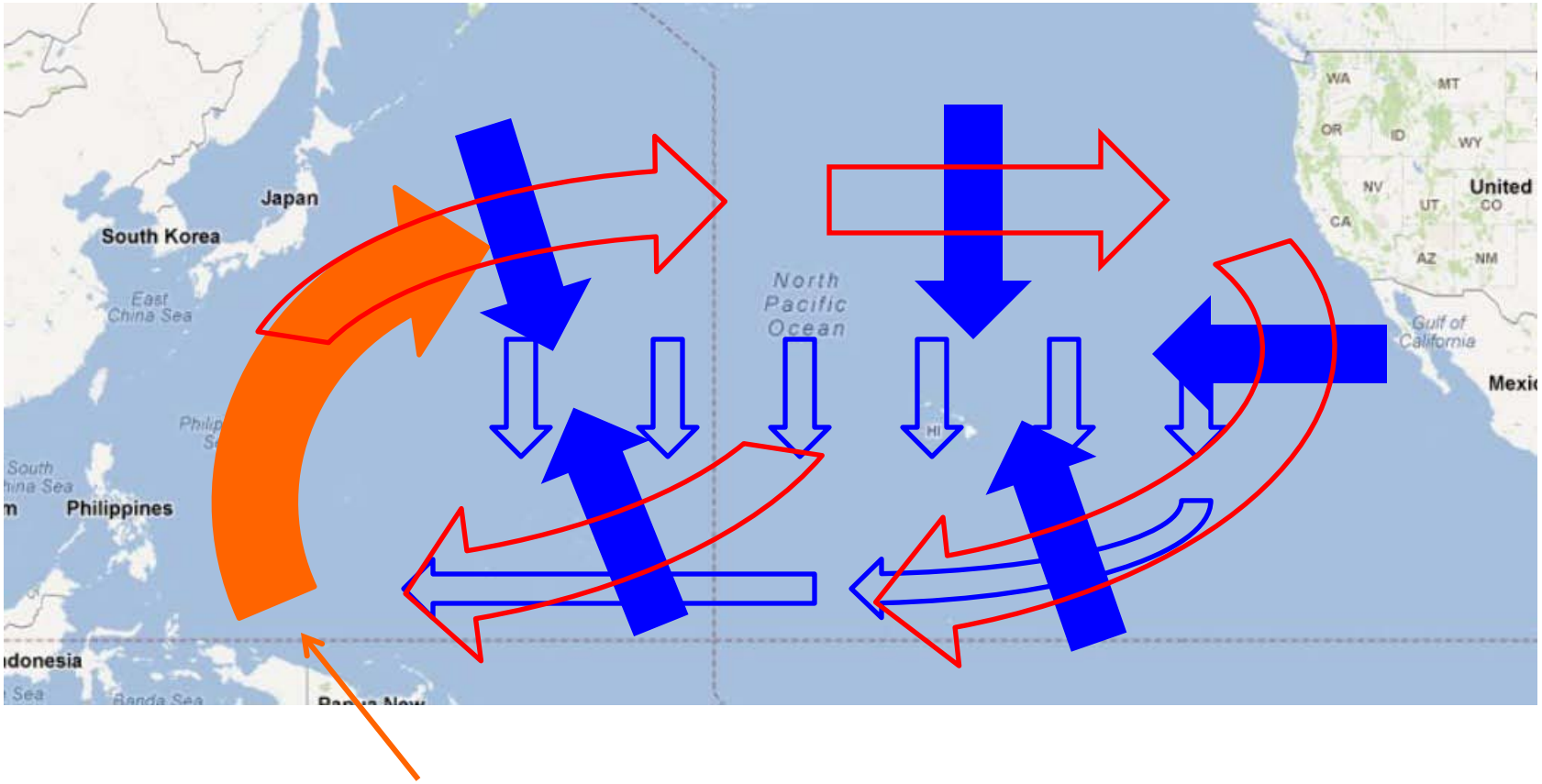

Intense western boundary current

examine rotating table