Introduction to Atmospheric Circulation

Start rotating table

Start heated bottle experiment

Scientific Practice

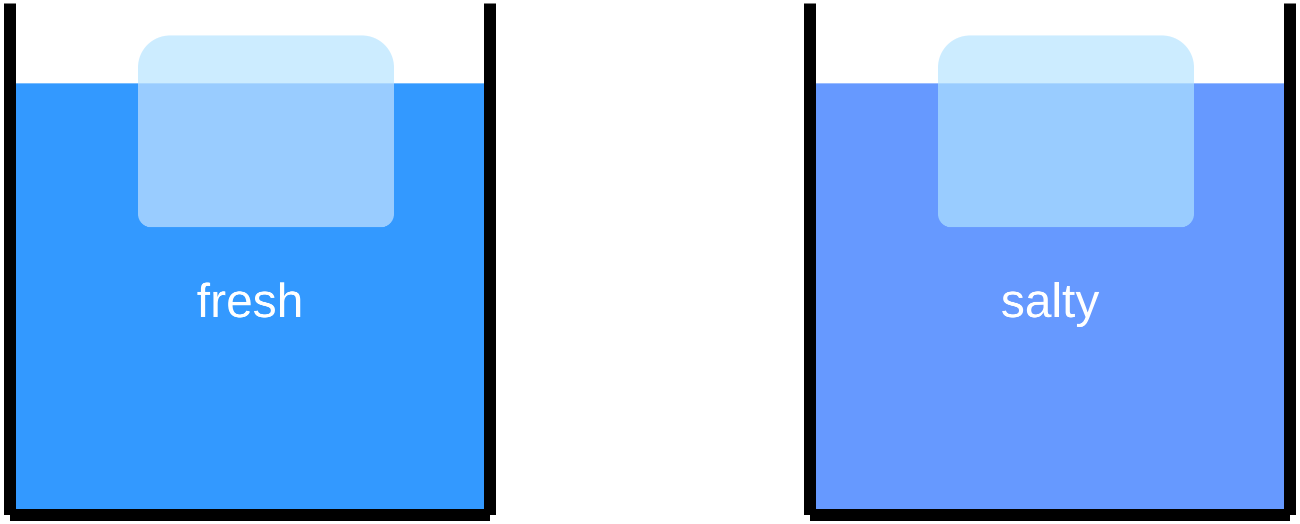
- Observe nature
- Develop a model*/hypothesis for what is happening
- Carry out experiments
- Make more observations
- Do numerical calculations
- Confirm** or refute model/hypothesis

* Models can be physical, conceptual, numerical, computer simulation, etc.

** Hypotheses can never be formally proved to be true

Which Ice Cube Will Melt Faster?

- In fresh water or salty water?
- Why?



Groups develop hypotheses

Start melting ice cube experiment

Motions in Fluids

- What kind of motions occur in fluids?
- What constrains motions in fluids?

Observe fluid motions in tubs

Observe fluid motions in rotating tank

Check melting ice cube experiment

Motions in Fluids

- What kind of motions occur in fluids?

  Groups describe motions in:
  - tubs
  - rotating tank

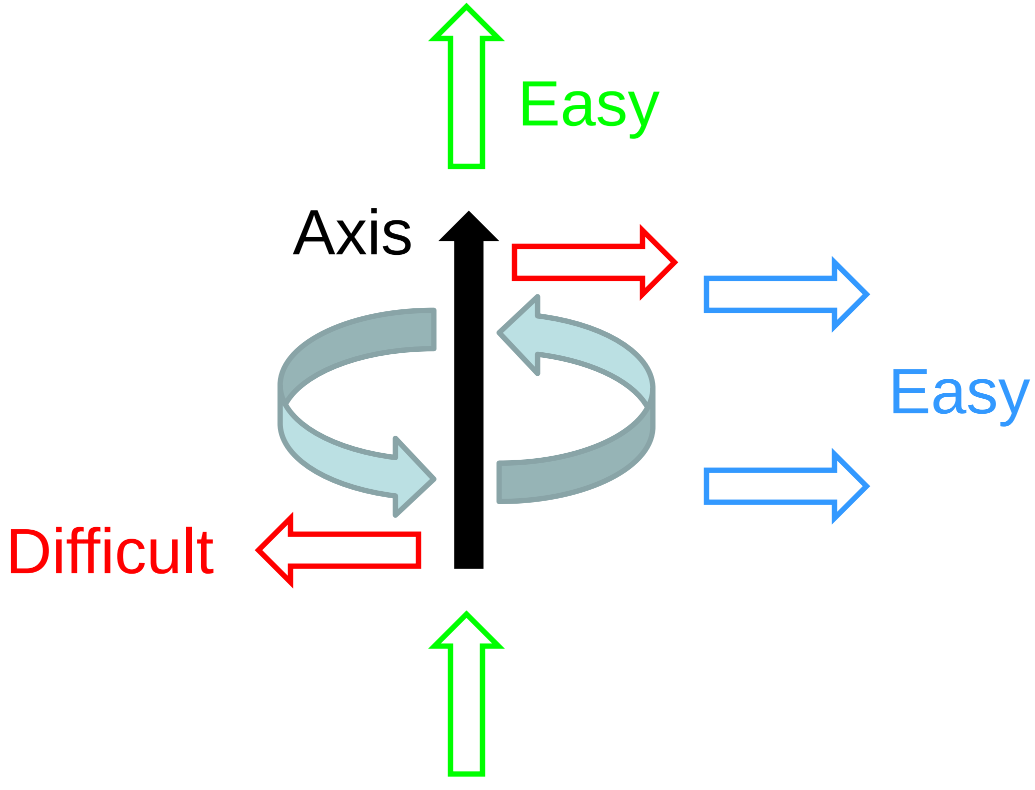
Check melting ice cube experiment

Spinning bicycle wheel experiment

How Does Rotation Affect Motion?

Fluid wants to maintain same angular momentum

→ *keep spinning around axis in same direction*



Angular Momentum

angular momentum $= m\,\Omega\,R^2$

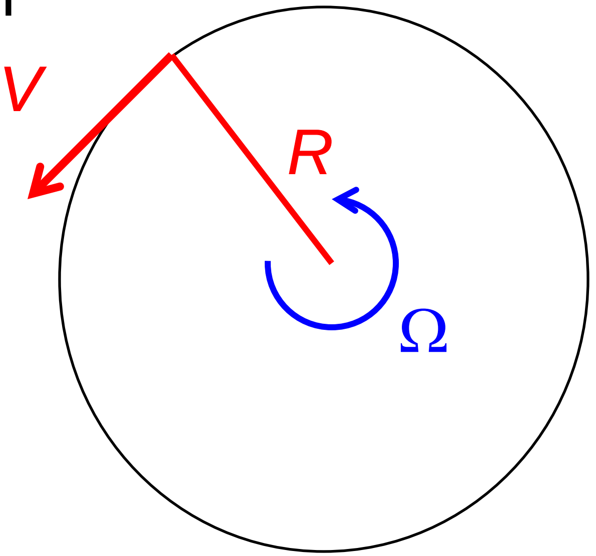
or $= m\,V\,R$

m = mass

Ω = rotation rate (revolutions per time interval)

R = radius from axis of rotation

V = rotational velocity



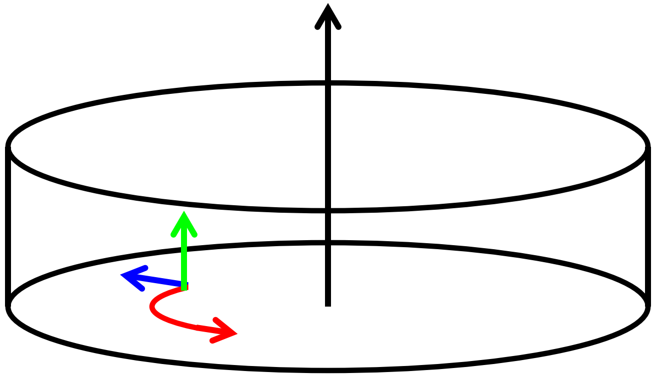
Rotating Tank

current configuration has "solid body" rotation

→ large scale Ω is the same everywhere

Groups answer whether angular momentum is same for

- Radial direction?
- Azimuthal direction (around the circle)?
- Vertical direction?



Momentum Constraint on Fluid Motion

- Easy to move fluid in direction where angular momentum is the same
- Difficult to move fluid in direction where angular momentum is different

- In particular, difficult to move fluid closer to or farther from axis of rotation

Put ice in rotating table

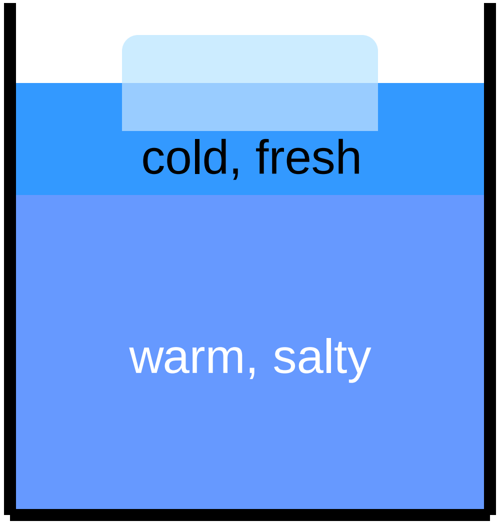
Ice Cube Melted Slower in Salty Water

- Was hypothesis confirmed or refuted?
- Was reason for slower melting correct?

Groups revisit reason for slower melting

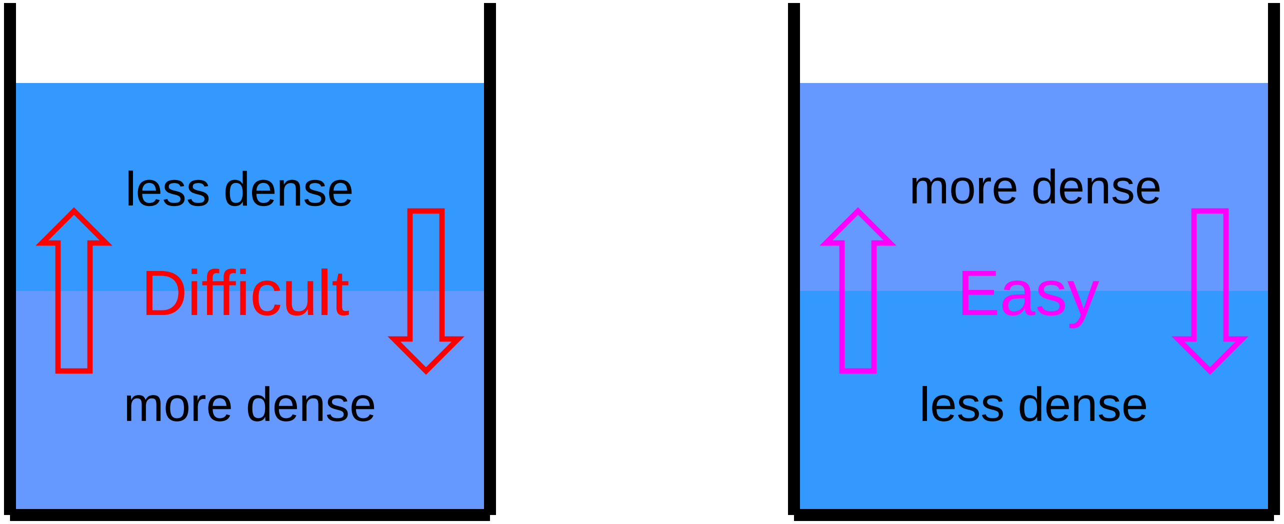
Ice Cube in Salty Water Melts Slower

- Salty water is denser than fresh water
- Melting ice produces layer of cold fresh water on top
- Ice cube isolated from warmer salty water



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



What Increases Density?

<u>Ocean/Lake</u>

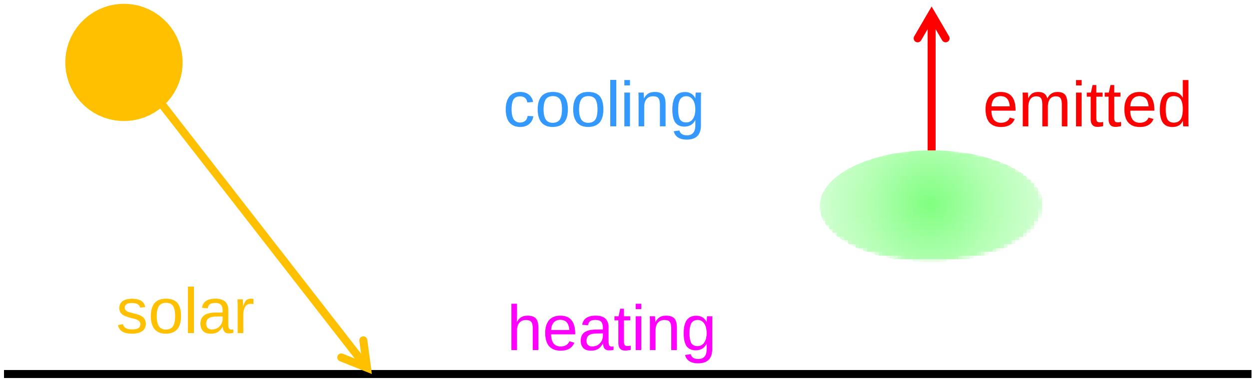
- Colder temperature (except below 4°C)
- More dissolved salt

<u>Atmosphere</u>

- Colder temperature
- More water vapor (H_2O molecule has less mass than N_2 and O_2 molecules)

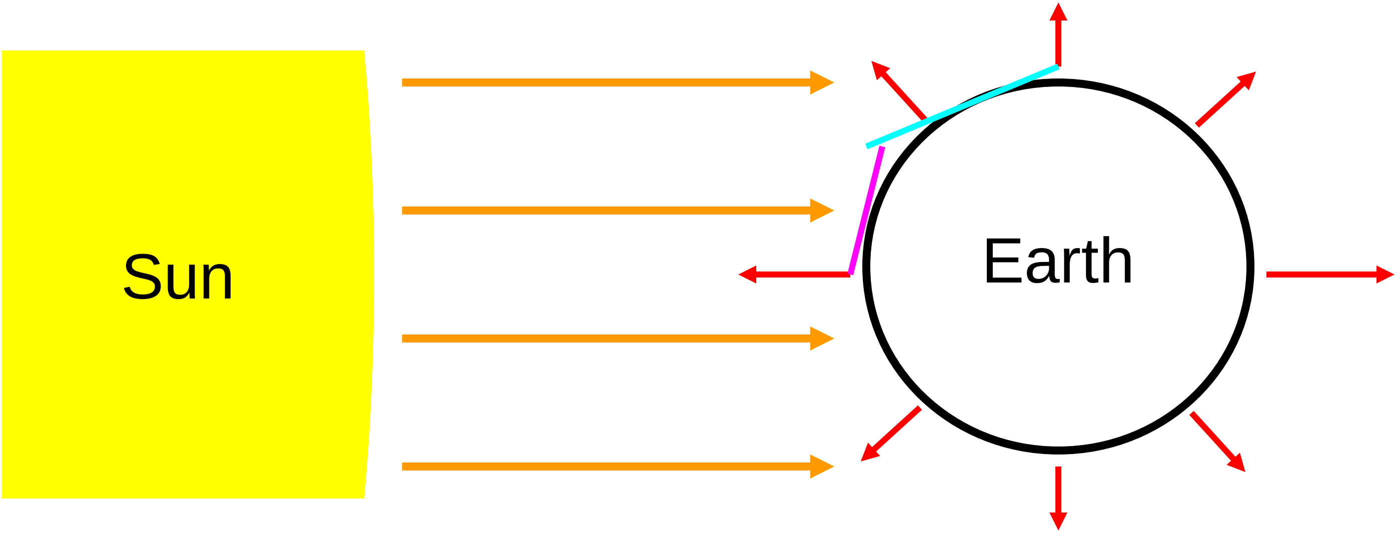
Earth's Energy Budget

- At surface, more solar radiation is absorbed than emitted to atmosphere
- In atmosphere, less solar radiation is absorbed than emitted to space
- *The atmosphere transports energy from the surface to high in the atmosphere where it can be emitted to space*



Earth's Energy Budget

- At low latitudes, more solar radiation is absorbed than emitted back to space
- At high latitudes, less solar radiation is absorbed than emitted back to space
- *The atmosphere and ocean transport energy from low latitudes to high latitudes to maintain energy balance*



Check heated bottle experiment

Set up tubs

Temperature, Density and Pressure

- Warm air and warm water are less dense than cold air and cold water
- Hydrostatic pressure is caused by the weight of overlying air or water

Hydrostatic Equation

$$p = \rho\, g\, h$$

density ρ	1,000 kg m^{-3} (water)	1 kg m^{-3} (air at sea level)
acceleration of gravity g	10 m s^{-2}	
depth of fluid h	4,000 m (ocean)	10,000 m (atmosphere)

Atmospheric pressure at sea level?

units should be N m^{-2}

Pressure at the bottom of the ocean?

Reference: my body weight is about 1000 Newtons (kg m s^{-2})

Hydrostatic Equation

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Atmospheric pressure at sea level? 100,000 N m^{-2}

Pressure at the bottom of the ocean? 40 million N m^{-2}

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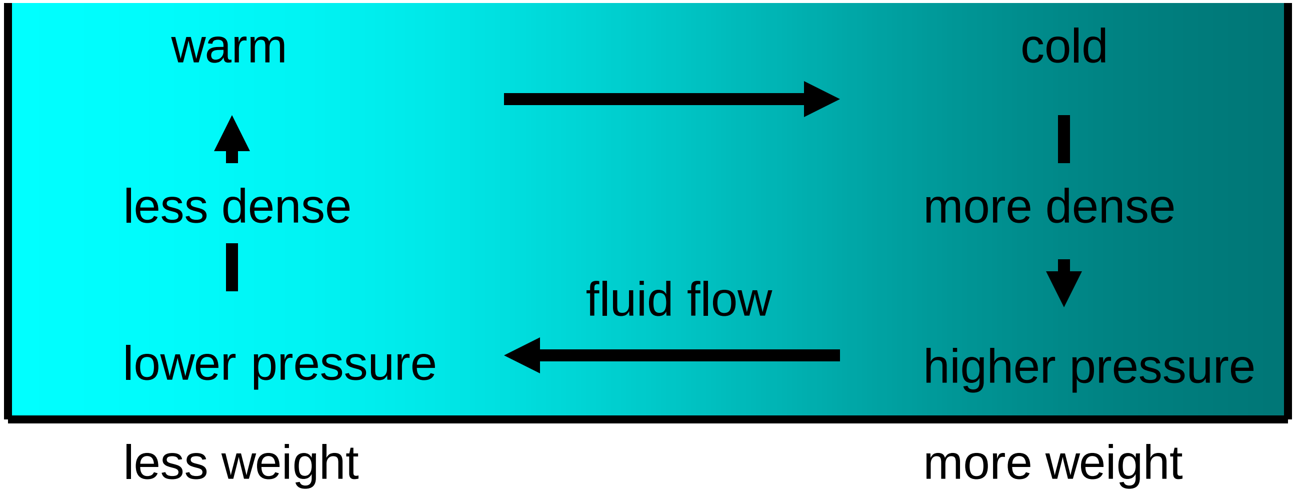
Atmospheric pressure at sea level? 100,000 N m^{-2} (100 Norris m^{-2})

Pressure at the bottom of the ocean? 40 million N m^{-2} (40,000 Norris m^{-2})

Reference: my body weight is about 1000 Newtons (kg m s^{-2})

Temperature, Density and Pressure

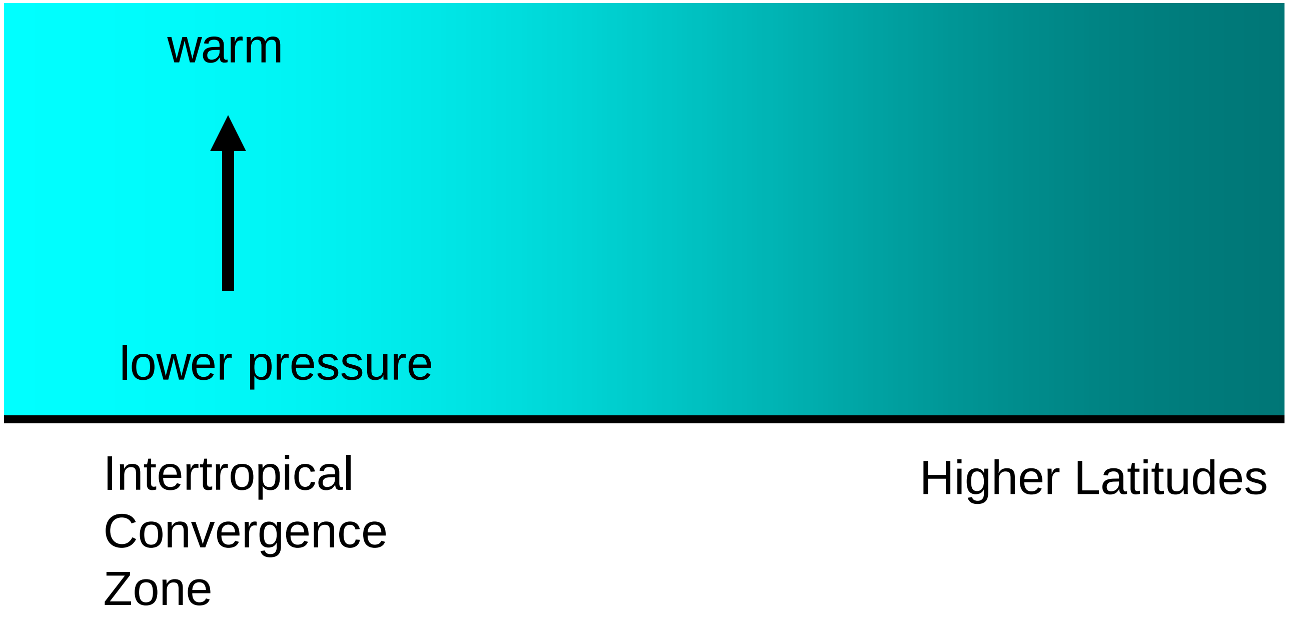
- Warm air and warm water rise, cold air and cold water sink
- Fluid flows from high pressure to low pressure



Tub experiment

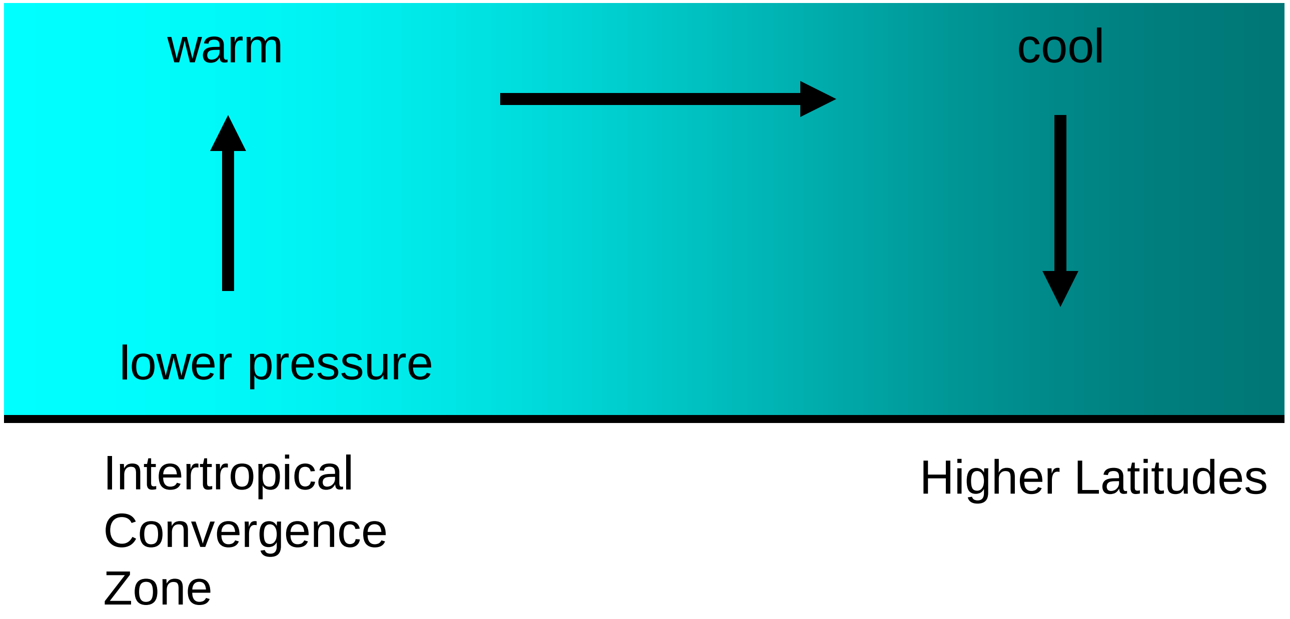
Hadley Circulation

- Sun heats air most strongly near equator
- Warm air rises in Intertropical Convergence Zone
- Warm air is less dense and surface pressure is lower



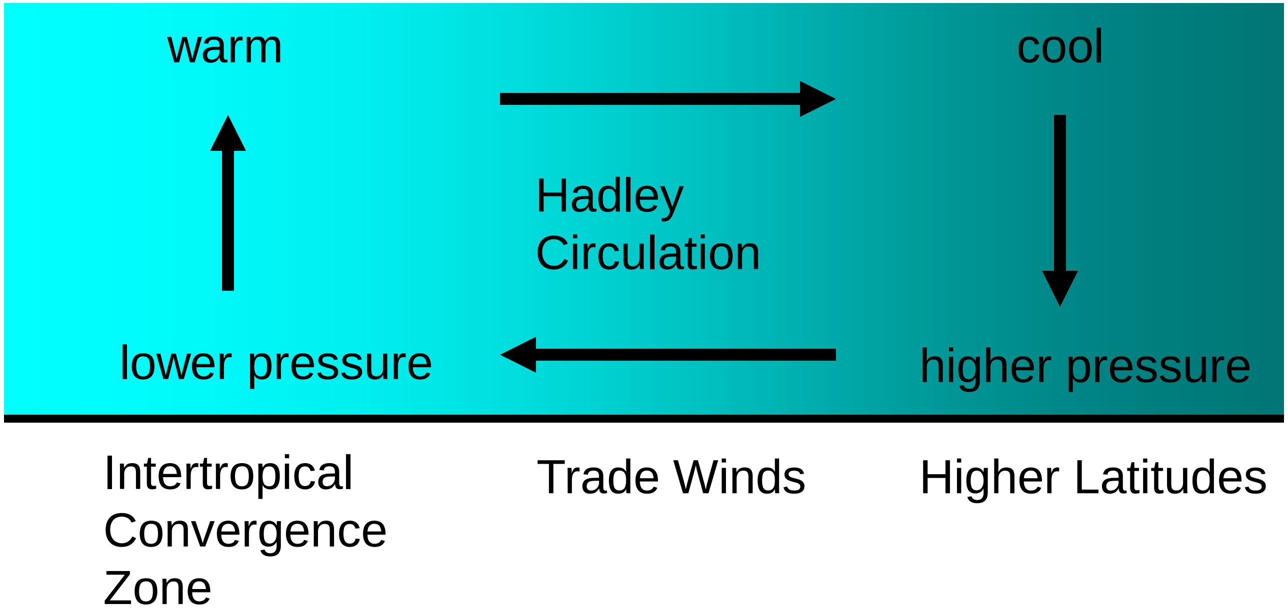
Hadley Circulation

- High above surface, warm air moves poleward
- Air cools by emitting thermal radiation to space
- Cool air sinks



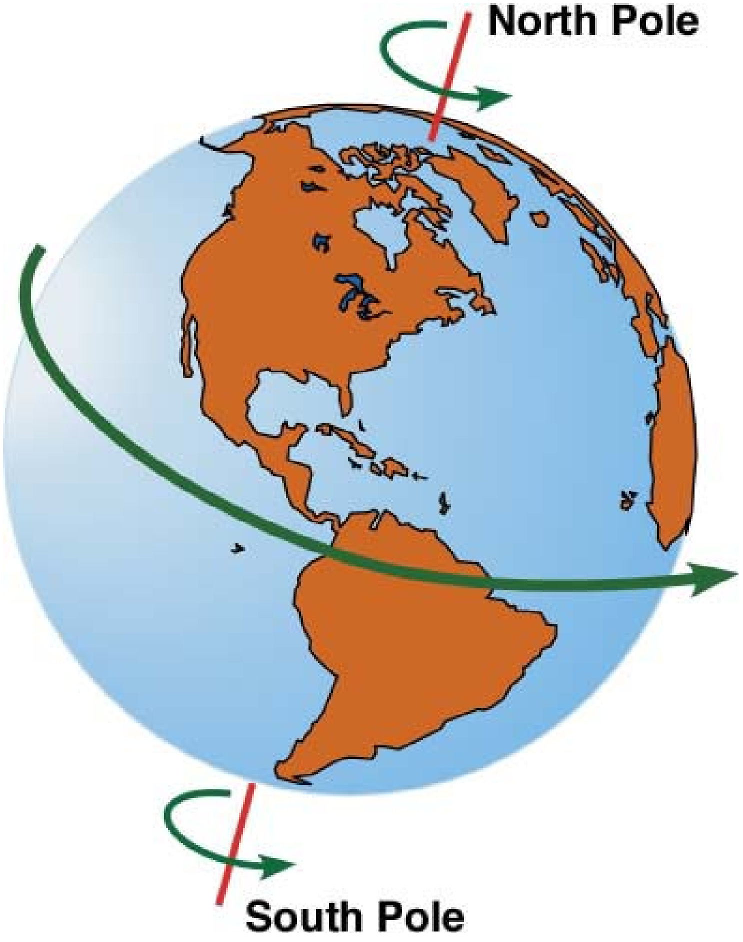
Hadley Circulation

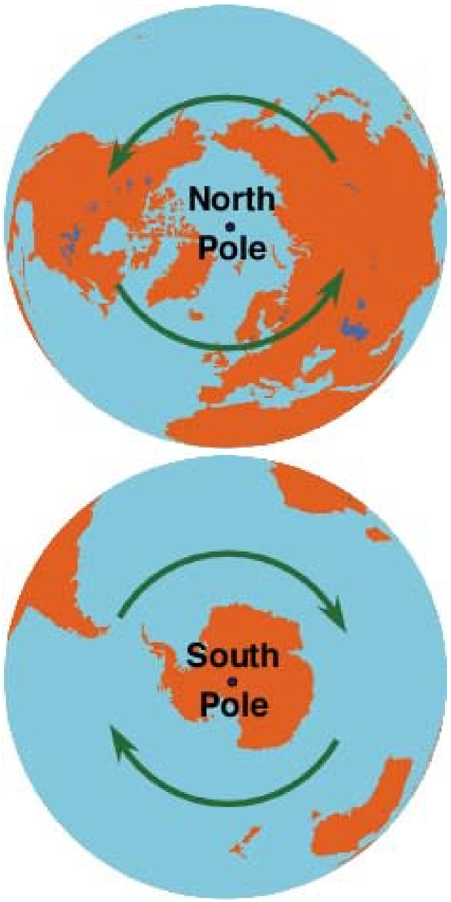
- Cool air is more dense and surface pressure is higher
- Higher pressure pushes air towards lower pressure
- Near surface, cool air moves equatorward in Trade Winds



Check tub experiment

Earth's Rotation





from http://www.physicalgeography.net/fundamentals/6a.html

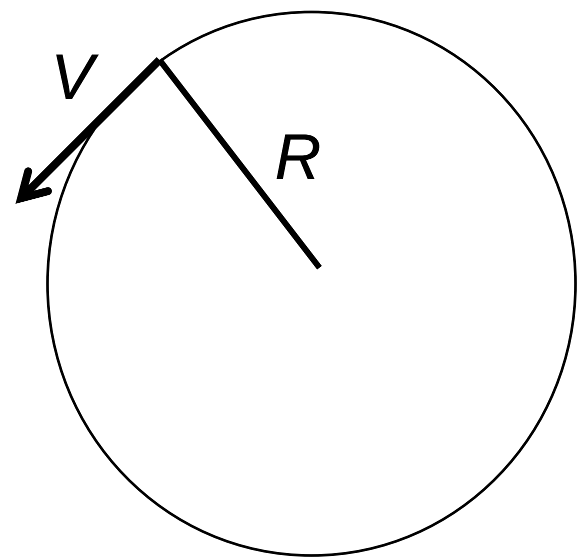
Conservation of Angular Momentum

If no torque (force in direction of rotation),
then angular momentum is conserved

$R_1 V_1 = R_2 V_2$

R = distance from axis of rotation

V = velocity



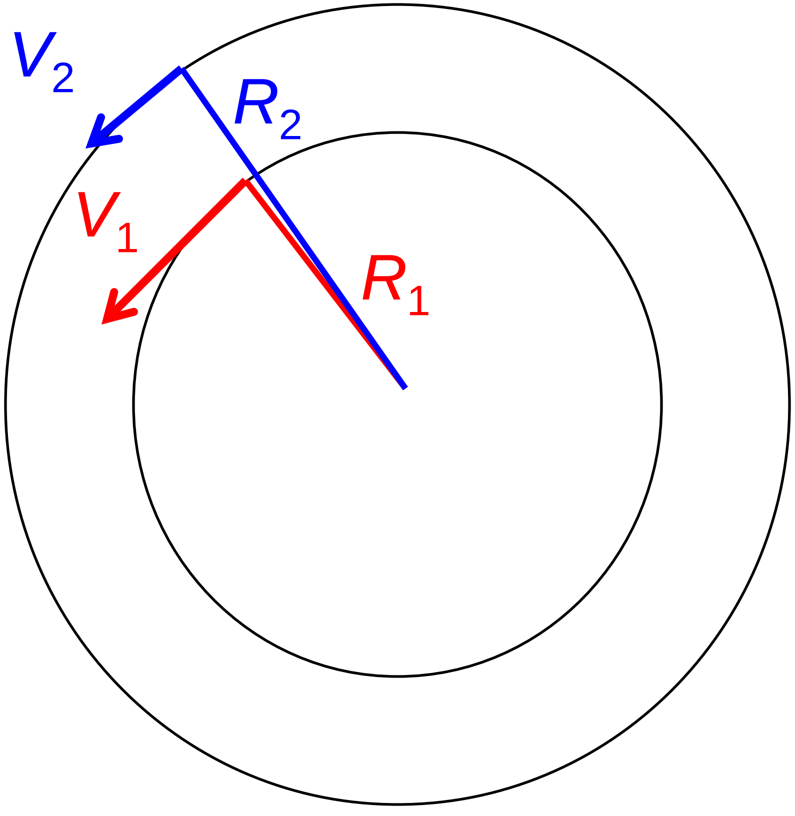
Conservation of Angular Momentum

If no torque (force in direction of rotation),
then angular momentum is conserved

$R_1 V_1 = R_2 V_2$

$R_1 < R_2$

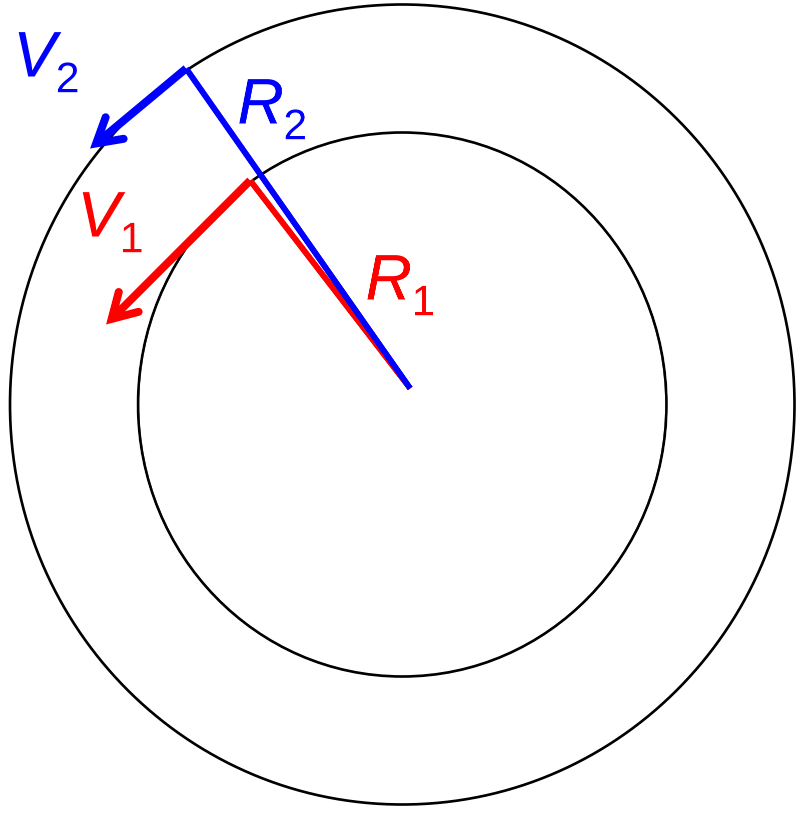
$V_1 > V_2$



Conservation of Angular Momentum

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

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

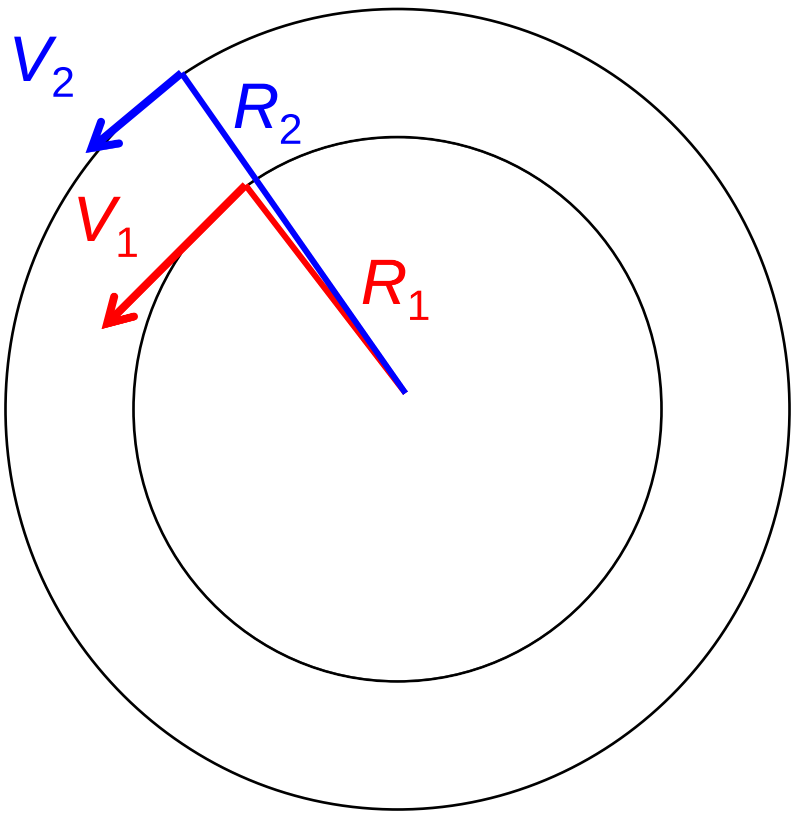


Conservation of Angular Momentum

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

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

Zero.

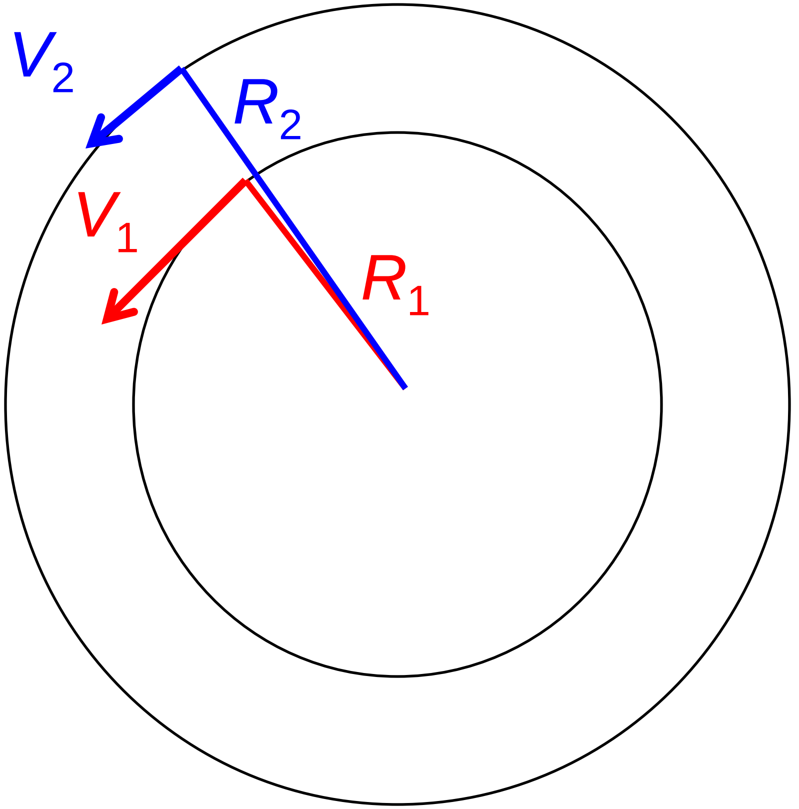


Conservation of Angular Momentum

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

Imagine that this air moves poleward while conserving angular momentum.

Is the air now rotating faster, slower, or the same as Earth?



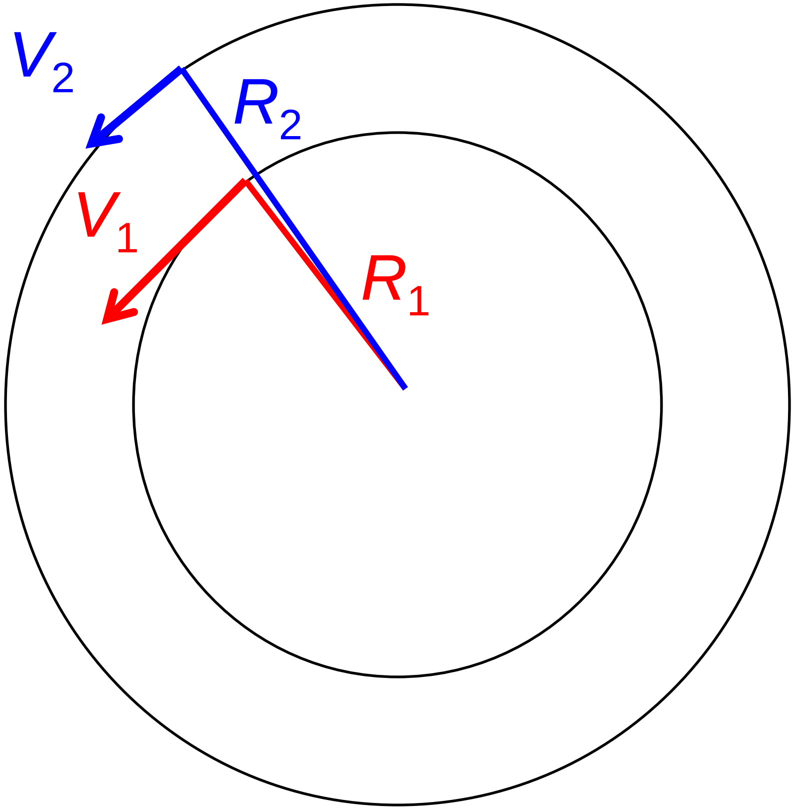
Conservation of Angular Momentum

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

Imagine that this air moves poleward while conserving angular momentum.

Is the air now rotating faster, slower, or the same as Earth?

Faster.



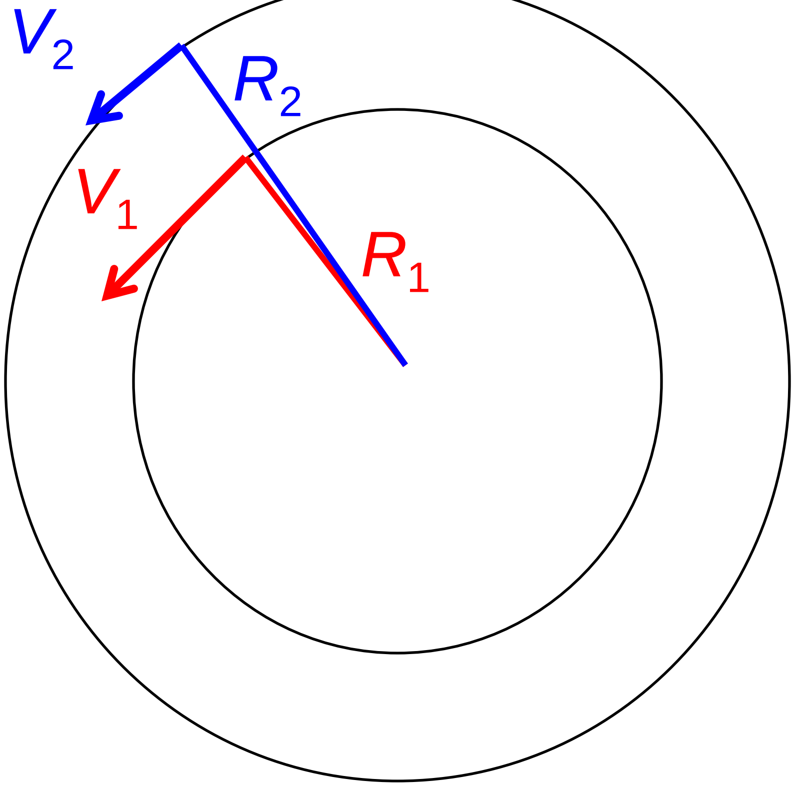
Conservation of Angular Momentum

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

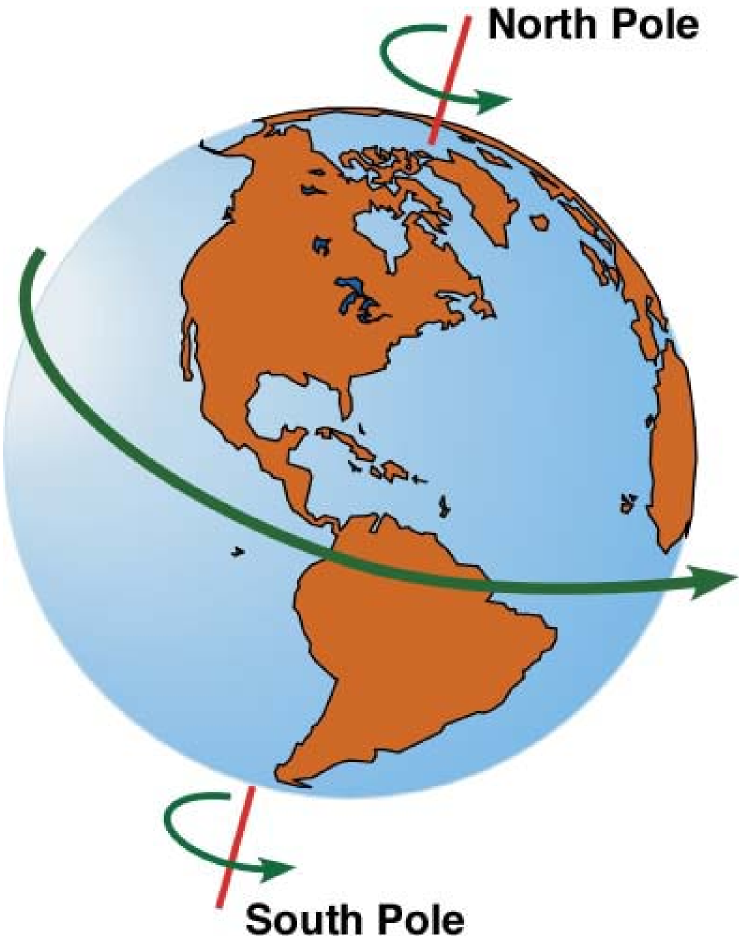
Imagine that this air moves poleward while conserving angular momentum.

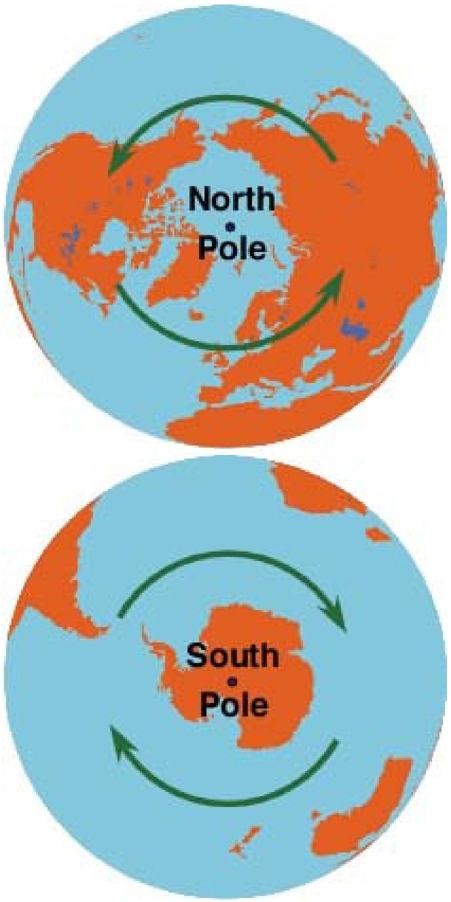
What is the direction of the wind relative to the Earth?

(from the west or from the east?)



Earth’s Rotation





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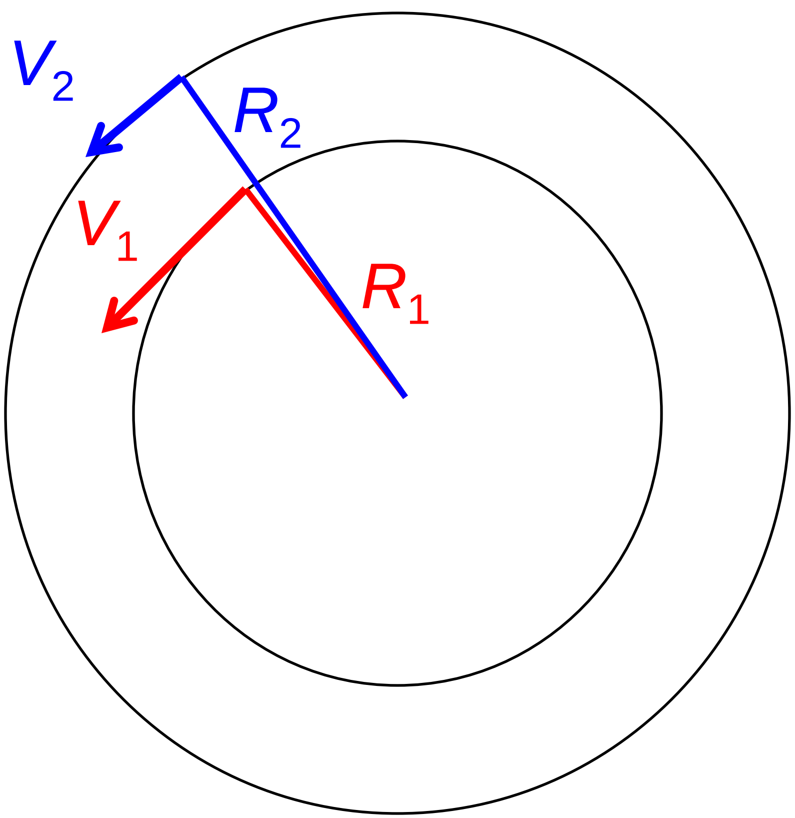
Conservation of Angular Momentum

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

Imagine that this air moves poleward while conserving angular momentum.

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

From the west (westerly).

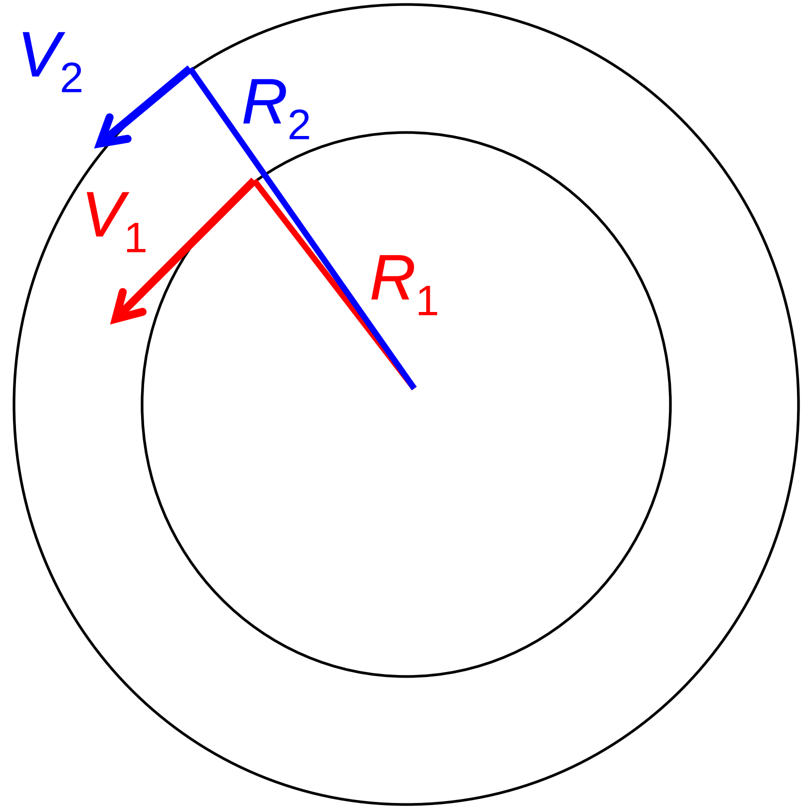


Conservation of Angular Momentum

Imagine that air at 30°N is rotating at the same rate as the Earth.

Imagine that this air moves equatorward while conserving angular momentum.

Is the air now rotating faster, slower, or the same as Earth?



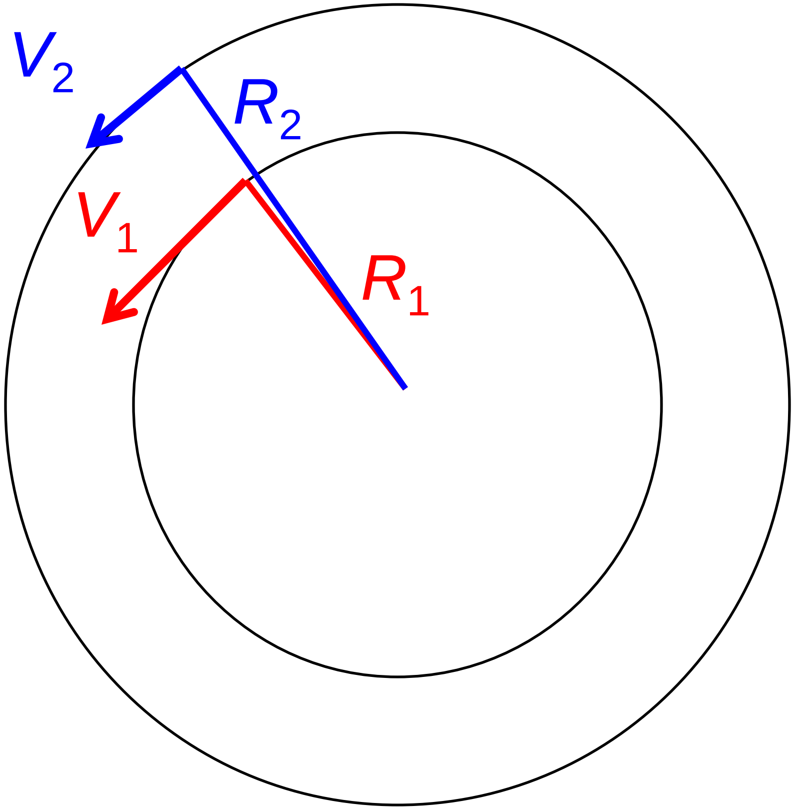
Conservation of Angular Momentum

Imagine that air at 30°N is rotating at the same rate as the Earth.

Imagine that this air moves equatorward while conserving angular momentum.

Is the air now rotating faster, slower, or the same as Earth?

Slower.



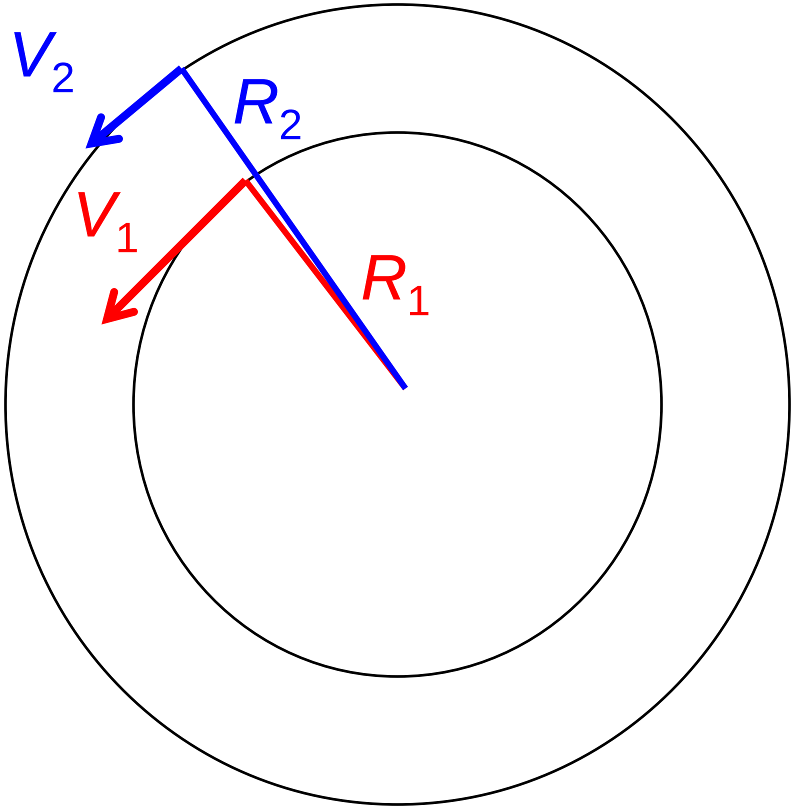
Conservation of Angular Momentum

Imagine that air at 30°N is rotating at the same rate as the Earth.

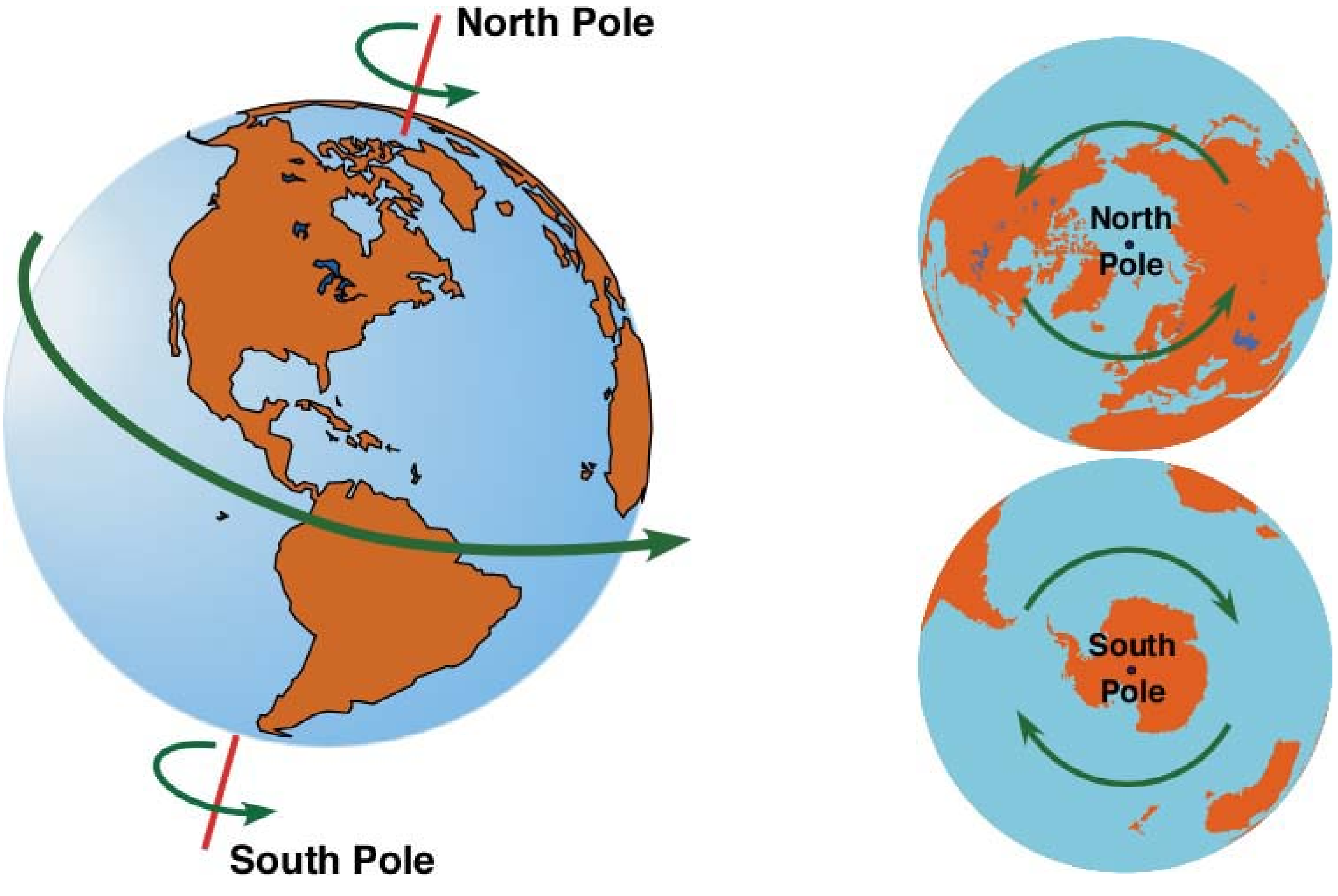
Imagine that this air moves equatorward while conserving angular momentum.

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

(from the west or from the east?)



Earth's Rotation



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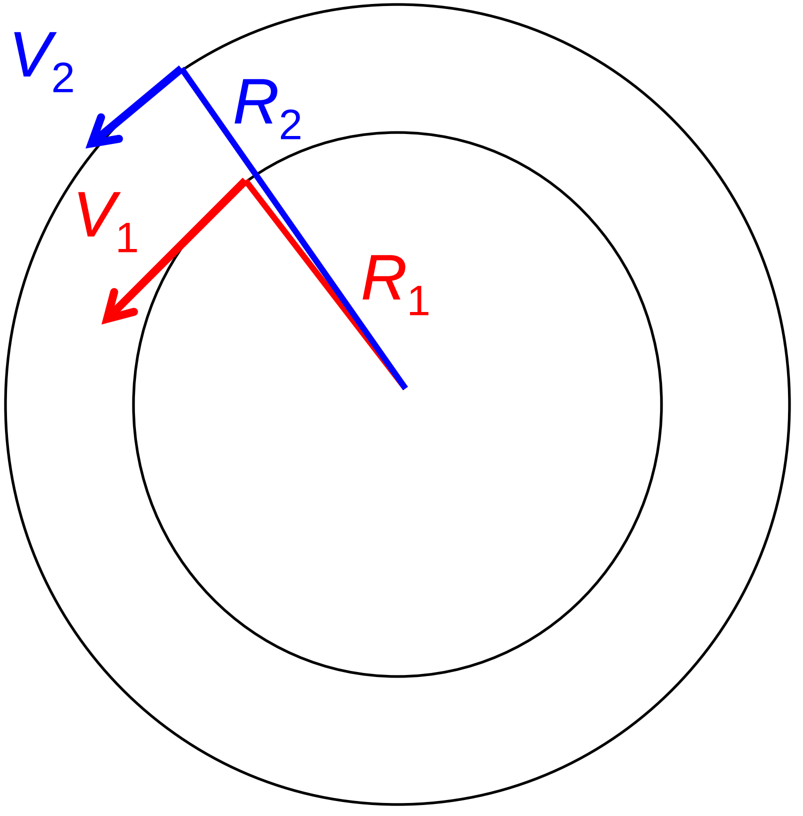
Conservation of Angular Momentum

Imagine that air at 30°N is rotating at the same rate as the Earth.

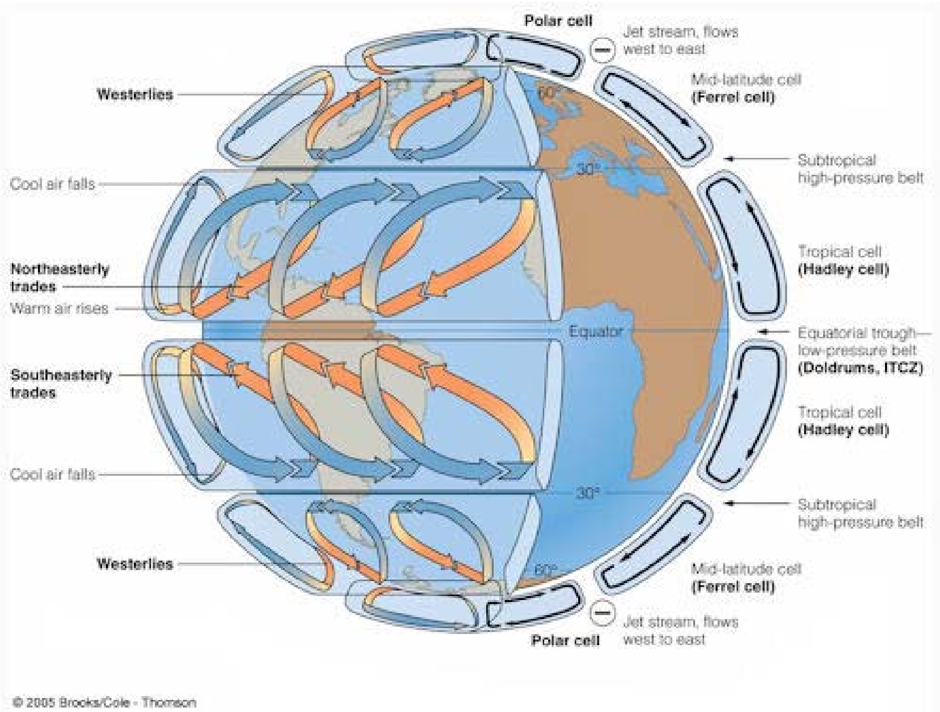
Imagine that this air moves equatorward while conserving angular momentum.

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

From the east (easterly).



Hadley Circulation and Trade Winds



Examine rotating table