Class 3: Fundamentals of atmospheric circulation

- How does moving air distribute energy?
- How has atmospheric circulation shaped the climate on Earth today?

Learning Objectives

1. Explain why air moves in predictable patterns across the globe
2. Explain how atmospheric circulation results in the observed global distribution of climates
3. Identify dry or wet regions on Earth based on the characteristics of air movement and pressure in those areas

Quiz Time!

Climate in the news

HURRICANE DORIAN

LATEST NEWS

With Hurricane Dorian threatening Florida, get unlimited access to the Miami Herald

AUGUST 29, 2019 04:40 PM

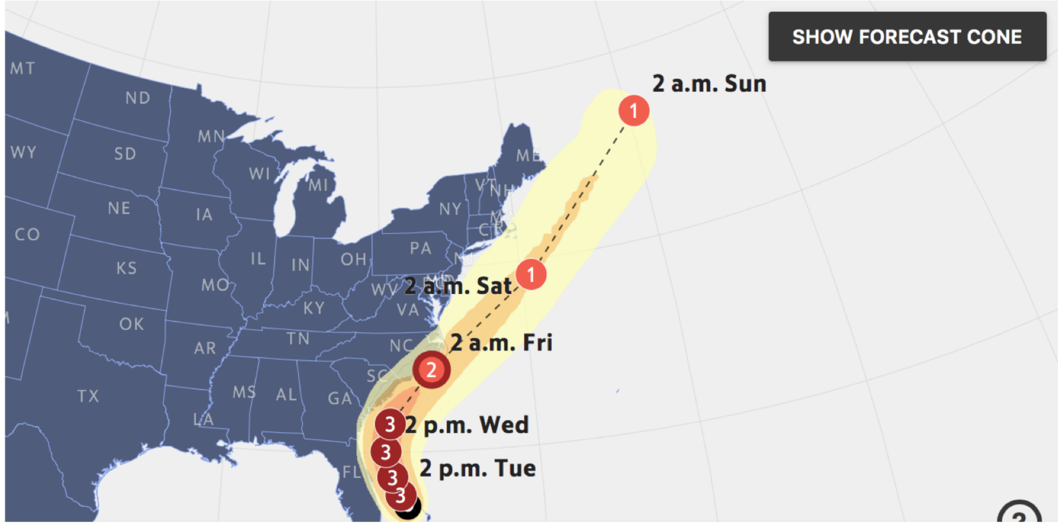
The Bahamas needs help following Hurricane Dorian. Here's how you can donate

SEPTEMBER 02, 2019 04:09 PM

Fort Lauderdale airport expected to reopen after noon on Tuesday

SEPTEMBER 02, 2019 07:26 AM

Stationary Hurricane Dorian hangs over Bahamas as a Cat 3, but could be on move soon



Hurricane Dorian

Last updated: 5 a.m. Tuesday, Sep 3

Sustained winds: 121 mph **Movement:** N at 0 mph

Five-day chance of hurricane-force winds:

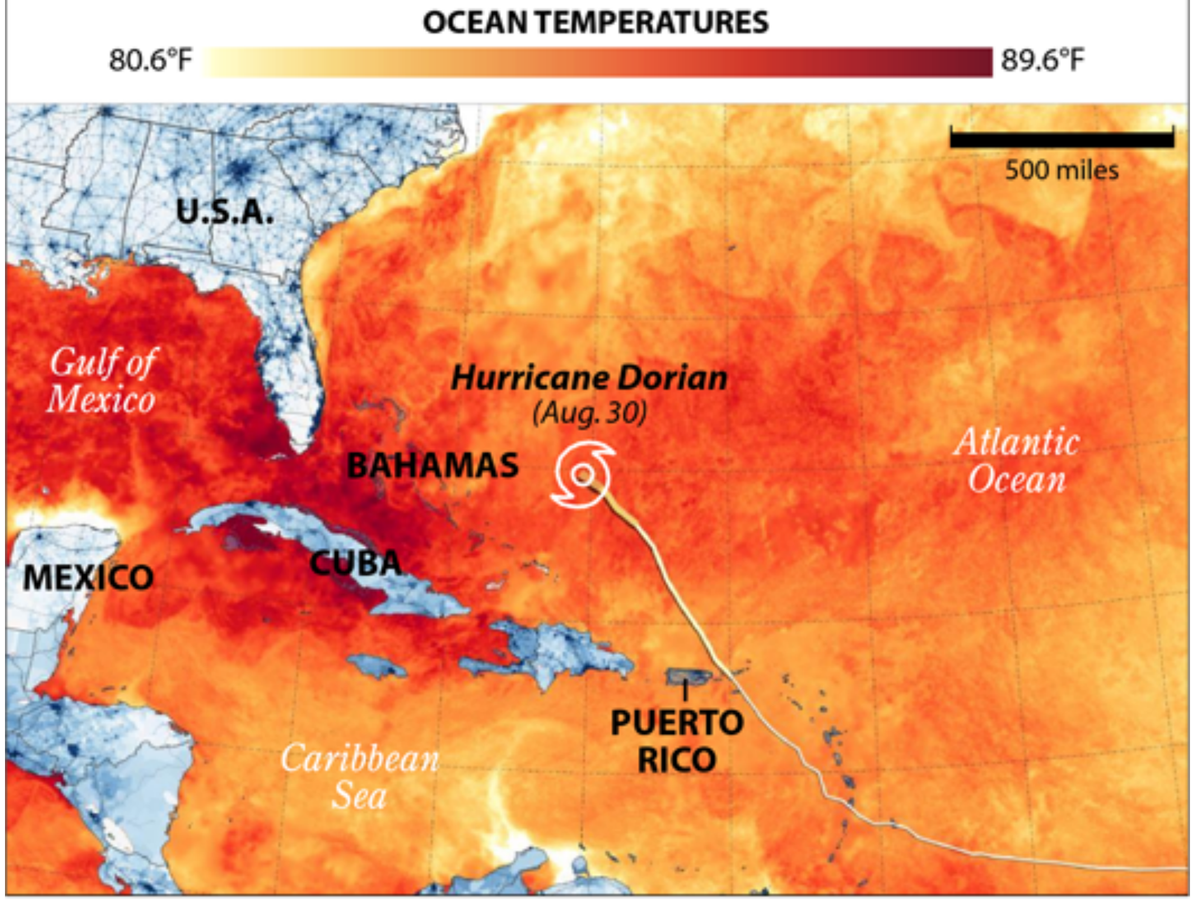
5% 20% 50% 70% >80%

Storm categories:

- S Tropical Storm (39-73 mph)
- 1 74-95 mph
- 2 96-110 mph
- 3 111-129 mph
- 4 130-156 mph
- 5 > 157 mph

Warmer Water, Stronger Hurricanes

Hurricanes intensify over warmer water, generally when sea surface temperatures are above 82°F (27.8°C). When Dorian reached the Bahamas on Sept. 1, it had grown into one of the most intense Category 5 hurricanes to make landfall.



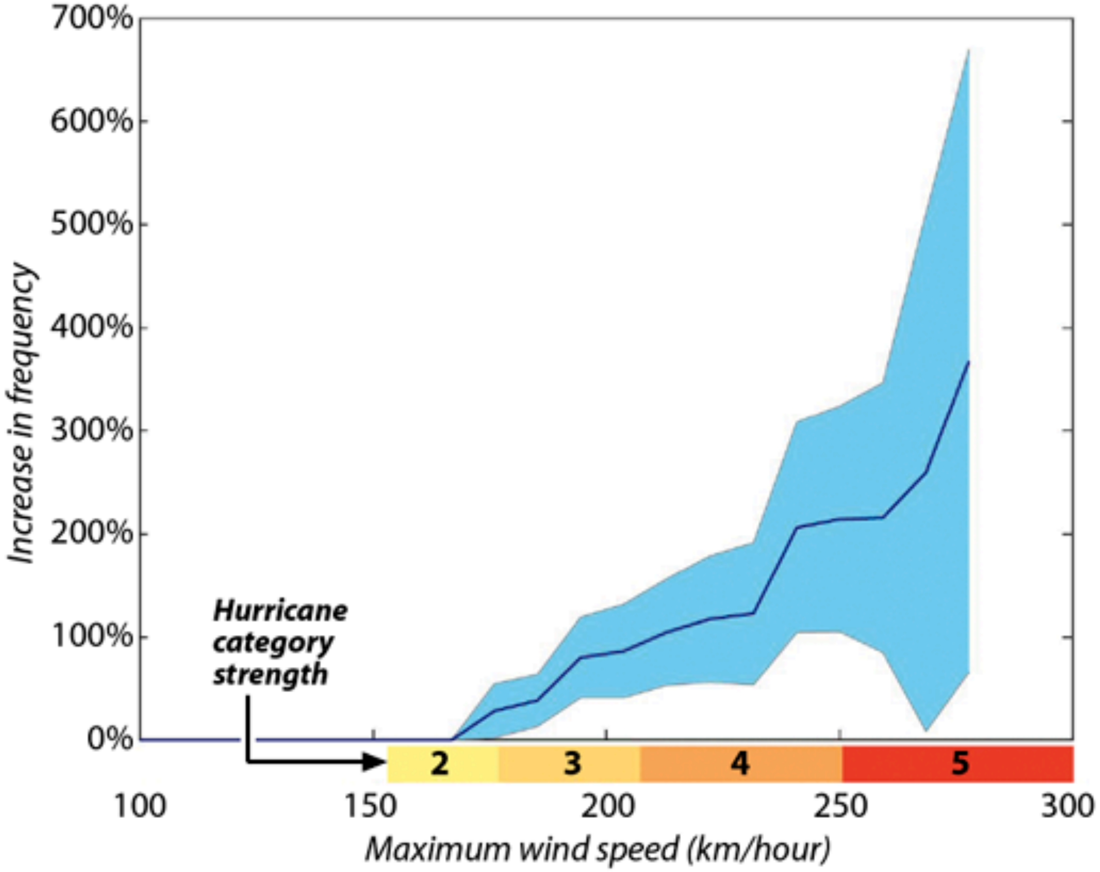
SOURCE: Joshua Stevens and Lauren Dauphin/NASA InsideClimate News

Monster Storms Are Growing More Common

The frequency of the most intense tropical storms worldwide has increased since 1980. Those with wind speeds over 250 kilometers per hour (about 155 mph) have more than tripled.

TROPICAL STORM STRENGTH AND FREQUENCY

Linear trends, 1980-2016



SOURCE: Kerry Emanuel, MIT InsideClimate News

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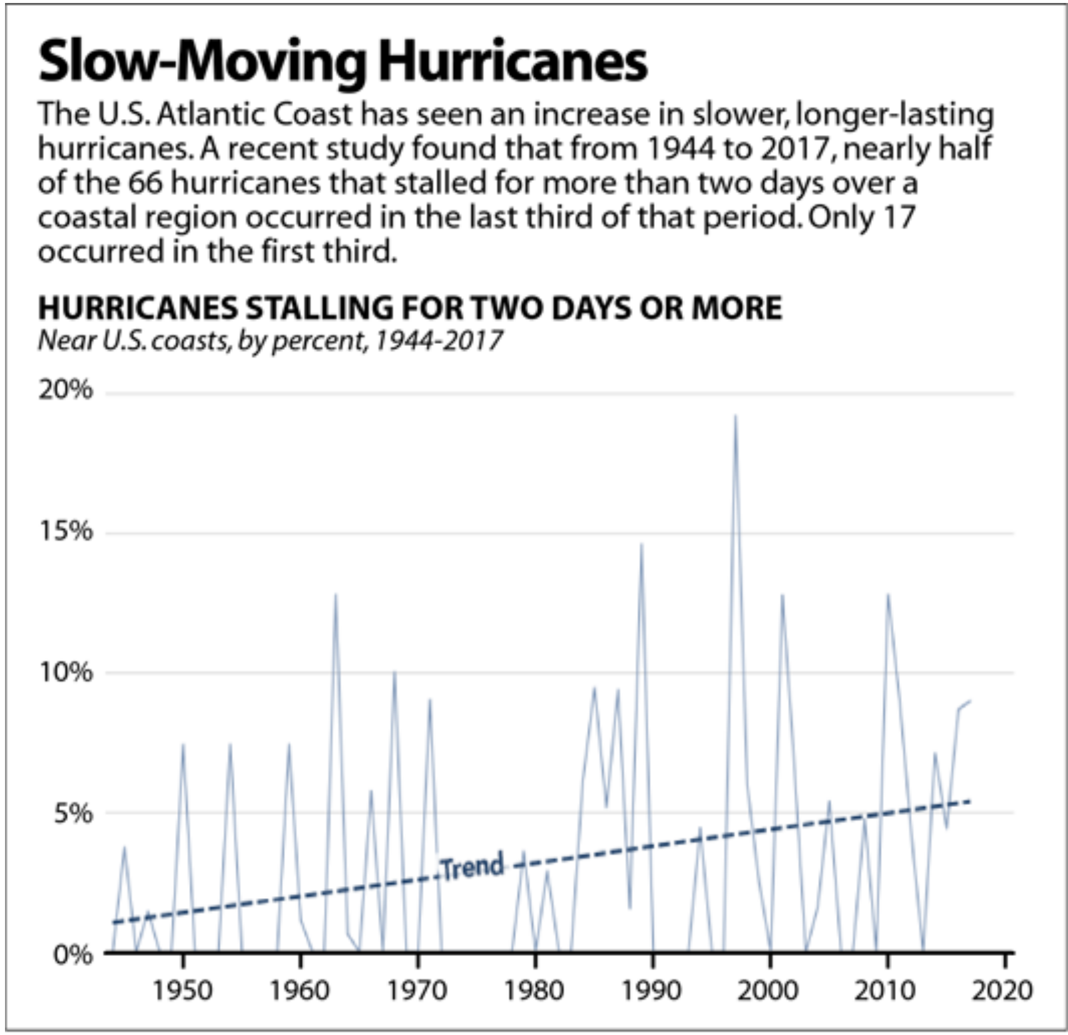
Why Are Hurricanes Like Dorian Stalling, and Is Global Warming Involved?

Penn State University climate scientist Michael Mann said that while there are uncertainties about what causes hurricanes to stall, some trends are becoming more clear.

"We are definitely seeing a trend toward stalling of these systems after they make landfall, and there may be a climate change connection, though this is really at the leading edge of the science and is still being debated," Mann said.

Climate models can't precisely identify the atmospheric changes that cause stalling, he said, "so it is possible that those same models are not capturing how climate change in influencing this particular aspect of hurricane behavior."



SOURCE: Tim Hall/NASA and Jim Kossin/NOAA InsideClimate News

https://insideclimatenews.org/news/03092019/hurricane-dorian-climate-change-stall-record-wind-speed-rainfall-intensity-global-warming-bahamas

Review of Last Week

Big Picture:

- The climate that any given area is controlled by many factors

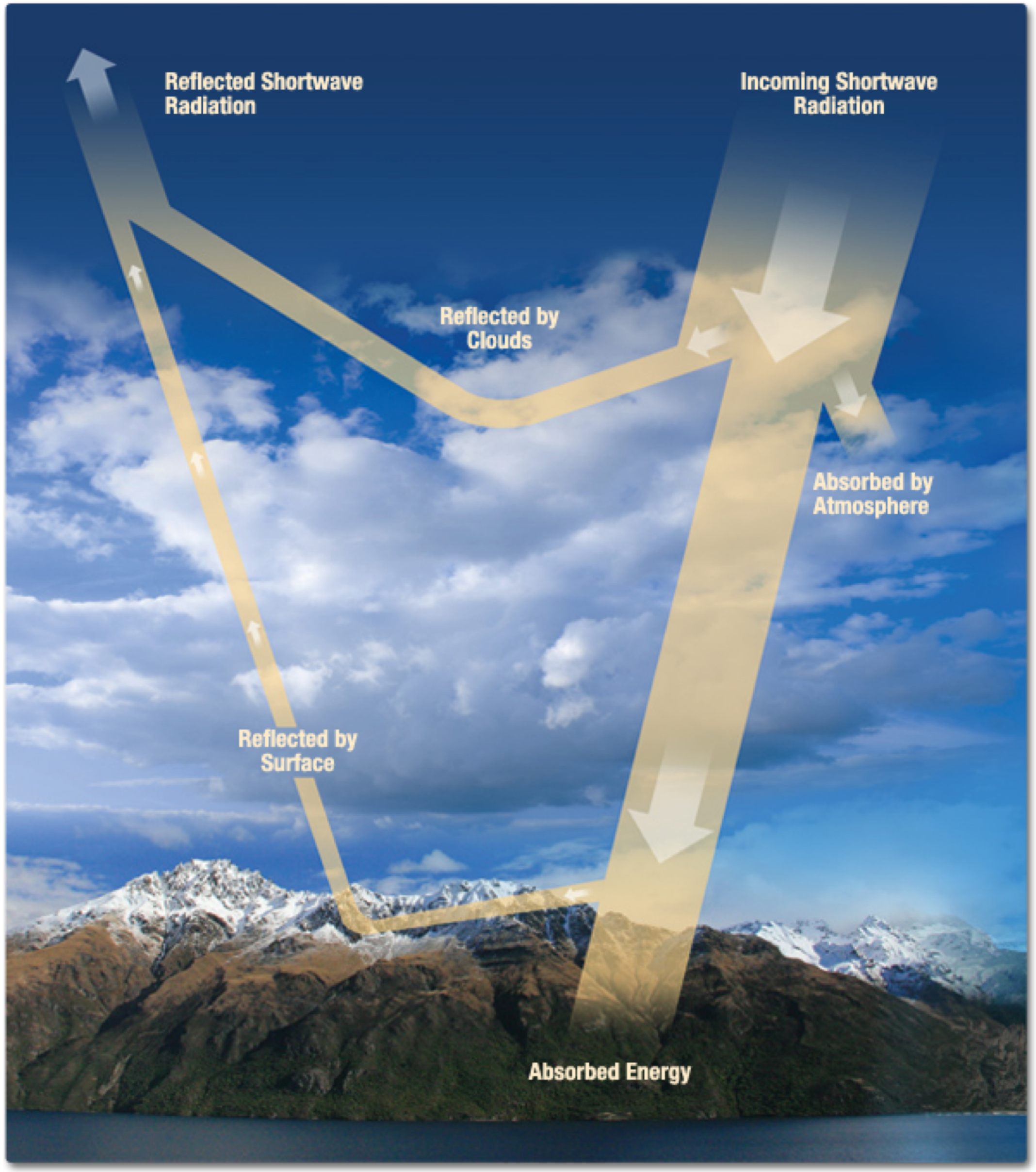
- The Earth as a whole has an average temperature that is the product of only a few variables

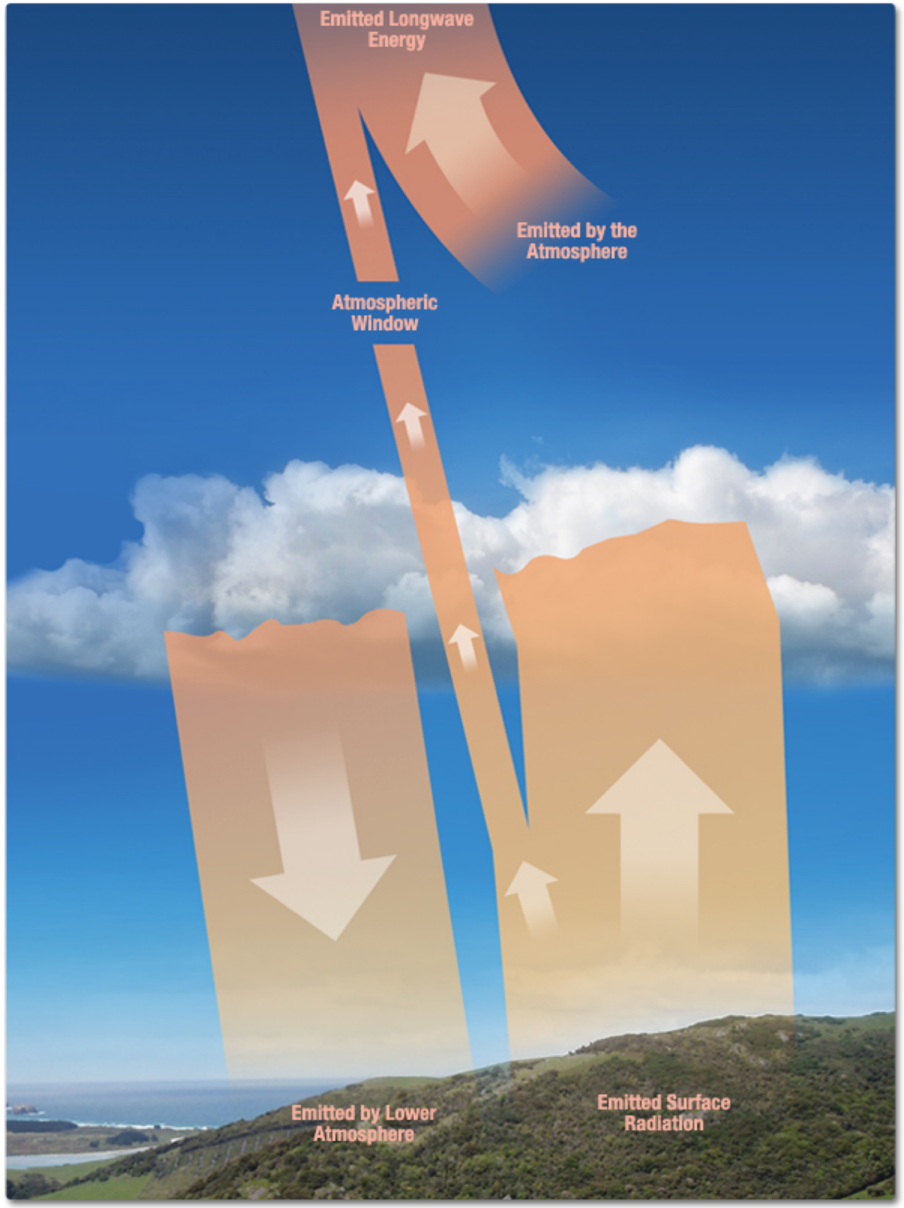
Review of Last Week

Big Picture:

- Earth has a *global* average temperature of ~15°C (59°F)
- Ignoring greenhouse effect, radiation balance of Earth suggests global average temp of ~-18°C (0°F)
- The greenhouse effect traps ~33°C (59°F) of outgoing energy

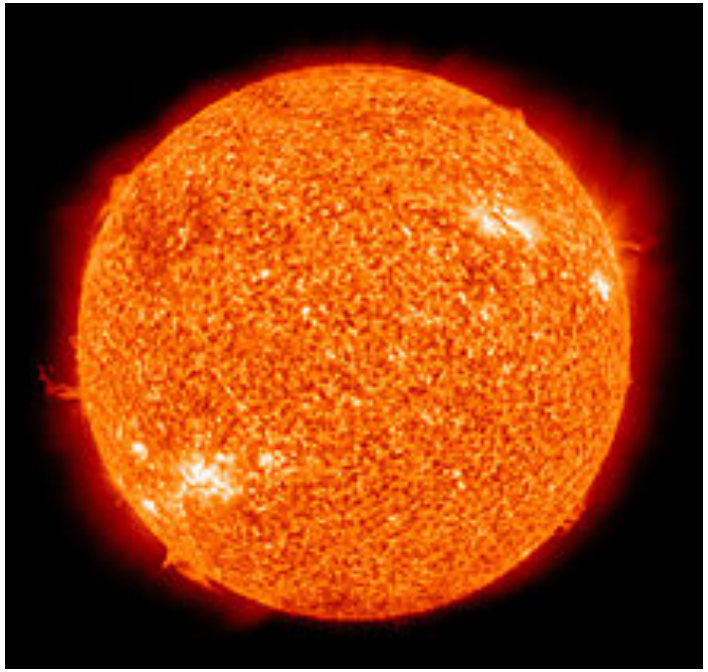
Review of Last Week





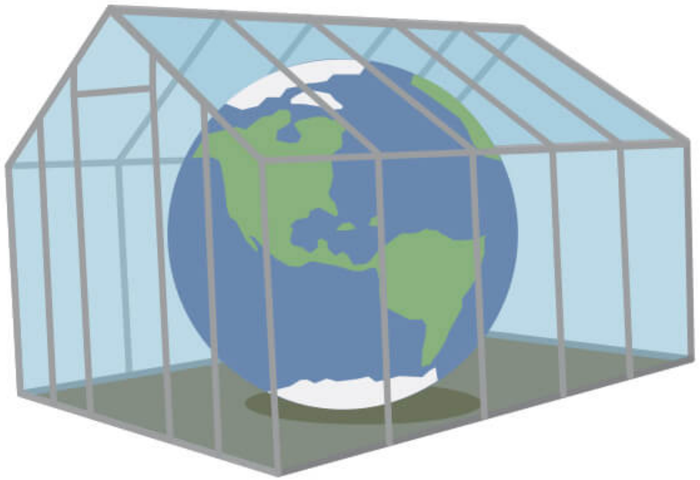
Review of Last Week – Global Temperature 'Knobs'

Solar Output



Albedo

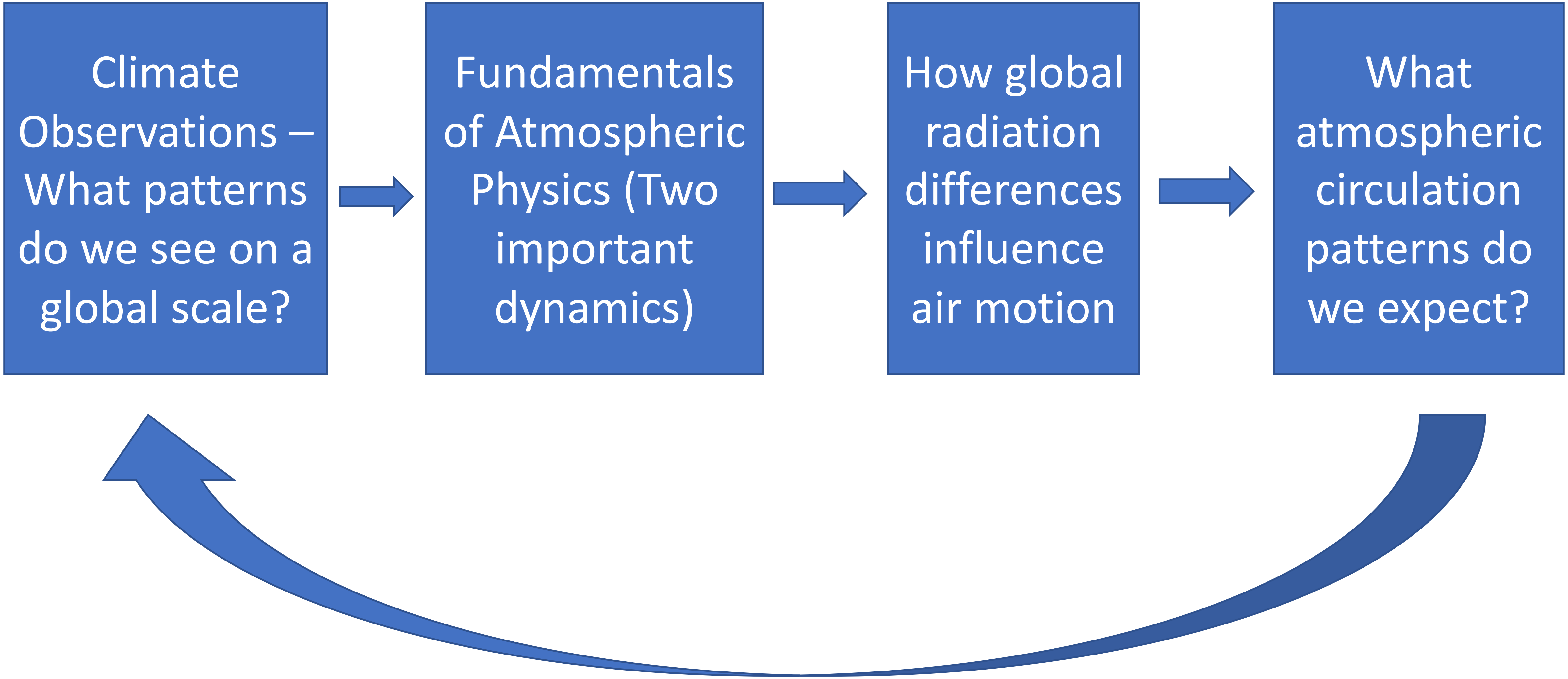
Greenhouse Effect



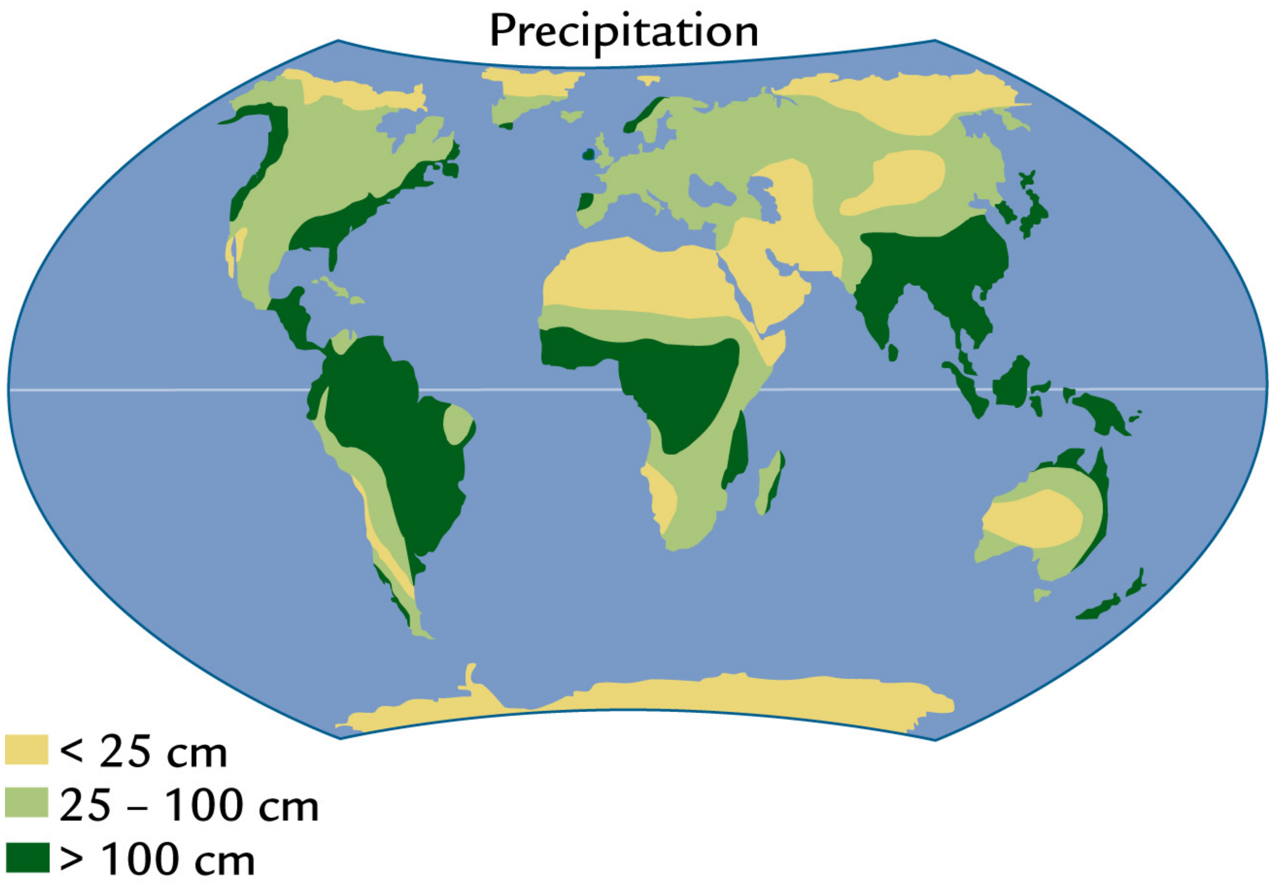
It's all about perspective

- Global average temperature does not explain regional differences in climate
  - Why are desert regions located where they are? Rainforests?
  - Why are the poles so much colder than the equator?
- Three things you'll learn today:
  - Where and why air rises
  - How air moves around the globe
  - Why you should care about the Coriolis effect

Today's Class

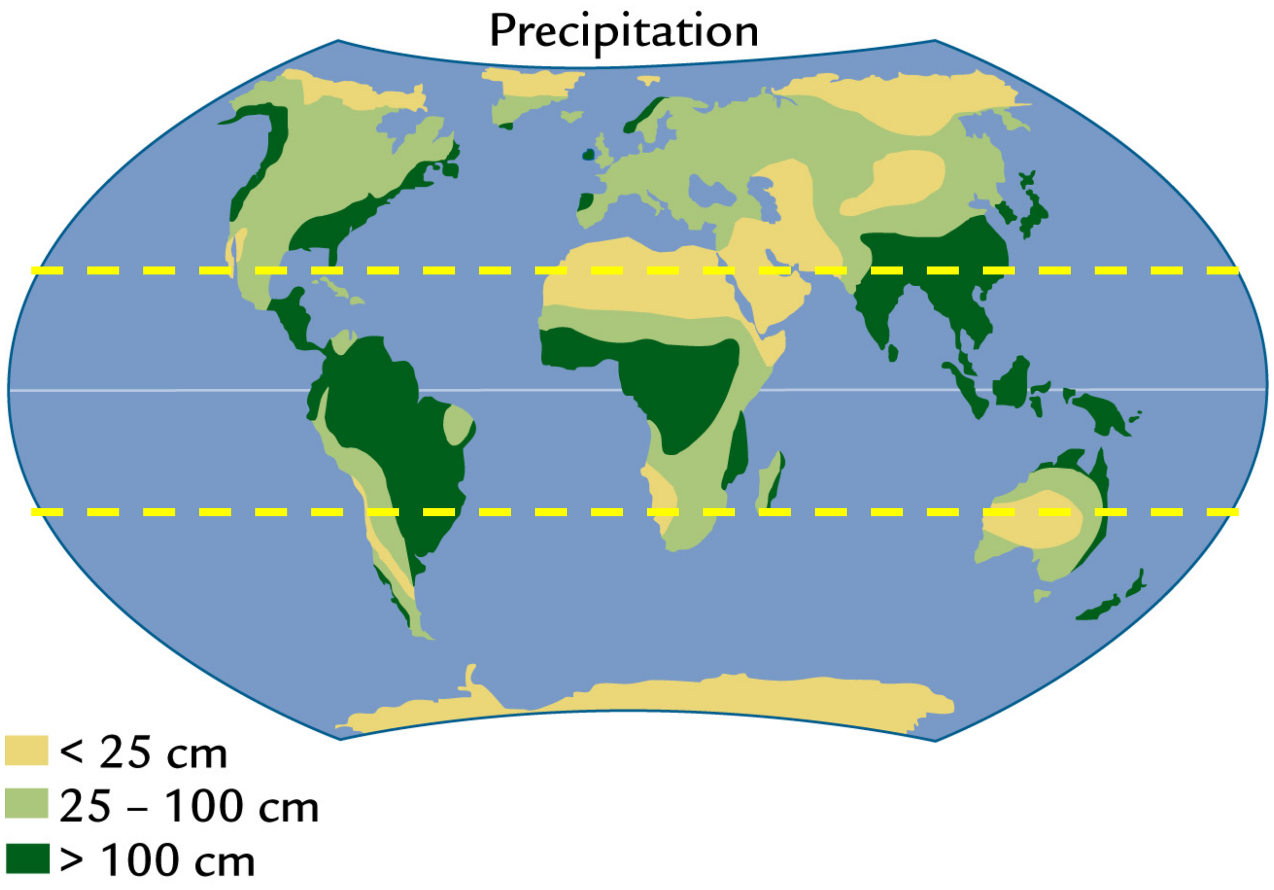


Climate Observations



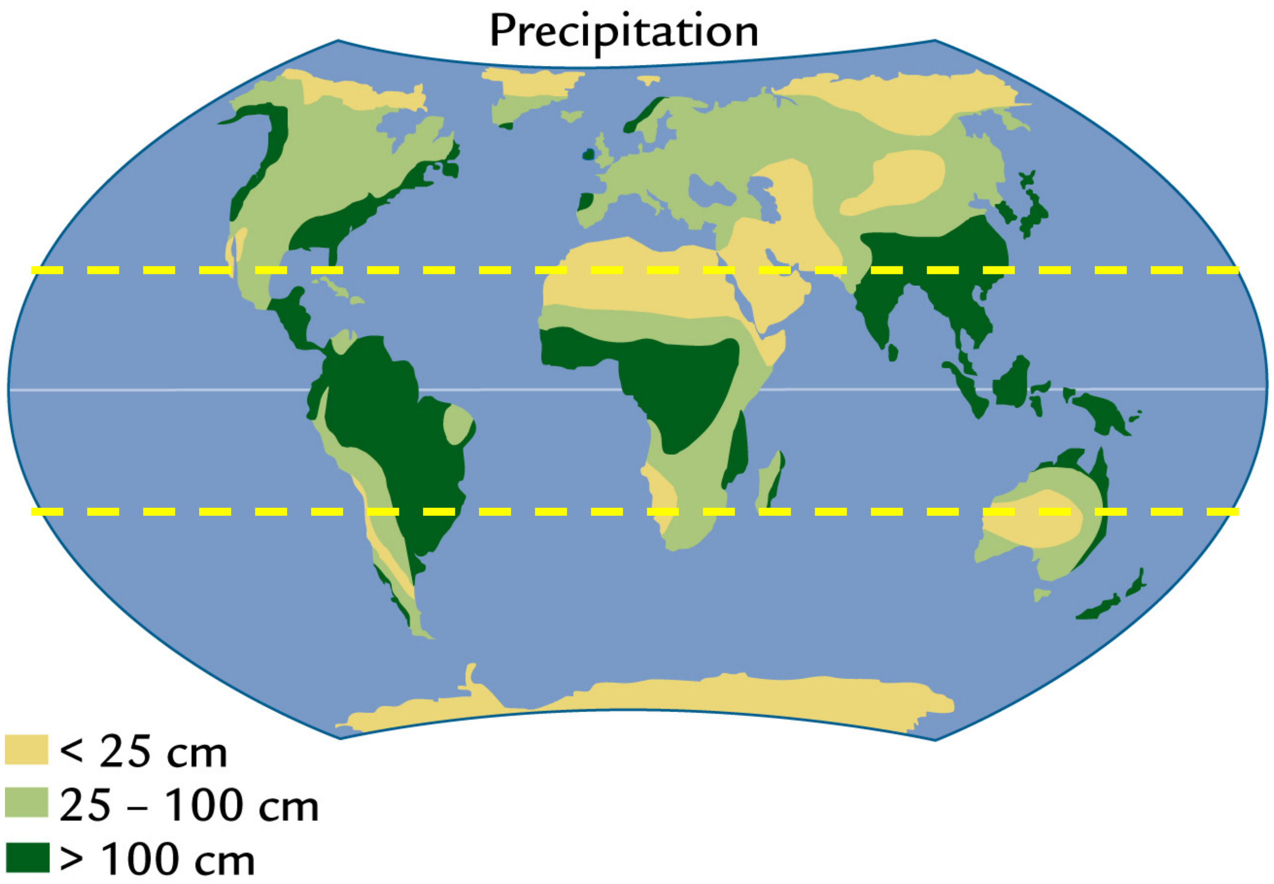
- Rainfall varies around the world, but there are some general patterns

Climate Observations



- Rainfall varies around the world, but there are some general patterns to it
- Lots of rain near equator
- Areas of low-rainfall around 30°N & S

Climate Observations



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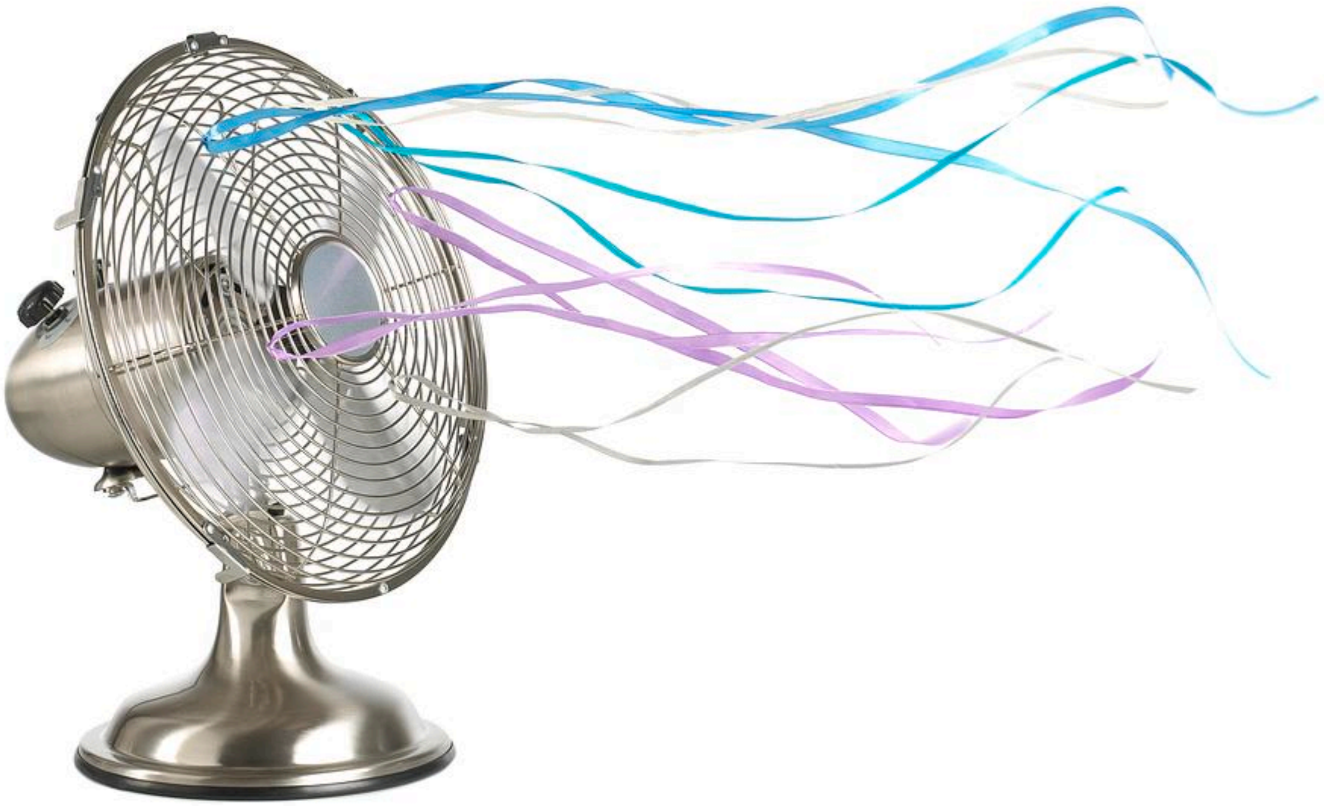
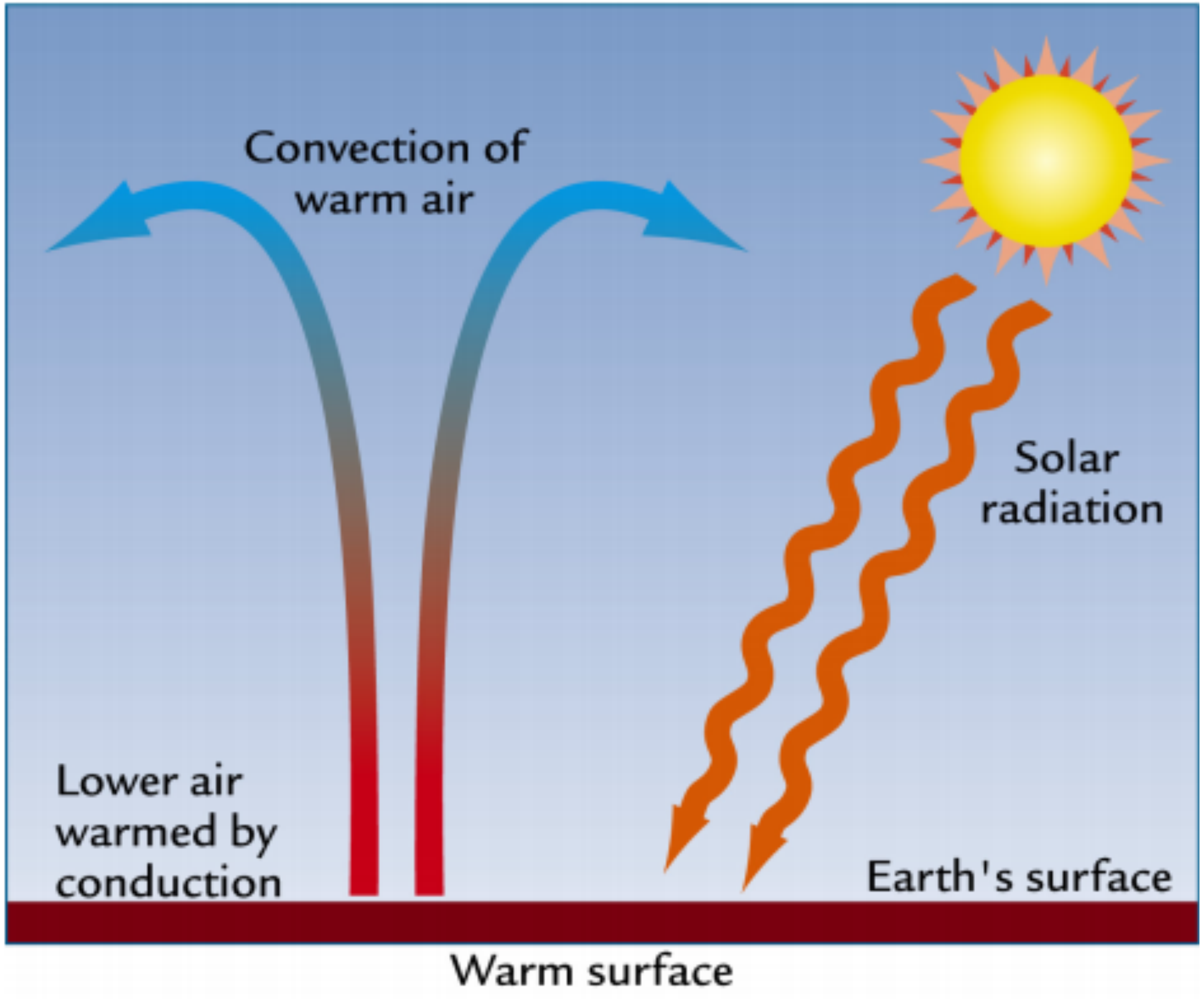
Fundamentals of Atmospheric Physics



Most of those regional climate differences are due to moving air!

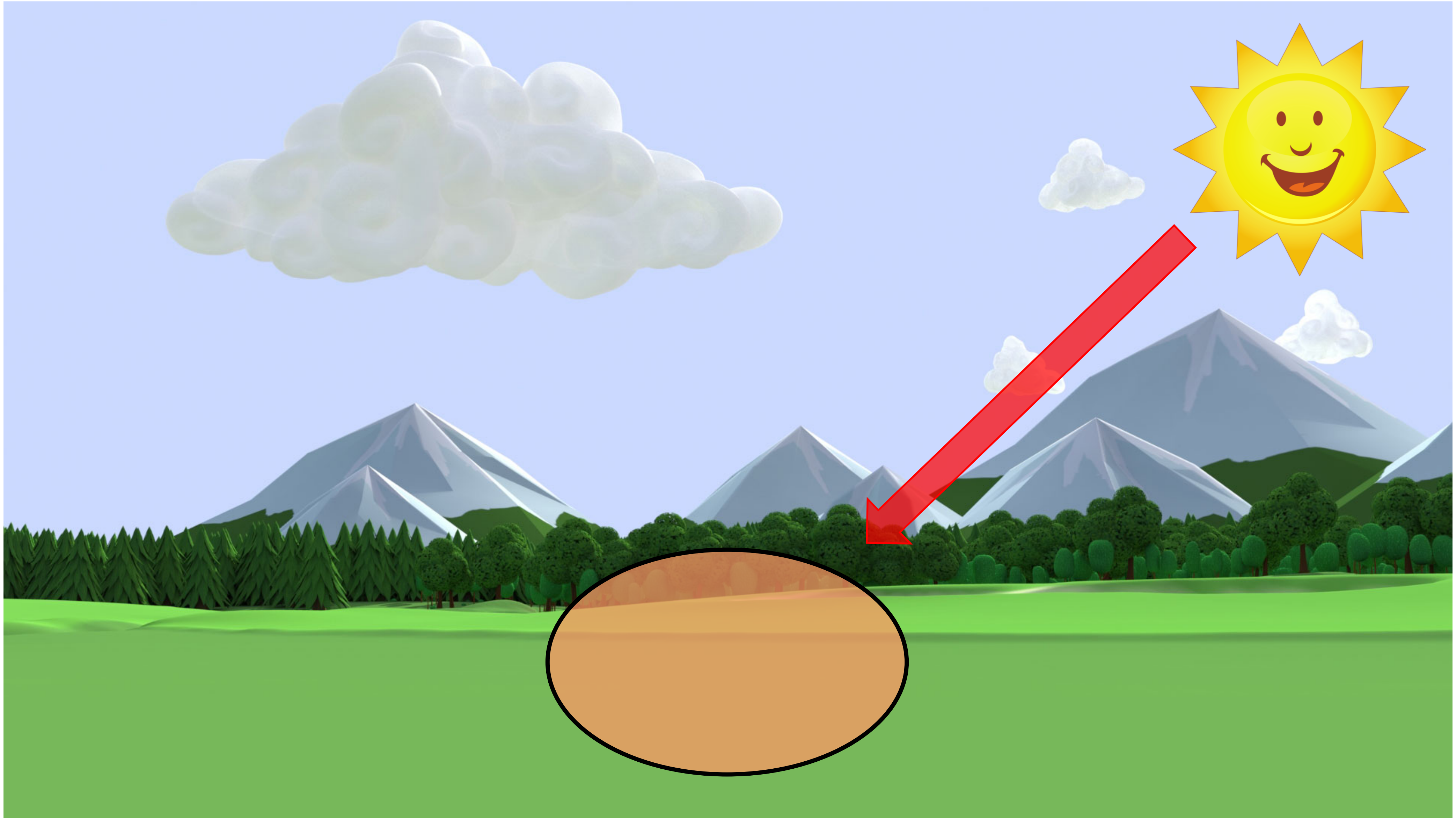
Fundamentals of Atmospheric Physics



Important Dynamic #1:

1. Heated air becomes less dense and rises
2. Rising air expands expands and cools
3. Eventually, air cools and increases in density until it matches the surrounding air, stopping its rise

Fundamentals of Atmospheric Physics



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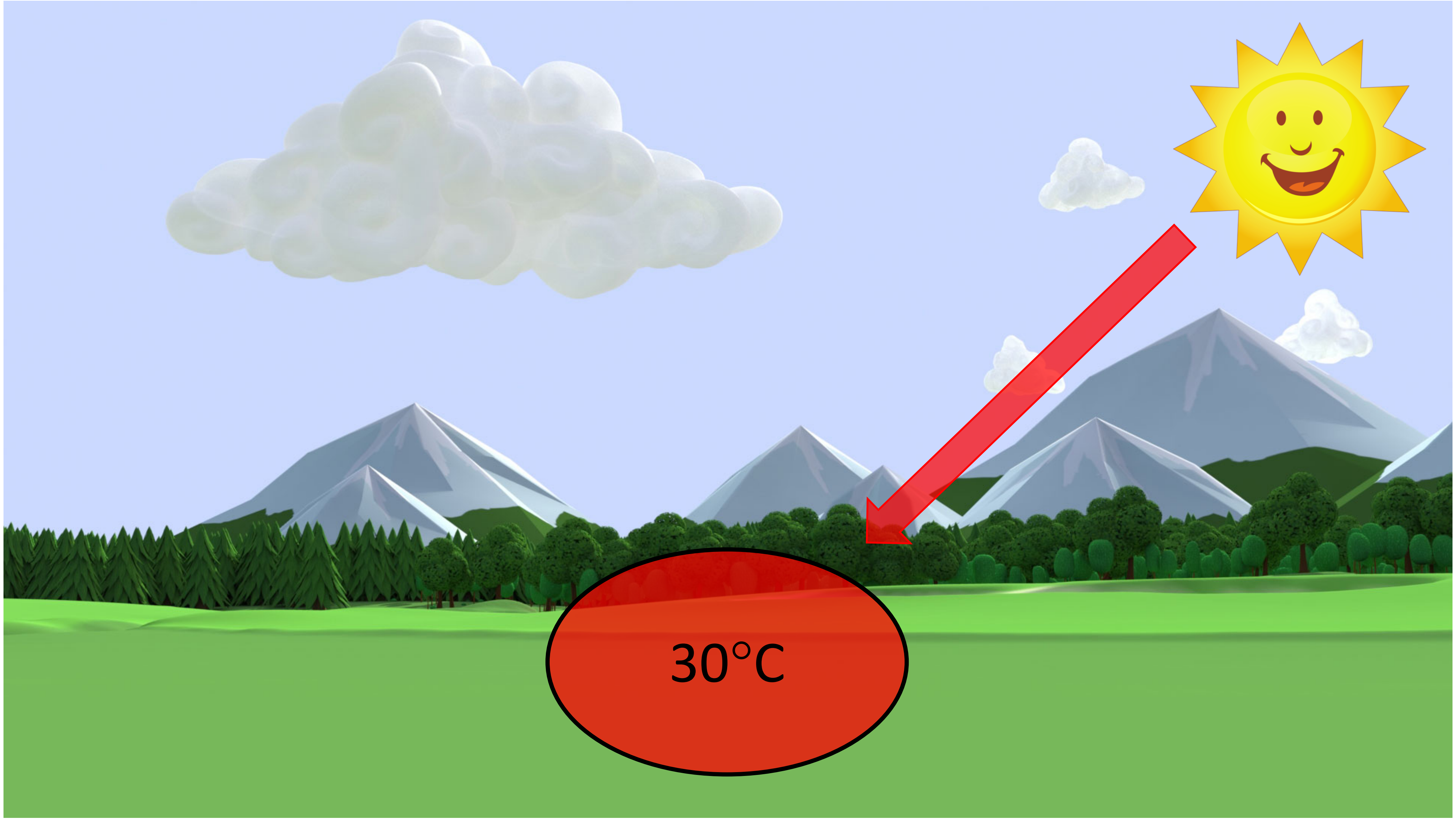

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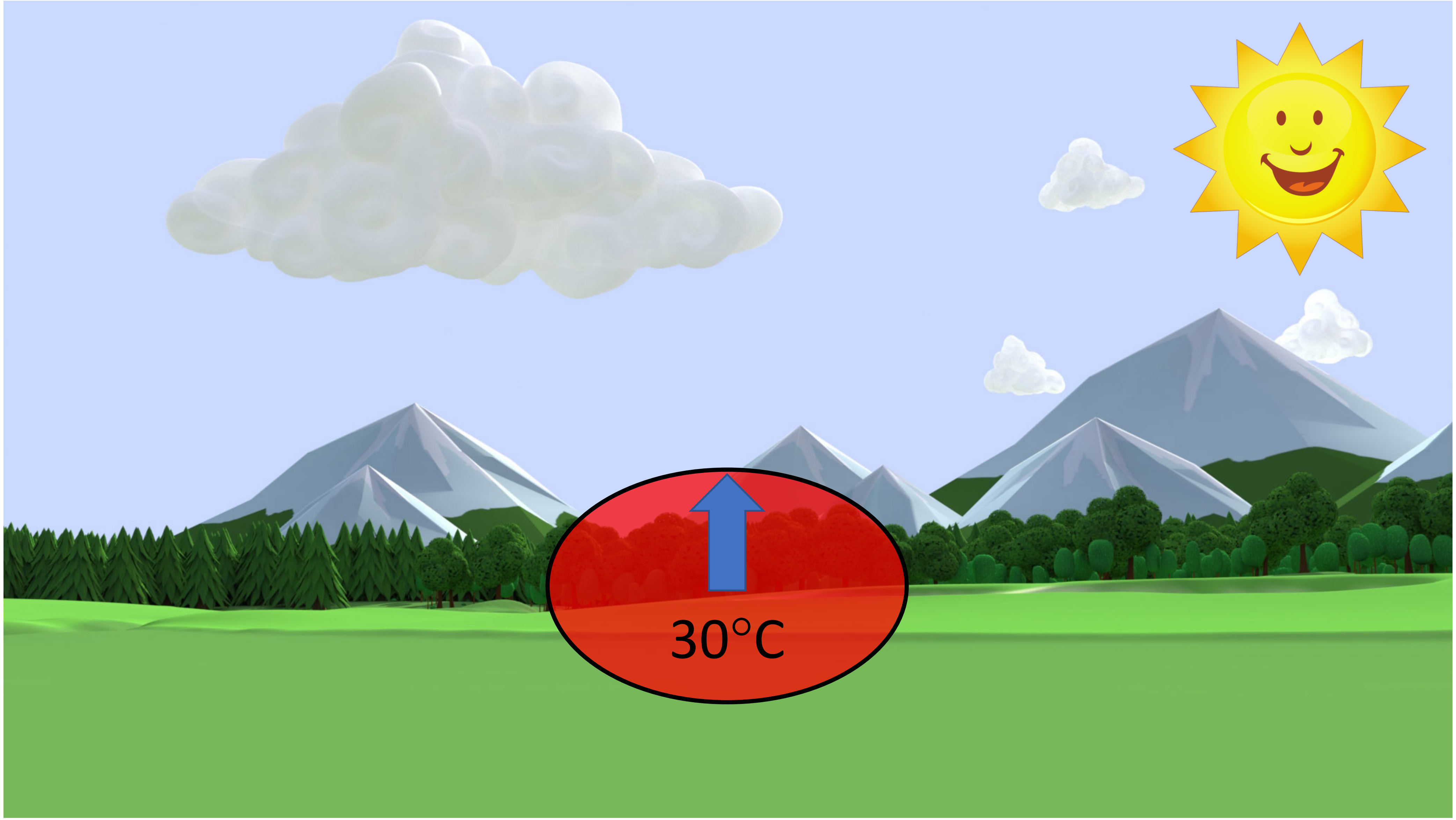

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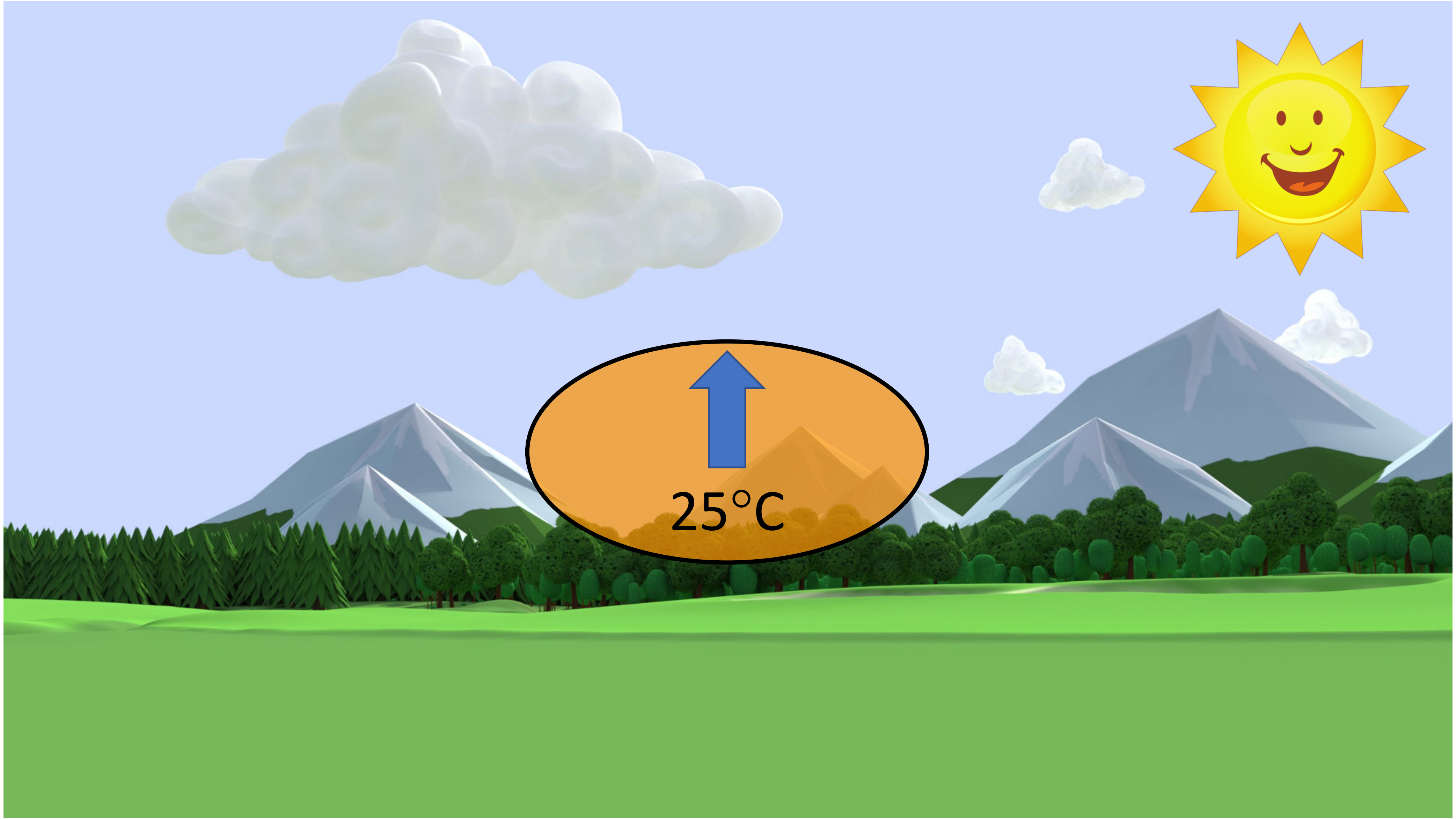
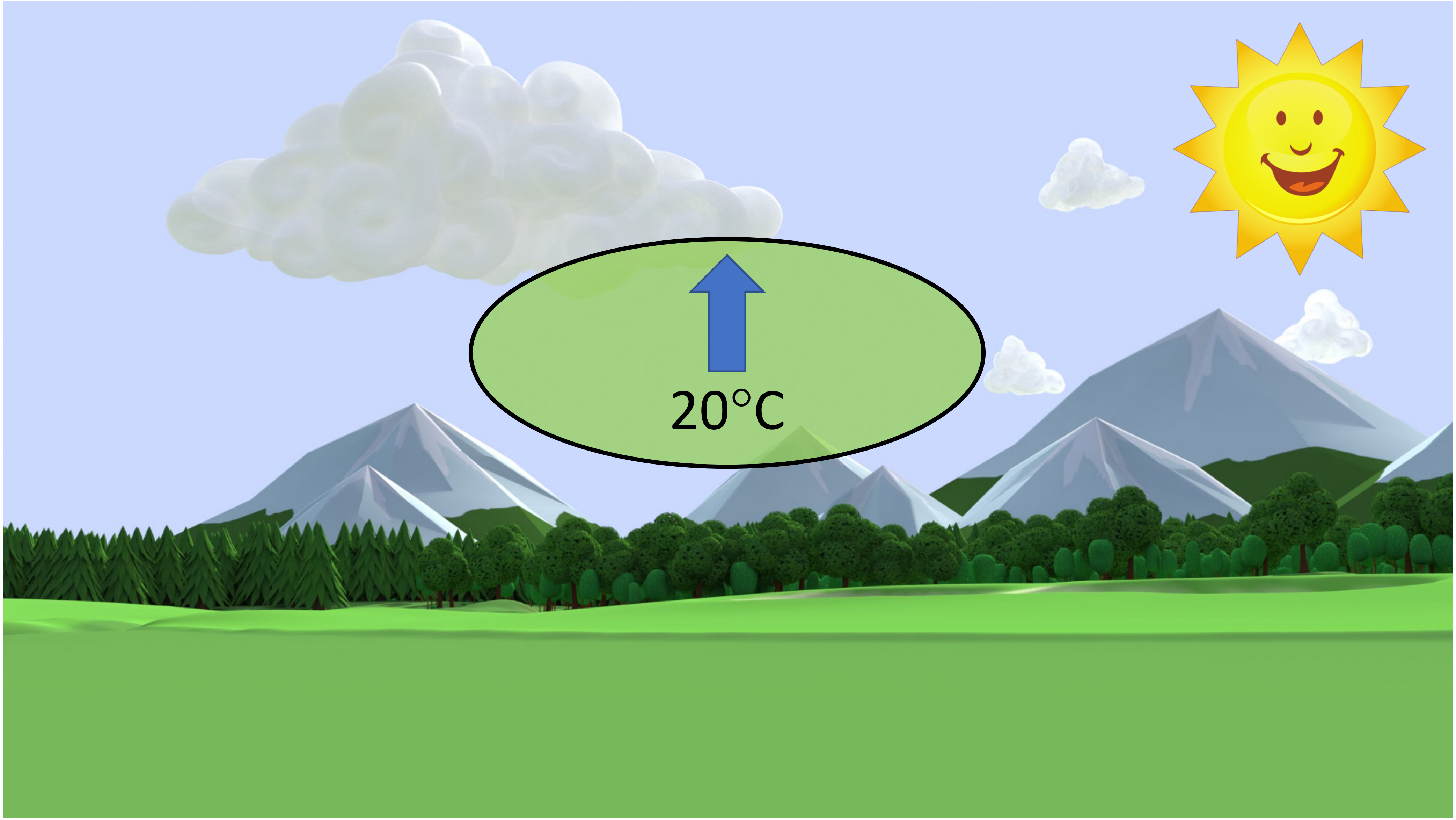
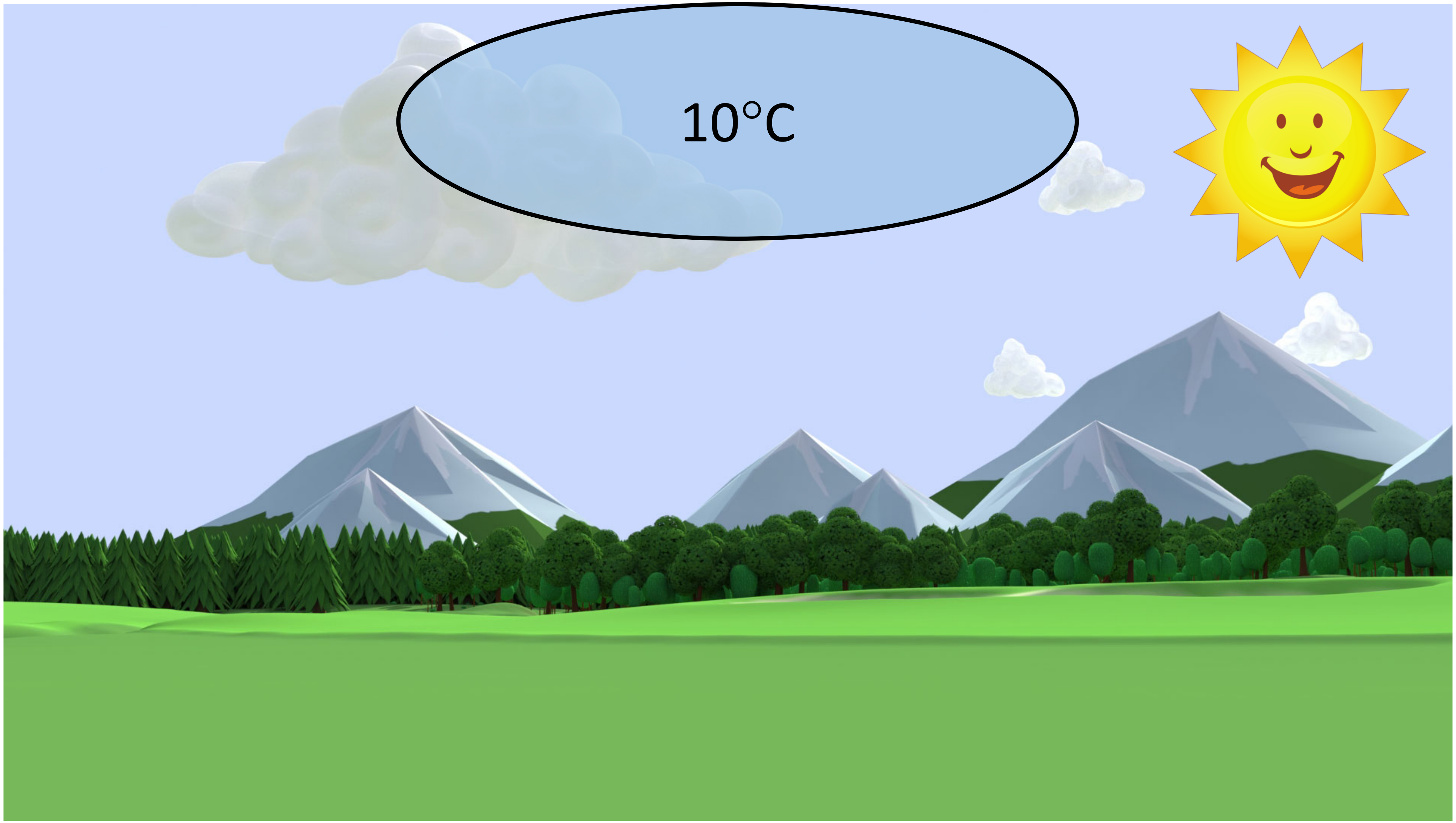


Fundamentals of Atmospheric Physics



Fundamentals of Atmospheric Physics

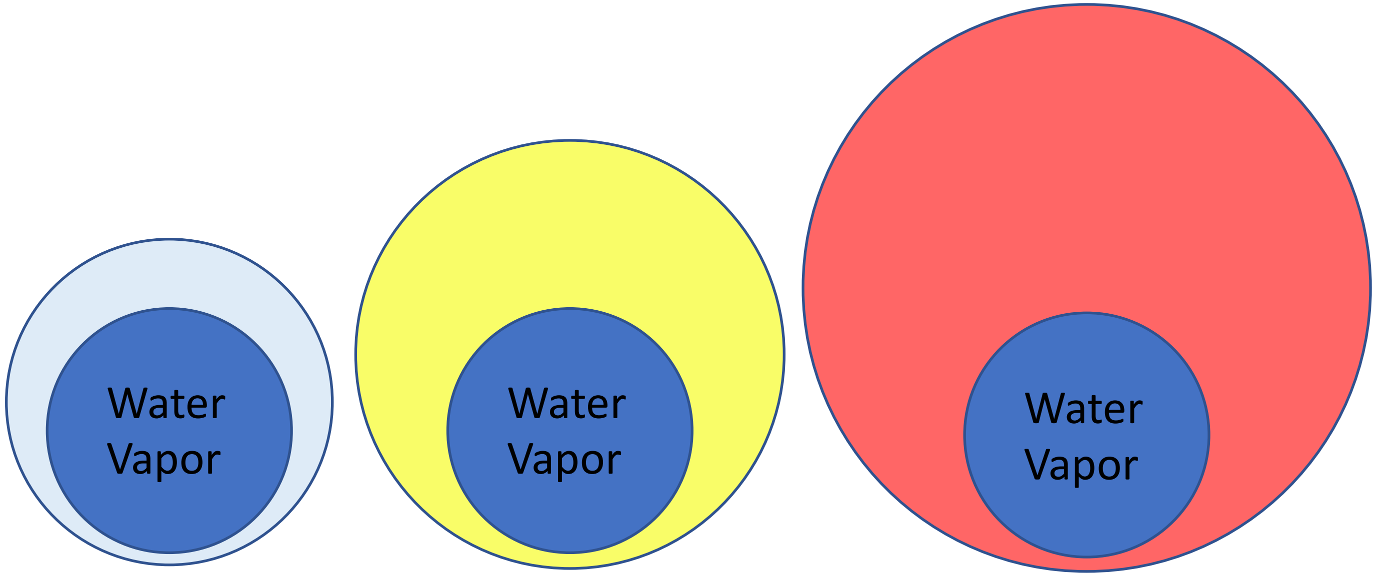


Fundamentals of Atmospheric Physics

Important Dynamic #2:

1. Warm air can hold more water vapor

Fundamentals of Atmospheric Physics



Air Temp: 10°C

Relative Humidity: 80%

Air Temp: 20°C

Relative Humidity: 40%

Air Temp: 30°C

Relative Humidity: 20%

Important Dynamic #2:

1. Warm air can hold more water vapor

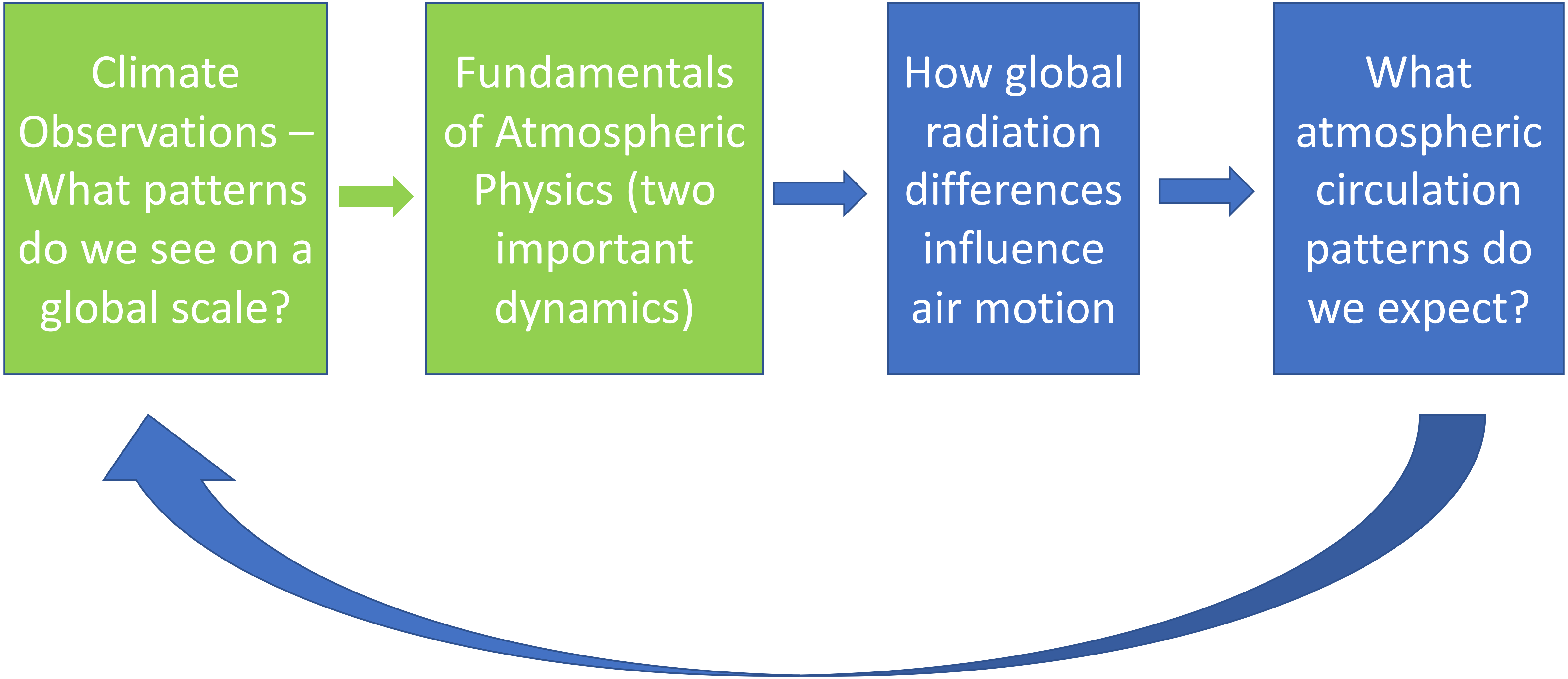
Fundamentals of Atmospheric Physics

Important Dynamic #2:

1. Warm air can hold more water vapor

2. When air reaches its water carrying capacity, liquid water condenses

Check In



Climate Observations – What patterns do we see on a global scale?
Fundamentals of Atmospheric Physics (two important dynamics)
How global radiation differences influence air motion
What atmospheric circulation patterns do we expect?

Comprehension Check

As air rises in the atmosphere, it…

A. Expands and cools
B. Expands and warms
C. Compresses and cools
D. Compresses and warms
E. Expands, then compresses

Check In

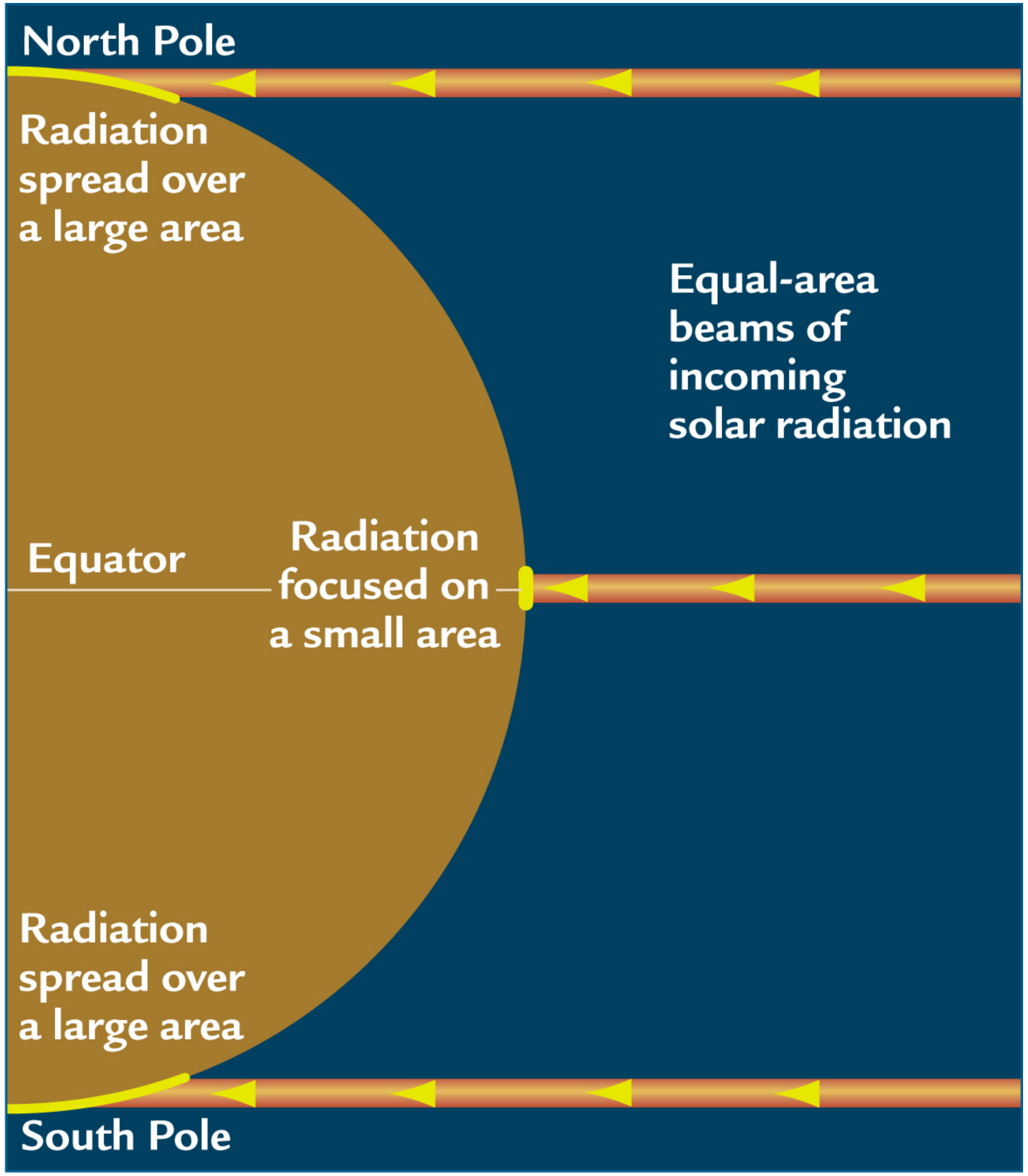
Climate Observations – What patterns do we see on a global scale?

Fundamentals of Atmospheric Physics (two important dynamics)

How global radiation differences influence air motion

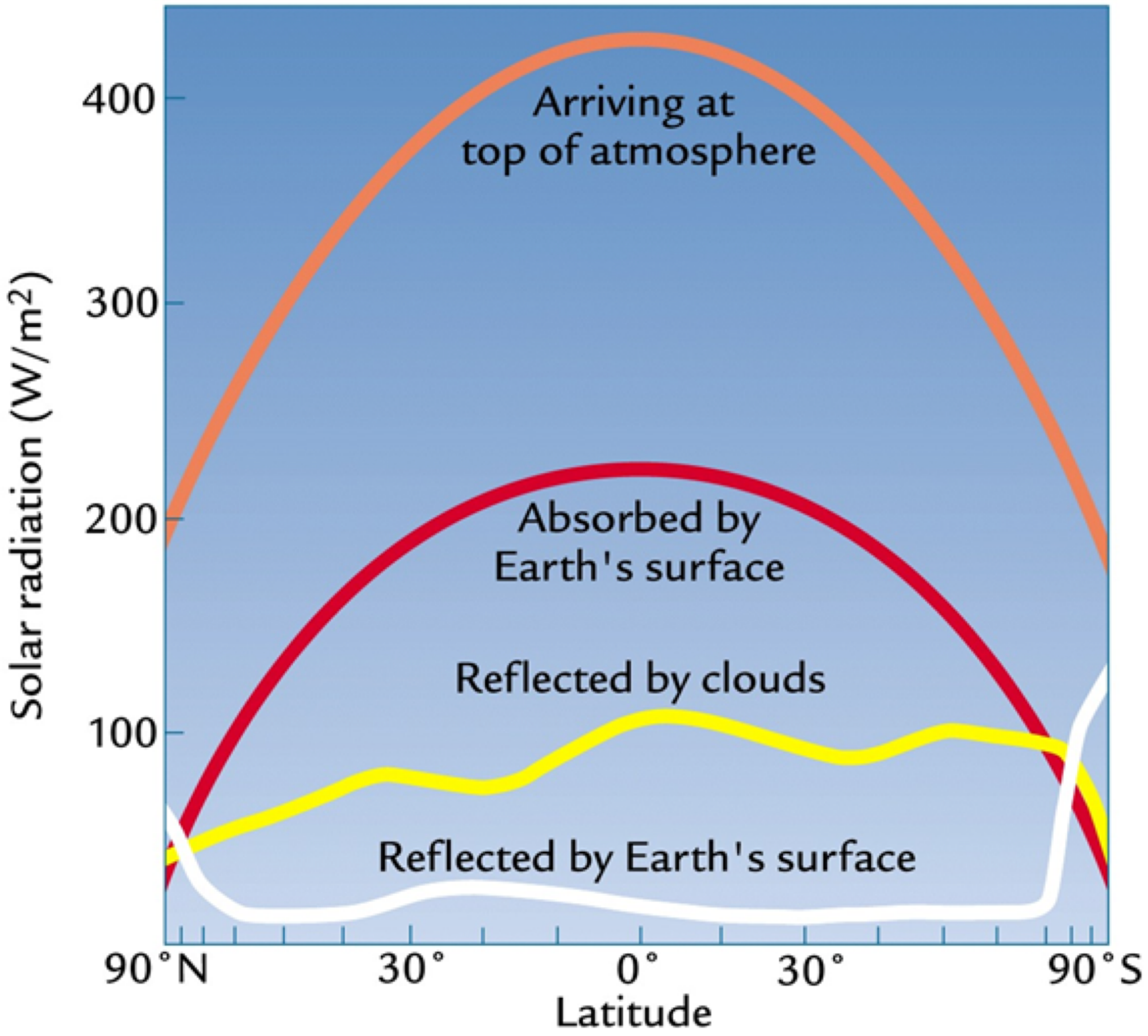
What atmospheric circulation patterns do we expect?

Differences in Heating Due to Solar Radiation



Radiation Imbalance

- Less solar radiation arrives at higher latitudes

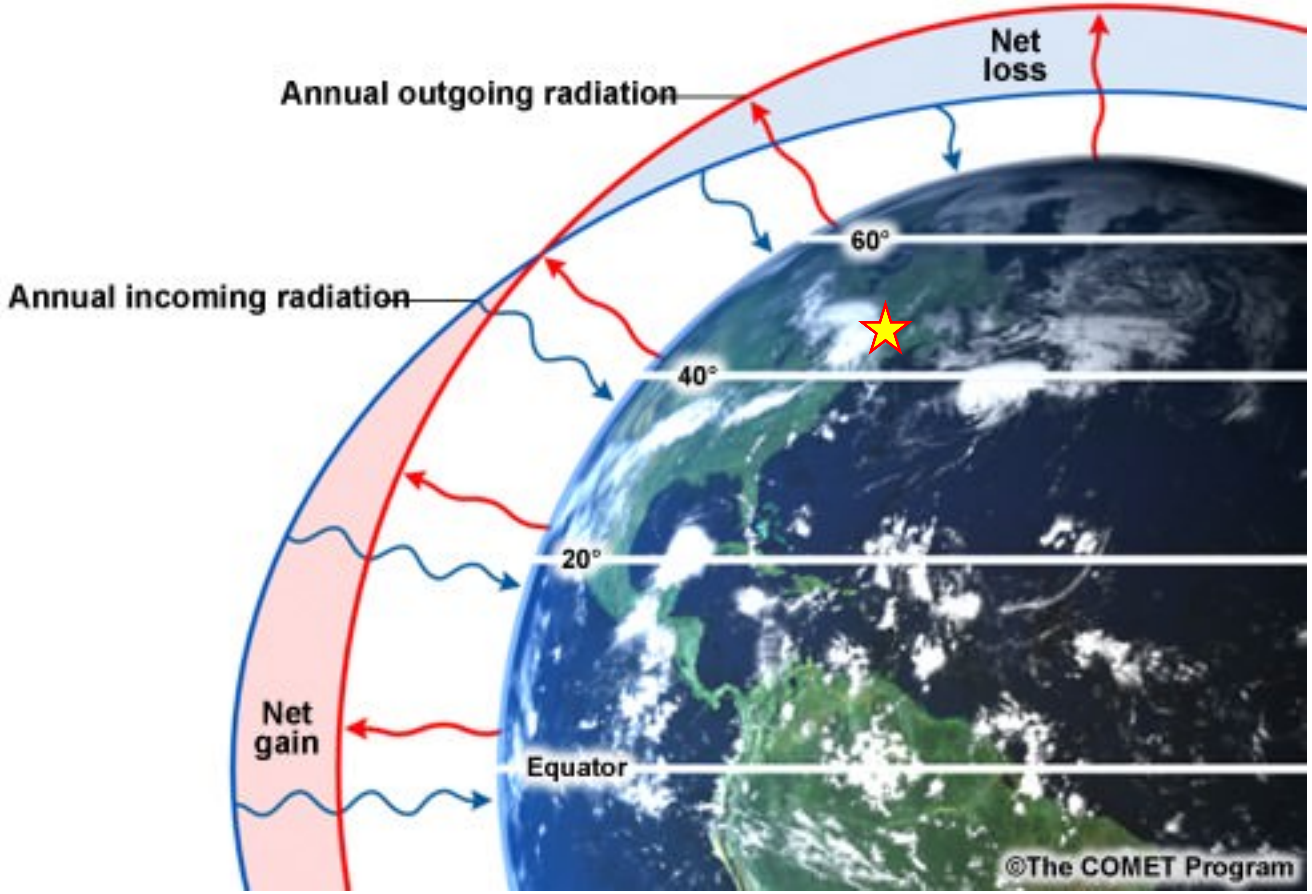


Radiation Imbalance

- Less solar radiation arrives at higher latitudes

- However, Earth's outgoing radiation varies *much* less with latitude

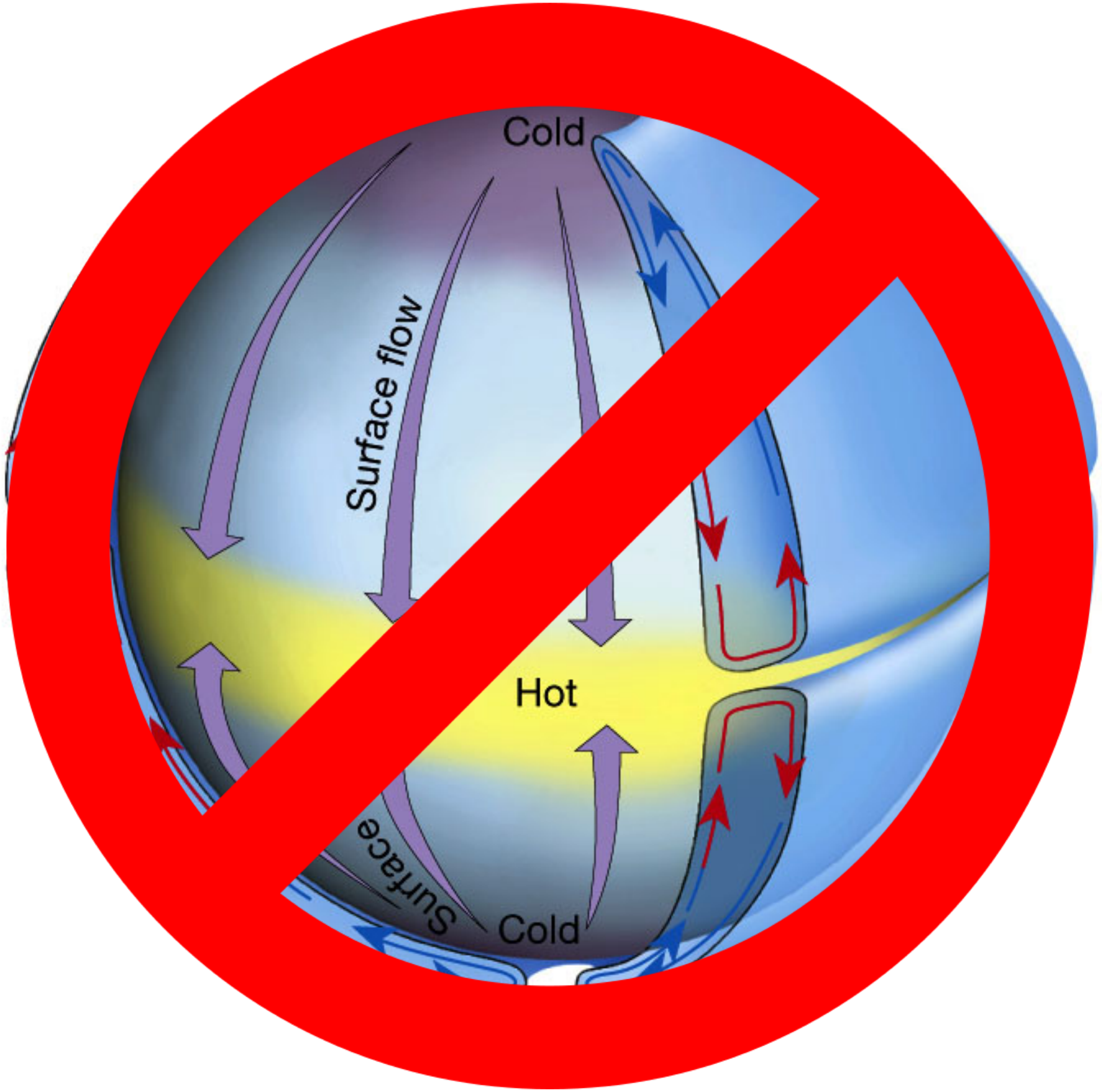
- This dynamic creates a radiation (energy) imbalance between the equator and the poles



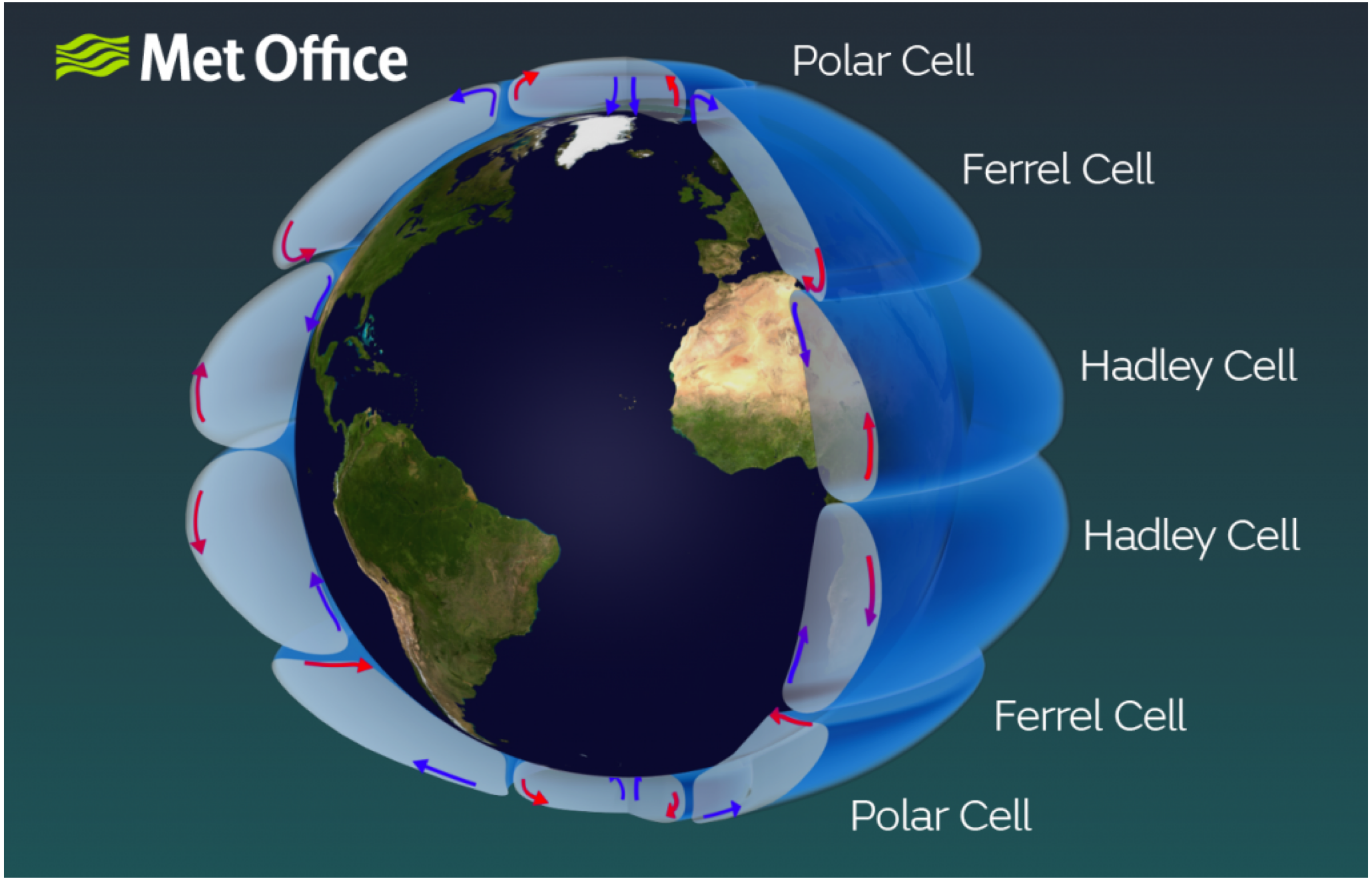
Global-Scale Circulation

- Earth's general radiation (heat) imbalance is simple, the equators are hot and the poles are cold

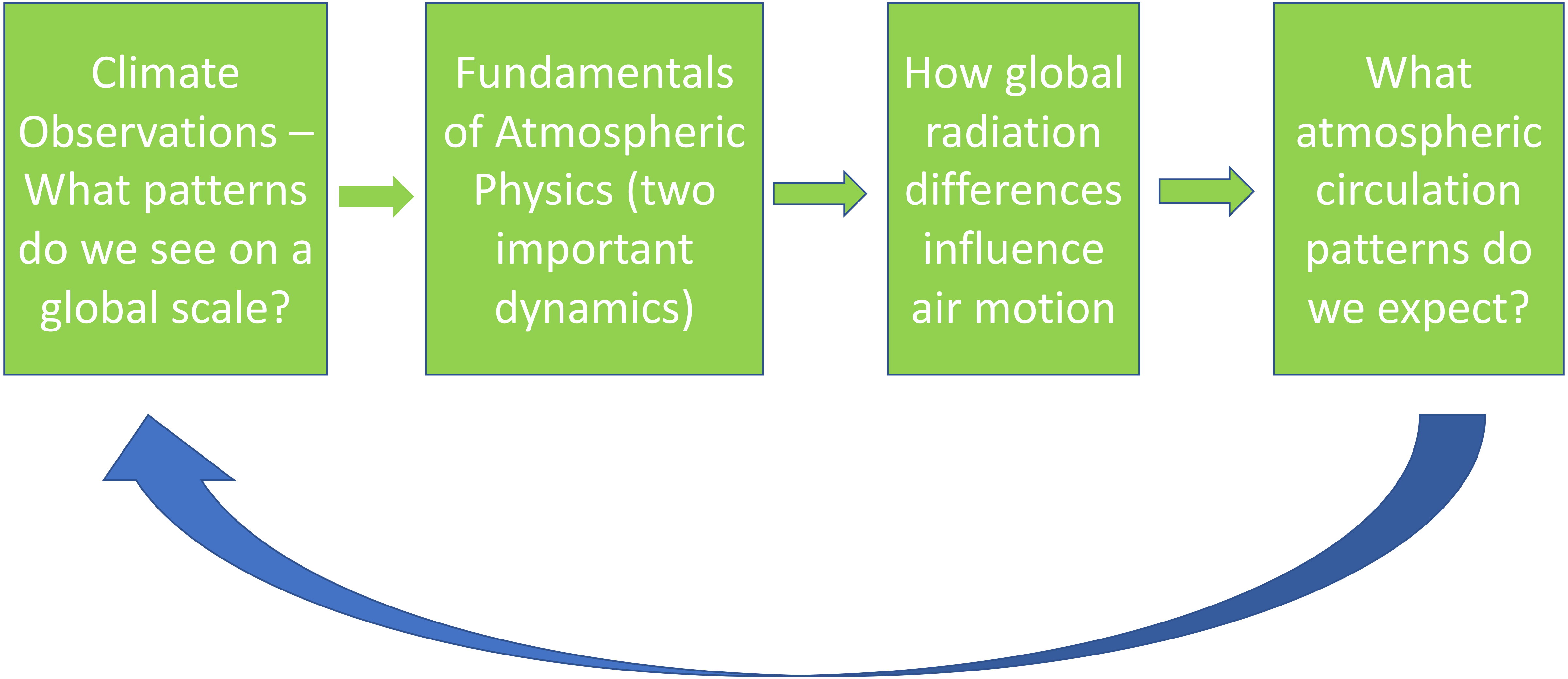
- Therefore, you may expect Earth to have air convection cells like this:



Global-Scale Circulation



Check In



Climate Observations – What patterns do we see on a global scale?
Fundamentals of Atmospheric Physics (two important dynamics)
How global radiation differences influence air motion
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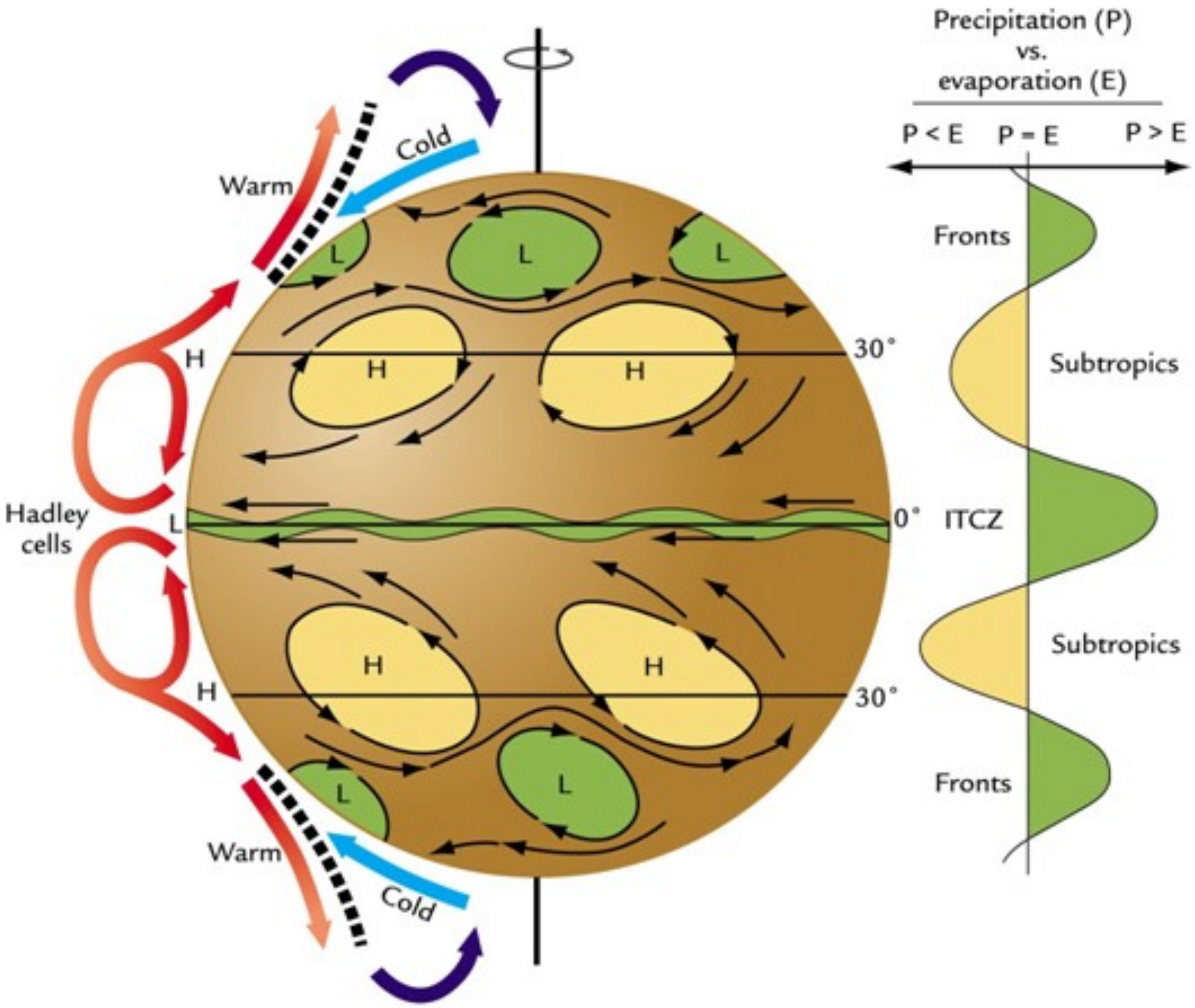
Comprehension Check

Why does air rise at the equator?

A. Air rises when it is heated
B. Air rises when it has more moisture than its surroundings
C. The equator receives the most direct incoming solar radiation, so air warms the most here
D. A & C
E. A, B, & C

Observed Global-Scale Circulation

- Air rises at equator
- Air sinks at 30°N & S
- Sinking air compresses and warms
- Creates areas of high pressure and warm, dry conditions at 30°N & S



Global-Scale Circulation

Equator (Amazon Rainforest)

Rising air =

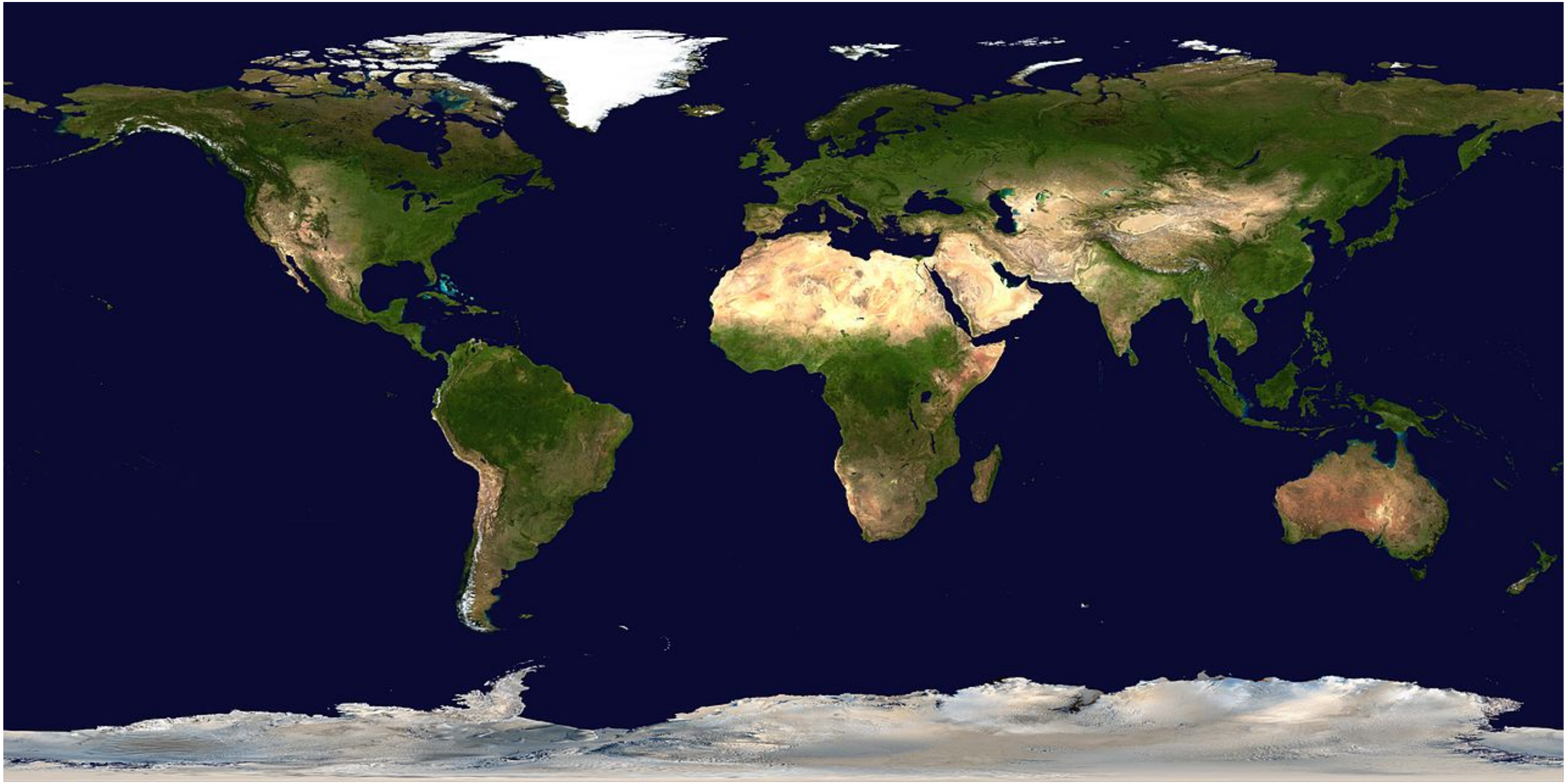
- Low pressure
- Lots of rain

~30°N (Sahara Desert)

Sinking air =

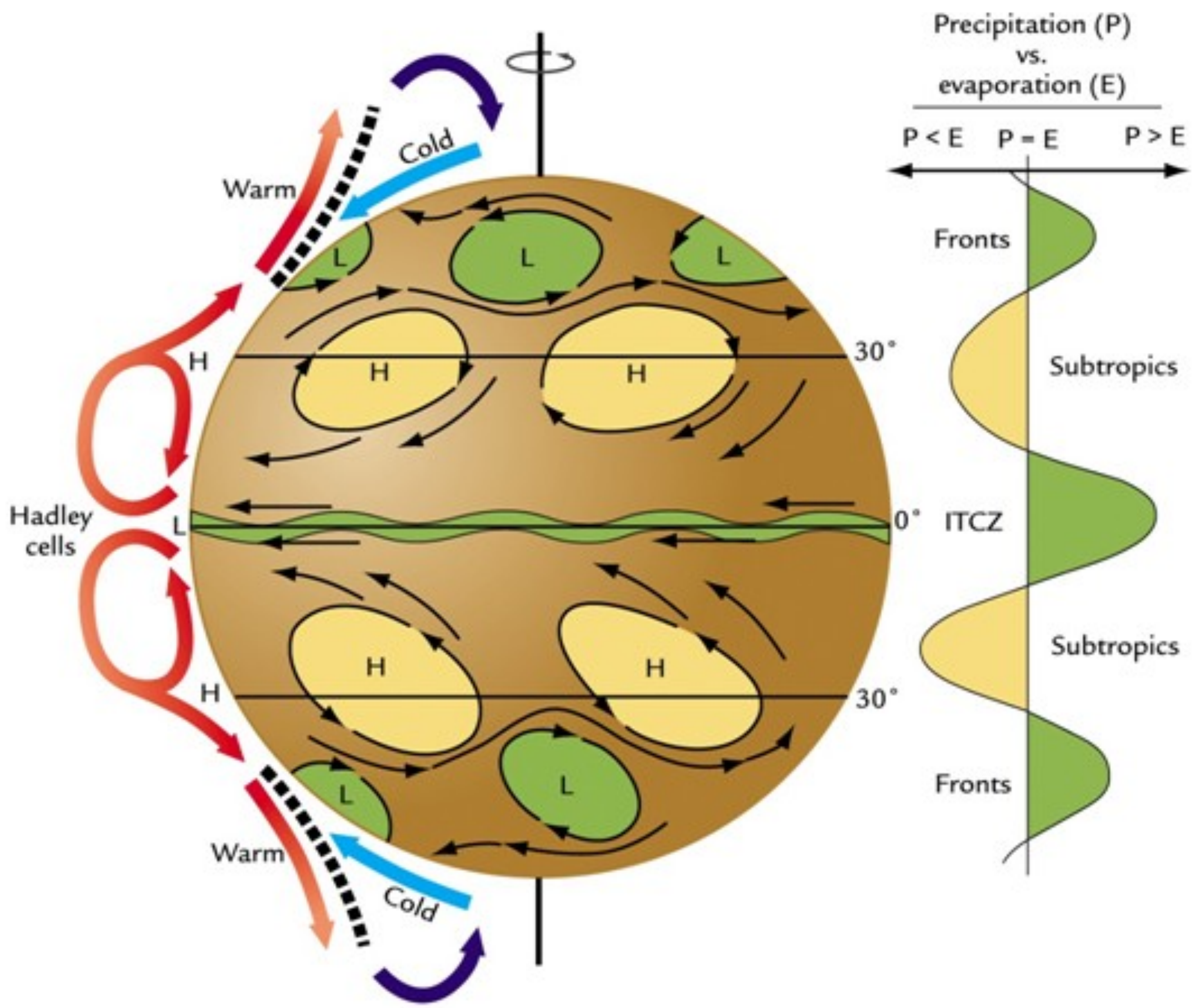
- High pressure
- Very little rain

Global-Scale Circulation



Global-Scale Circulation

- Question: Why are the pressure zones rotating?

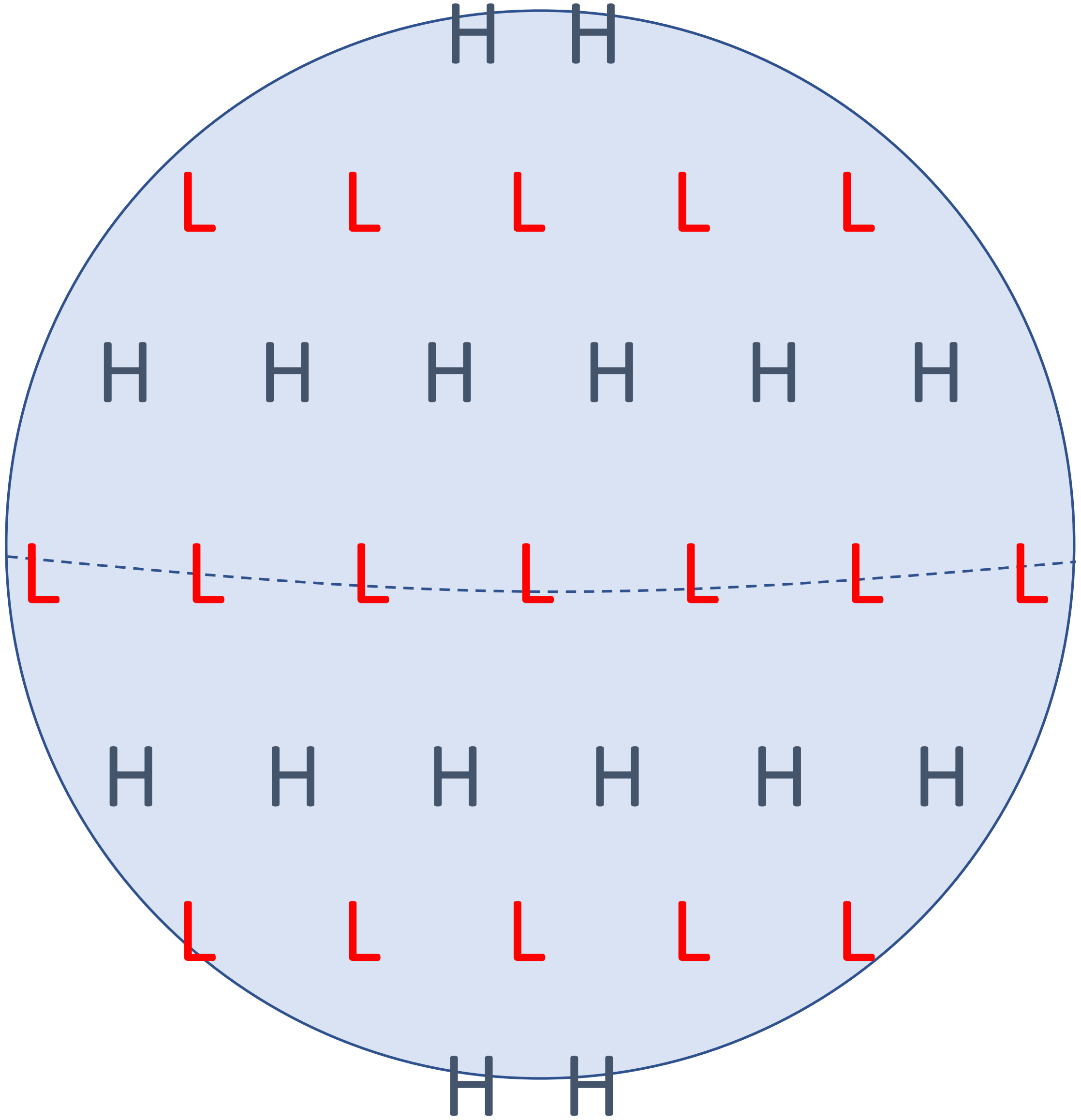


The Coriolis Effect

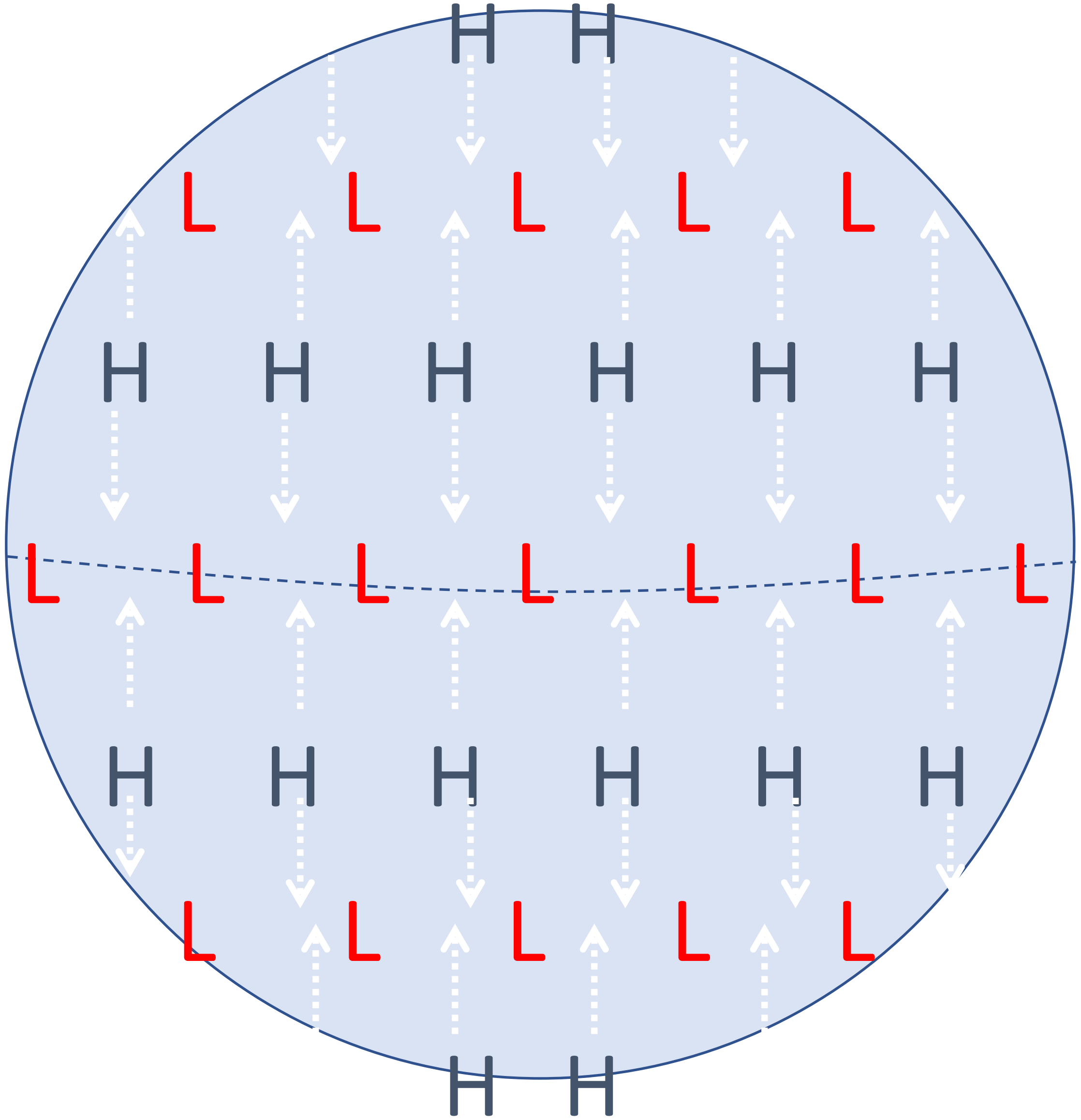
The Coriolis Effect

- Discovered by Gaspard-Gustave de Coriolis (1792 – 1843)
- He did not deal with any natural systems, but studied the transfer of energy in waterwheels

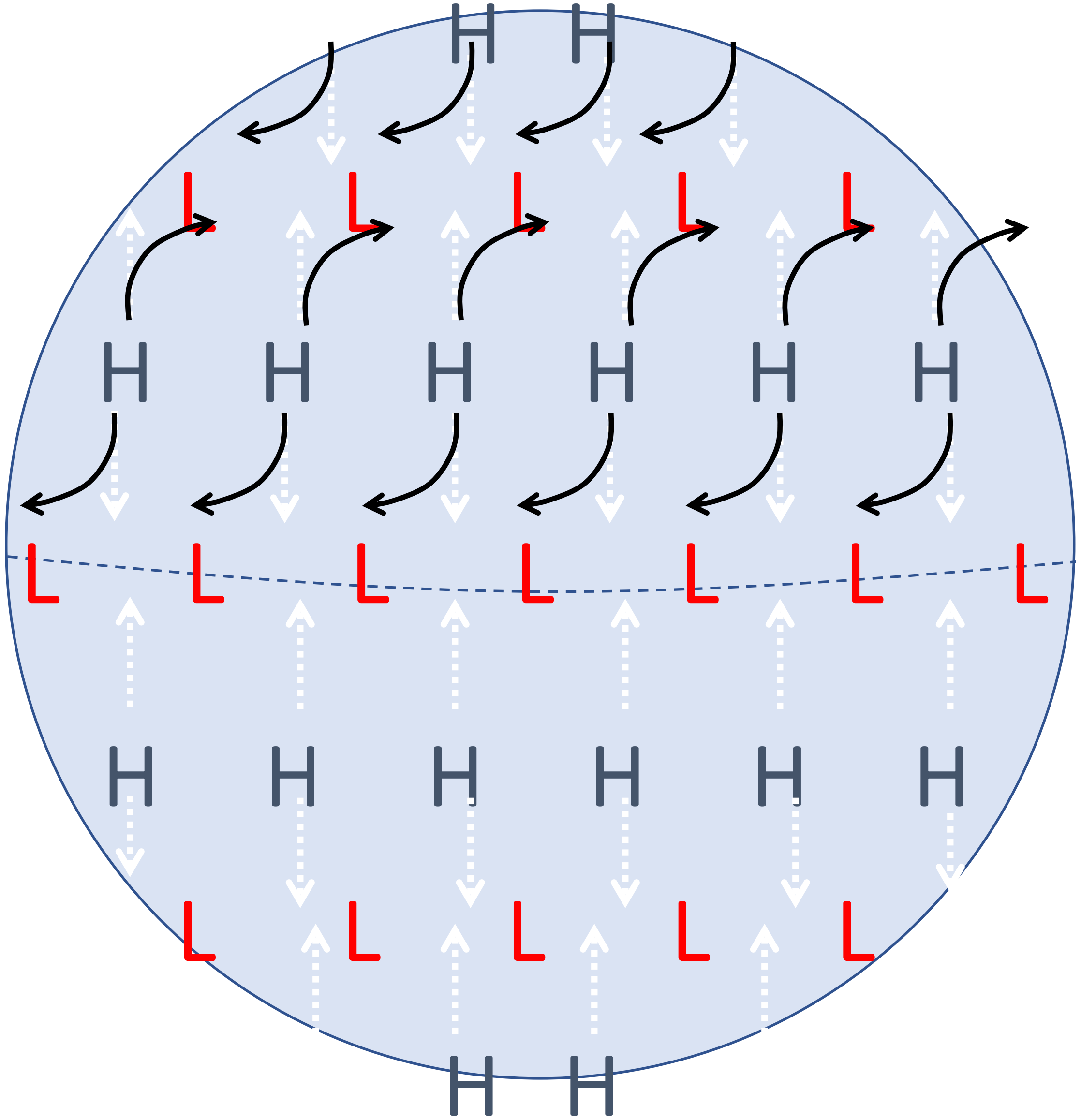
The Coriolis Effect



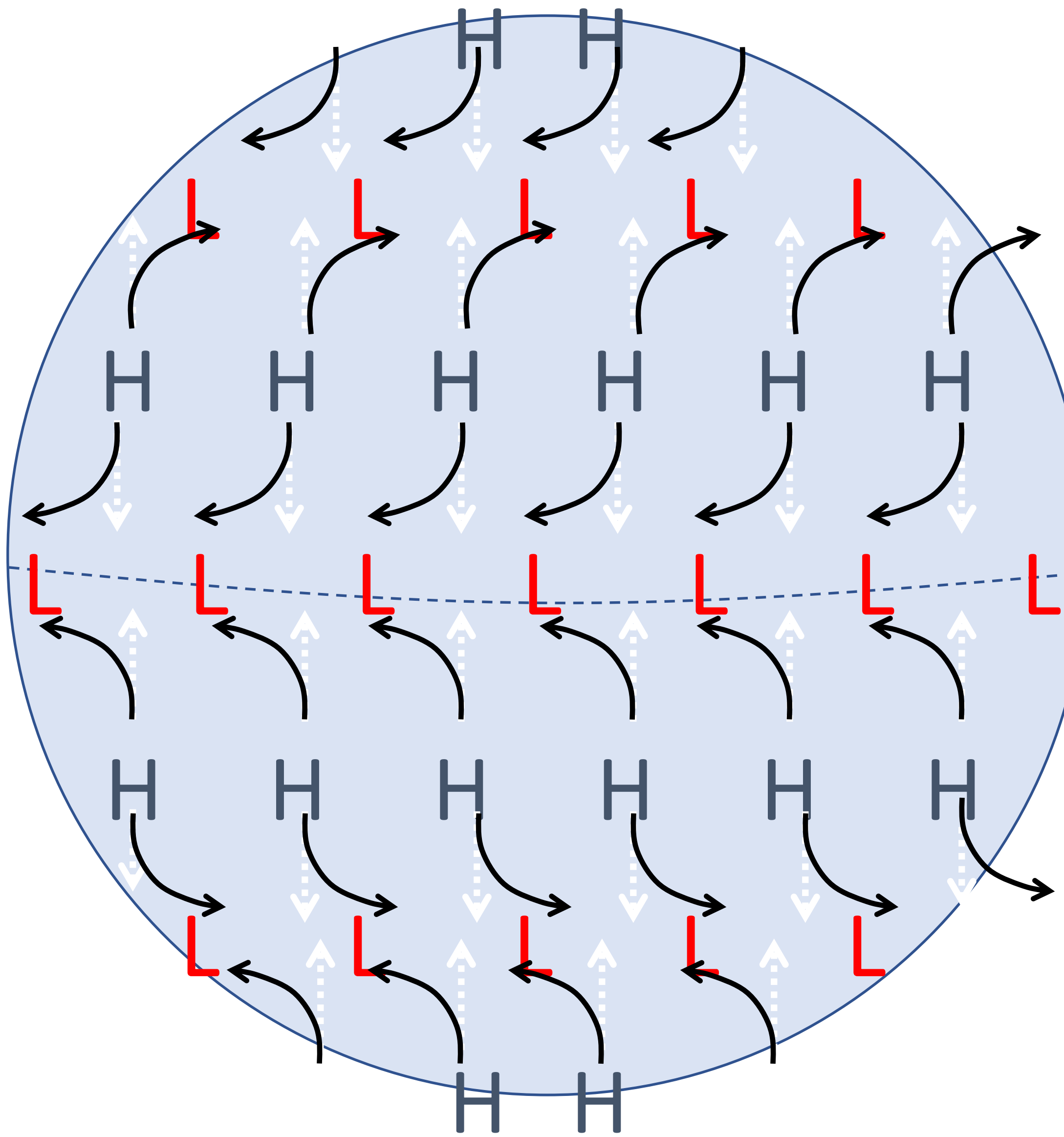
The Coriolis Effect



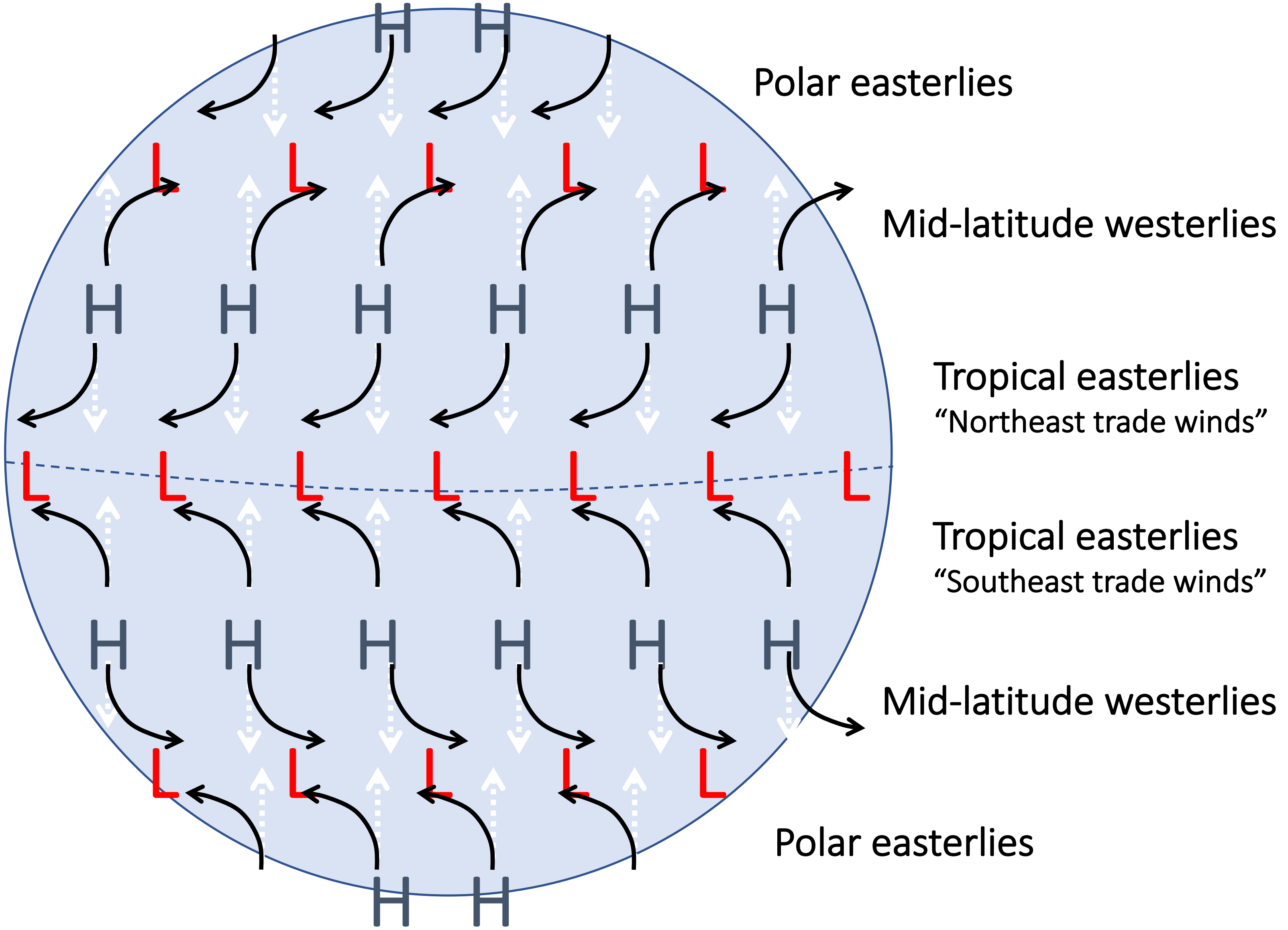
The Coriolis Effect



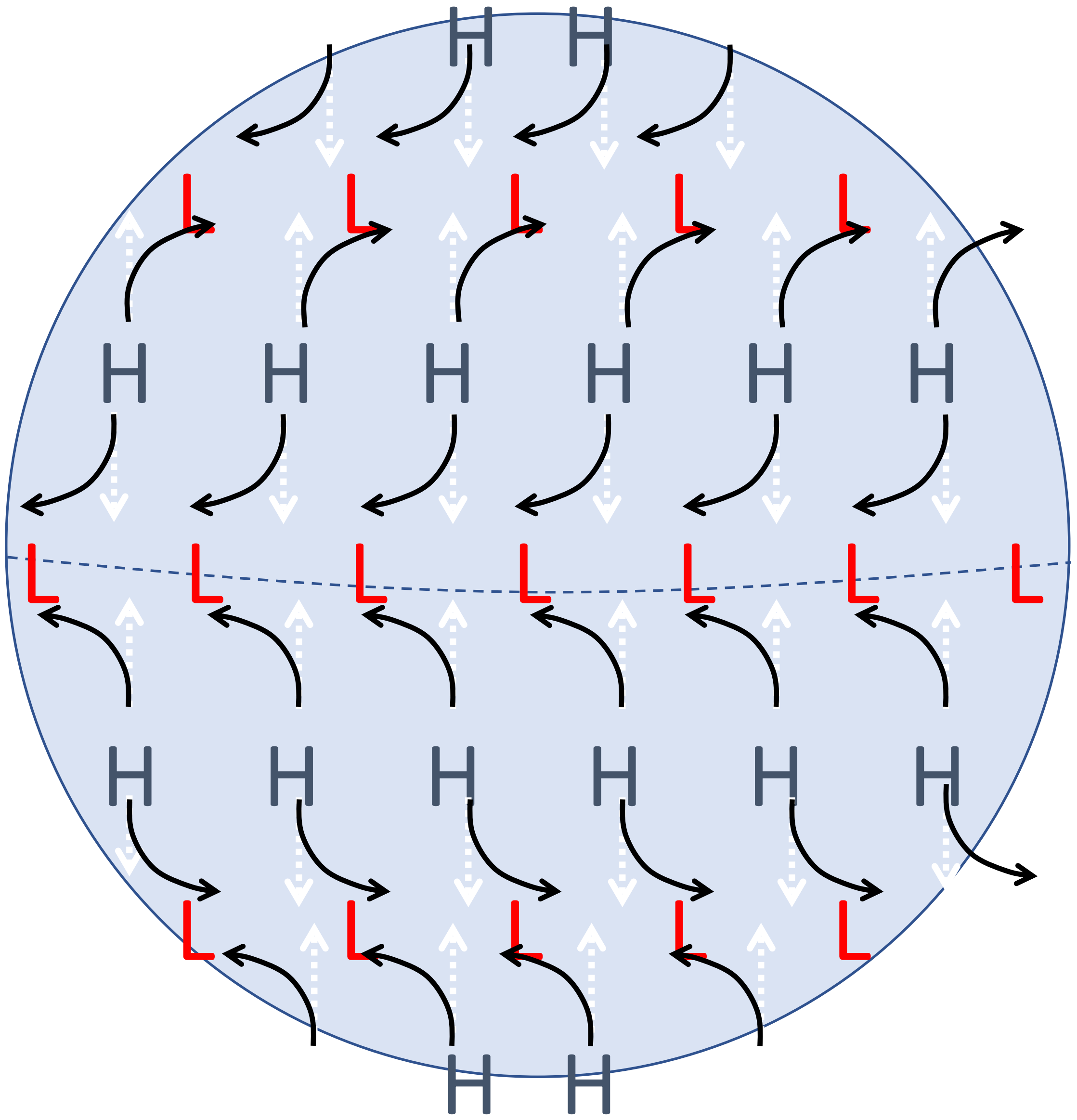
The Coriolis Effect

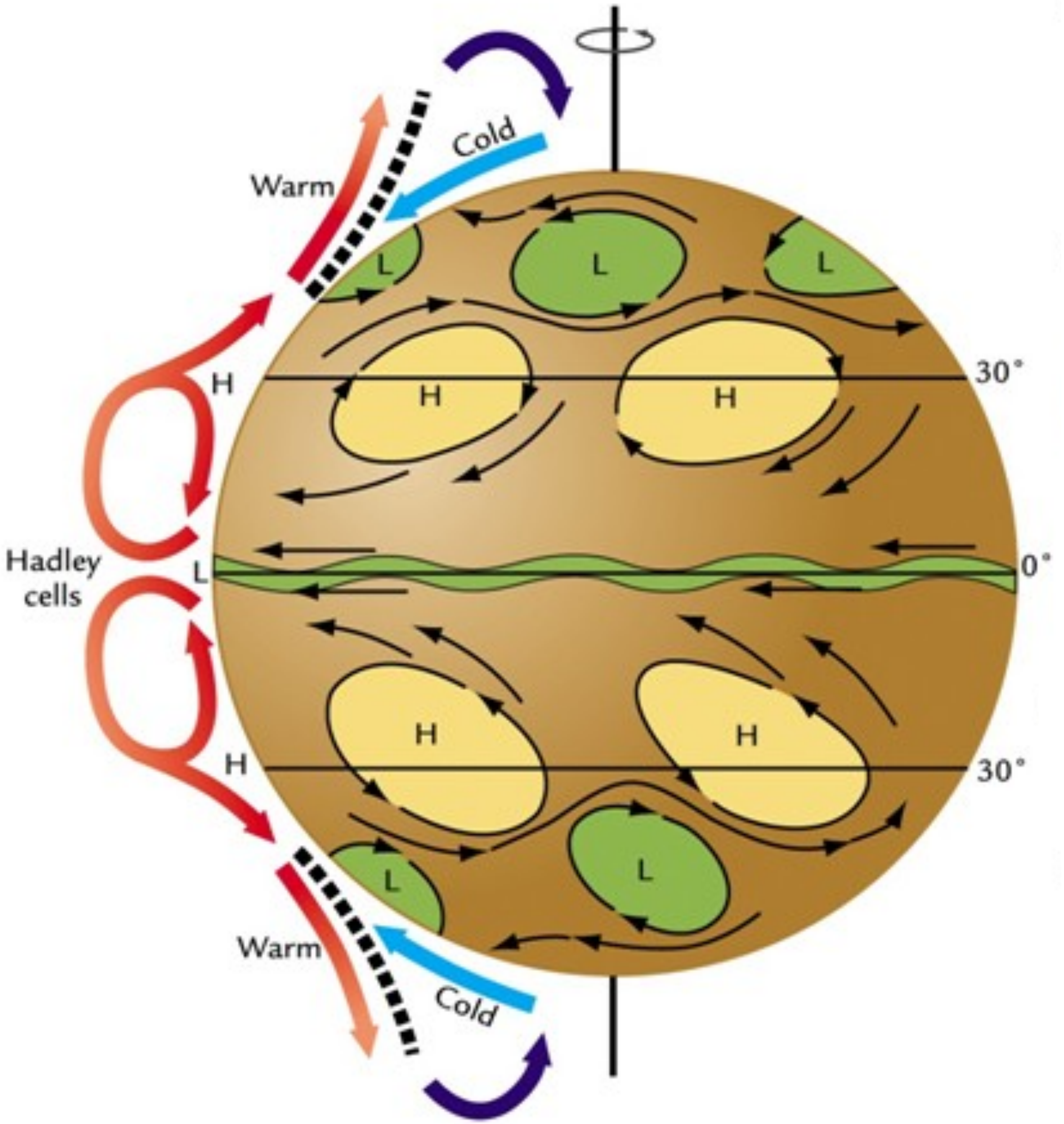


The Coriolis Effect



Global-Scale Circulation & Coriolis





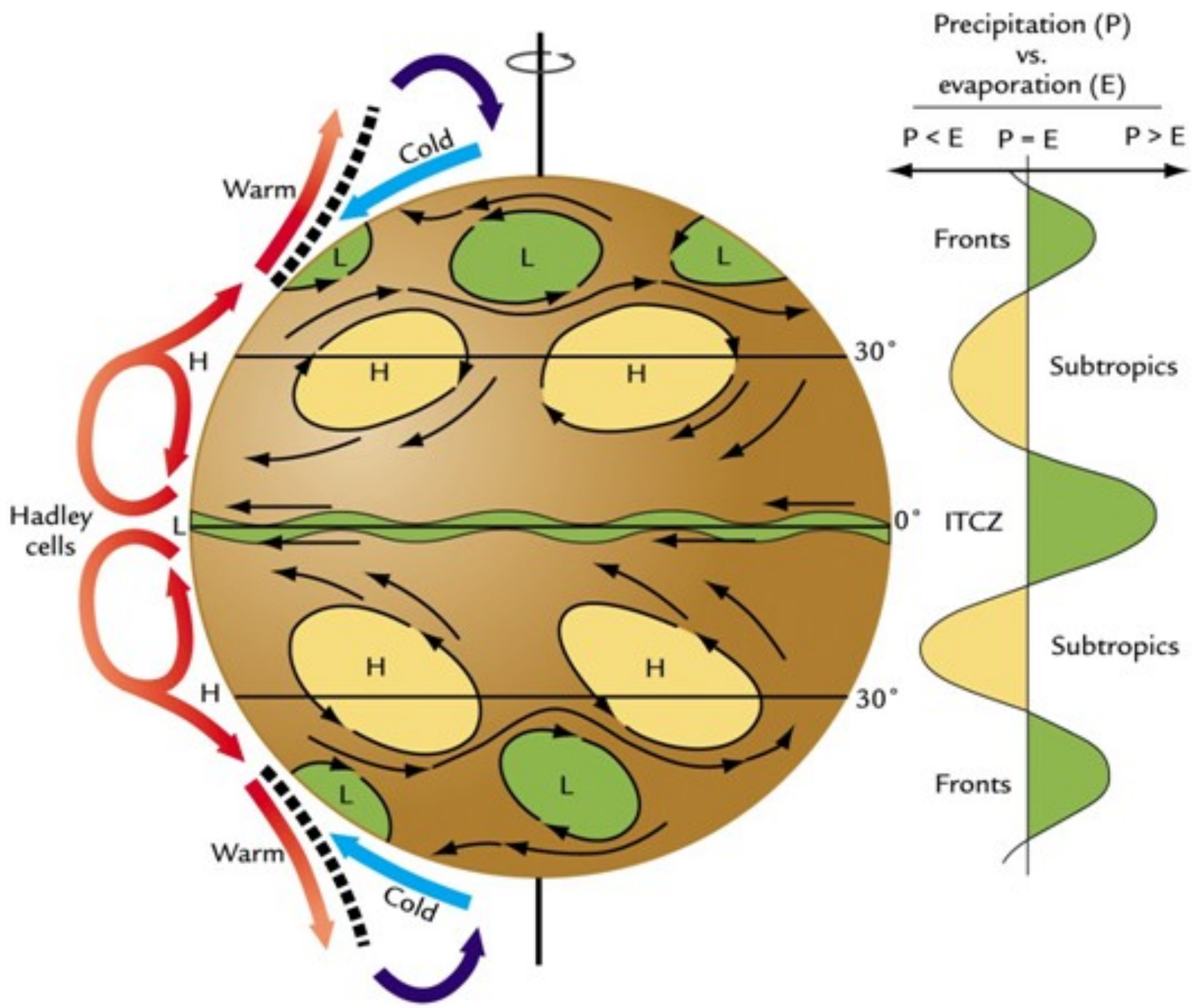
Comprehension Check

What causes the Coriolis Effect?

A. The difference in Earth's gravity between the equator and poles
B. The difference in rotation speed between the equator and poles
C. The temperature difference between the equator and poles
D. The elevation difference between the equator and the poles

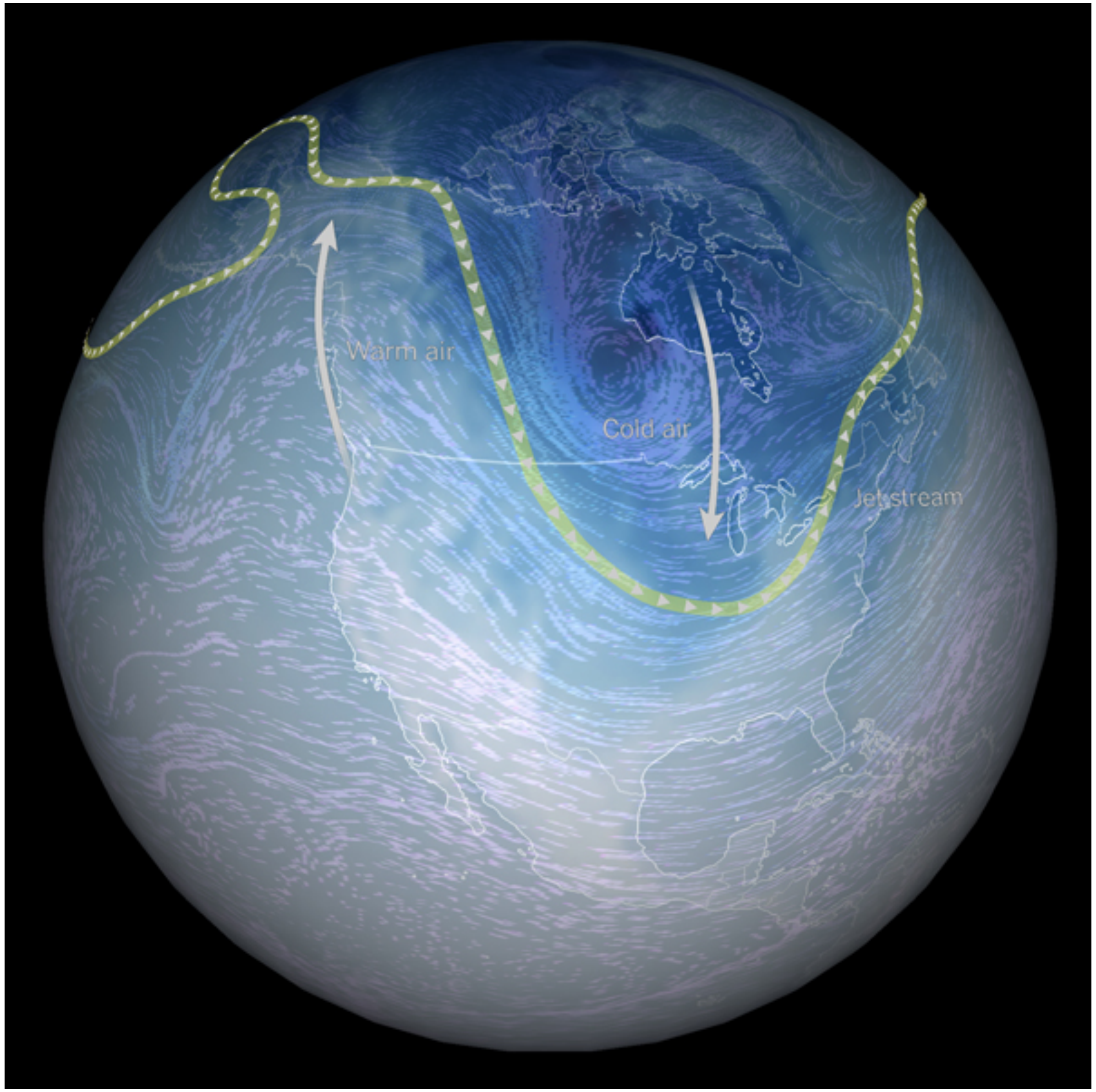
Consequences of Coriolis – High Latitudes

- Area of east-moving air at high latitudes in both hemispheres
- Formed by convergence of high and low pressure systems
- Called the 'Polar Jet'



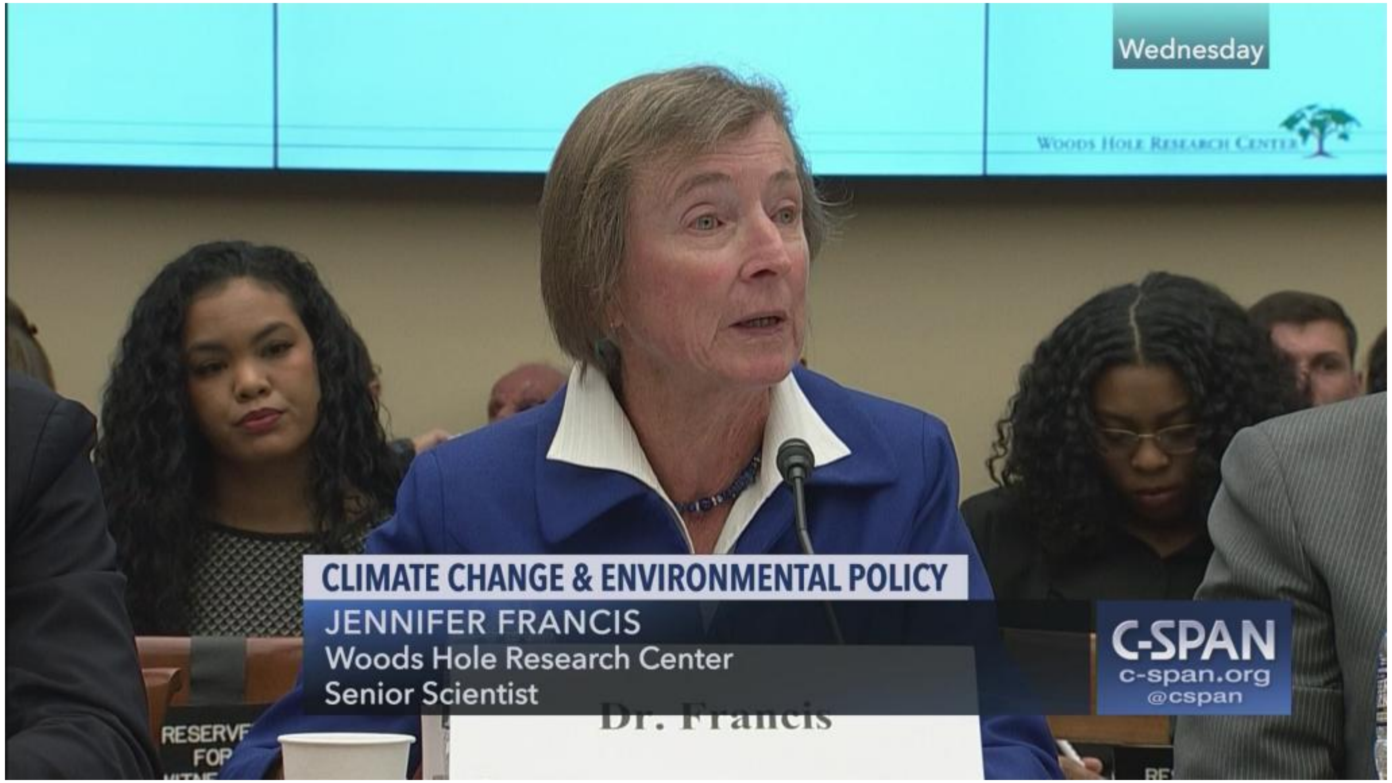
How Will This Affect You?

- The polar jet separates cold, polar air from warm, temperate air
- Is the jet stream becoming more wavy?
- Fast-warming Arctic may be responsible



Dr. Jennifer Francis – Jet Stream Expert

- Dr. Jennifer Francis is a senior scientist at Woods Hole Research Center (formerly from Rutgers)
- Research: How climate change is affecting the jet stream
- Jet stream might become more ‘loopy’



Dr. Francis testifying at a congressional hearing about climate change on Feb. 13, 2019.

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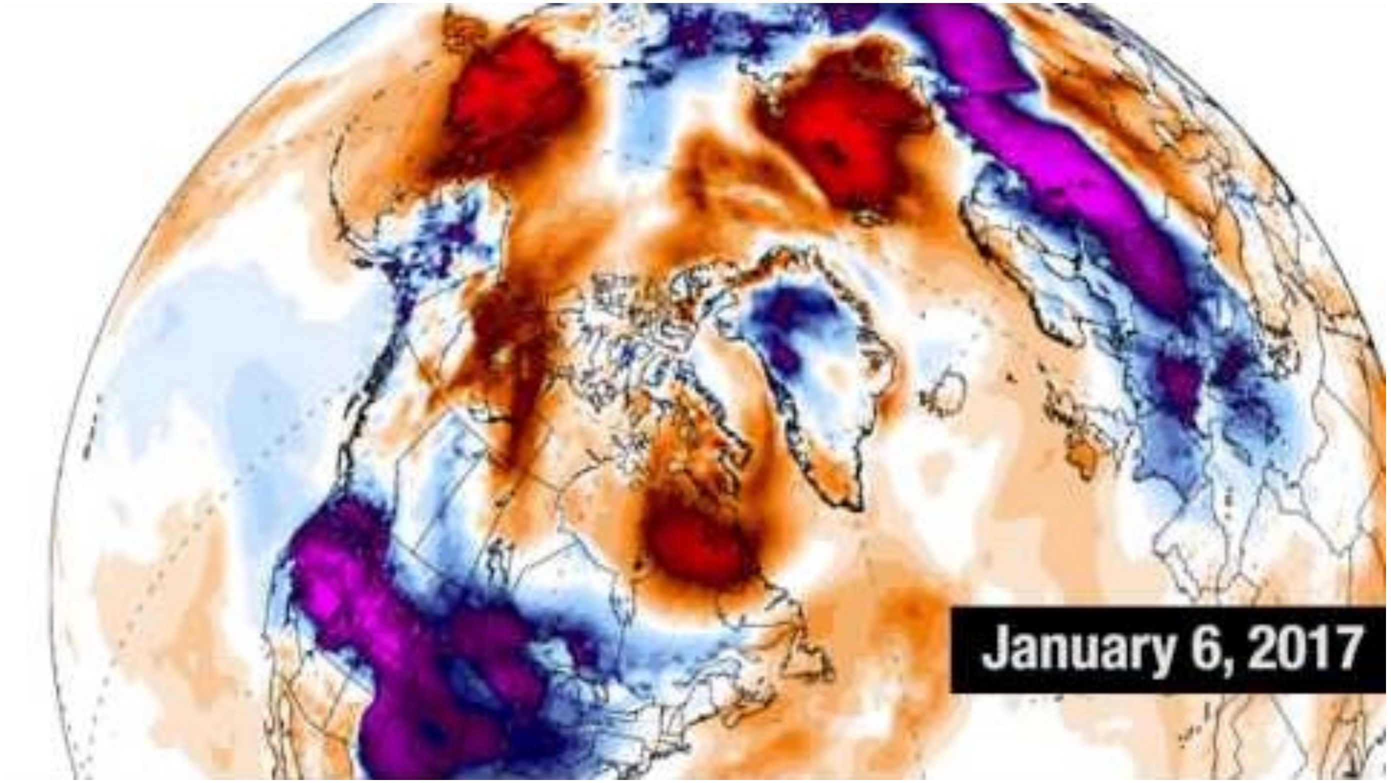
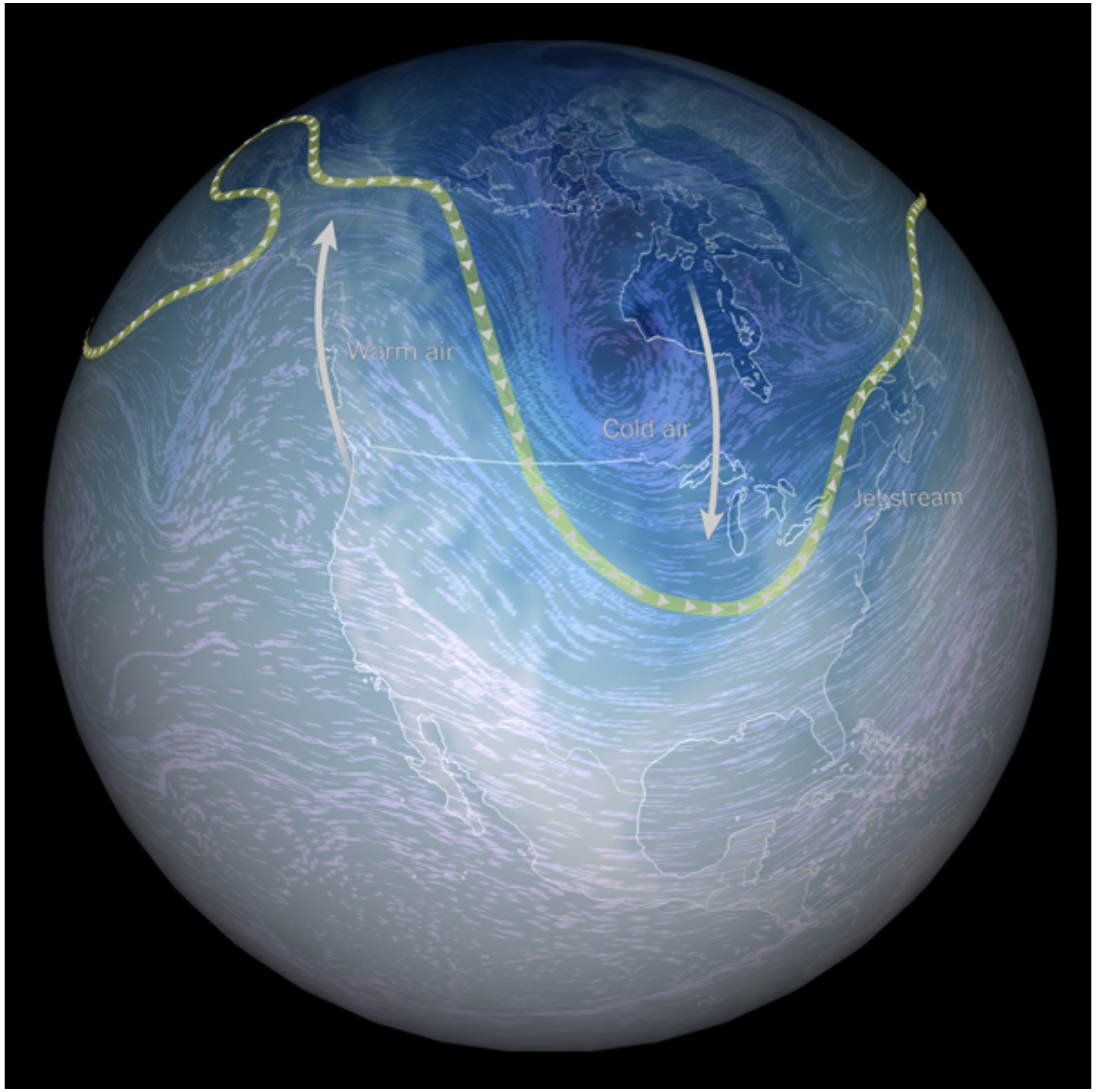


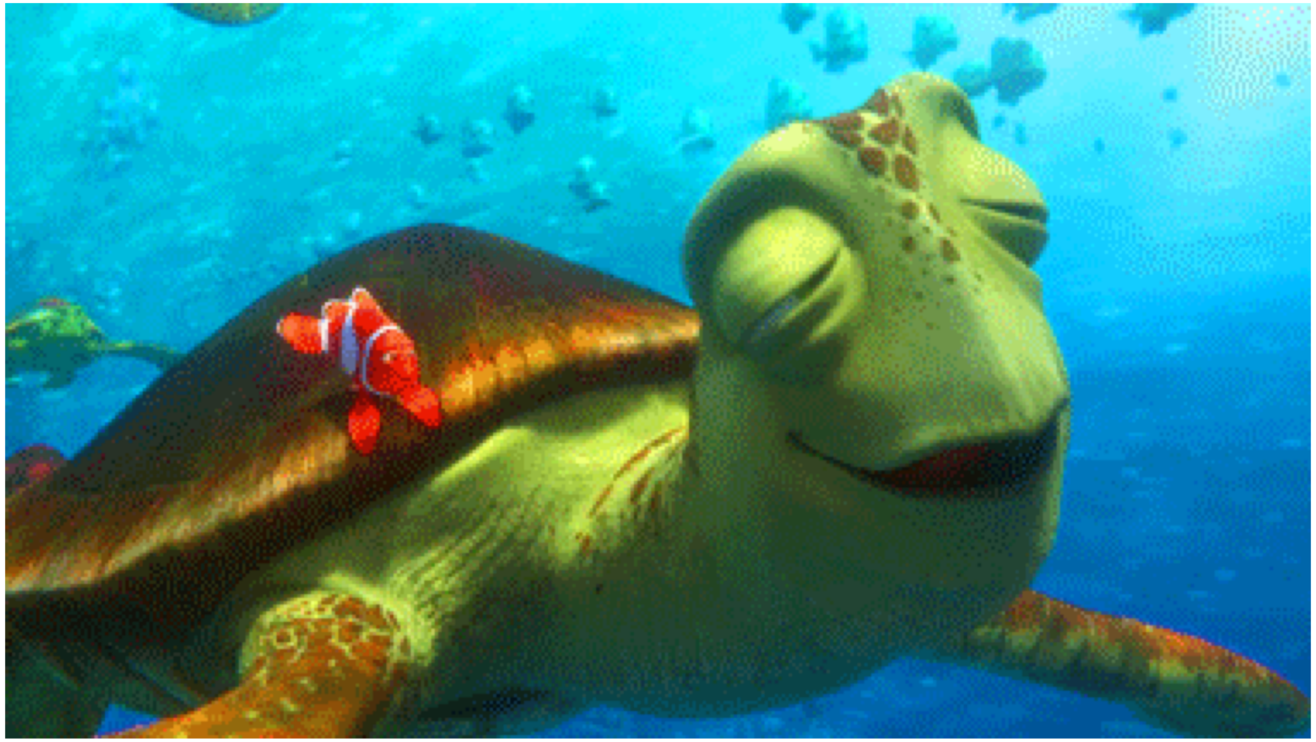
Dr. Francis testifying at a congressional hearing about climate change on Feb. 13, 2019.

Takeaways

Takeaway Messages:

- Atmospheric circulation is caused by unequal heating of the Earth
- Air moving from high to low pressure is deflected by the Coriolis Effect
- The polar jet is boundary between us and polar air
- Is it getting more loopy?





Class 4: The ocean's effect on climate

- How do ocean currents affect regional and global climate?
- How does the ocean impact temperature and carbon dioxide levels?

Learning Objectives

1. Draw a sketch of major ocean circulation patterns including overturning
2. Predict what would happen if ocean circulation were perturbed, specifically if overturning were to slow or cease
3. Explain how ocean currents result in the observed global distribution of climates
4. Describe how the ocean affects atmospheric carbon dioxide levels and temperature