

Geoscience

GEOLOGY, ATMOSPHERE & WEATHER, ECOLOGY, & HUMAN SYSTEMS



GEOSCIENCE

Suggested pacing: 3 lessons per week

Unit	Lesson	Date	Topic	Pages	
GEOLOGY	Intro	Wed, Jan 21	Introduction and Tips for Success		
	1	Mon, Jan 26	Continental Drift	4-5	
	2	Wed, Jan 28	Plate Boundaries	6-7	
	3	<i>Self-paced</i>	Activity: A Ring of Fire	8-11	
	4	Mon, Feb 2	Weathering vs Tectonics	12-13	
	5	Wed, Feb 4	Faults and Earthquakes	14-15	
	6	<i>Self-paced</i>	Activity: Shake, Rattle, Resilient	16-17	
	7	Mon, Feb 9	Go With the Flow	18-19	
	8	Wed, Feb 11	The Cryosphere	20-21	
	9	<i>Self-paced</i>	Activity: Stream Table Study	22-23	
	10	Mon, Feb 16	How Old are Rocks?	24-25	
	11	Wed, Feb 18	Geologic Time	26-28	
	12	<i>Self-paced</i>	Geology Unit Assessment	29-31	
WEATHER & ATMOSPHERE	13	Mon, Feb 23	Geology Quiz Show	-	
	14	Wed, Feb 25	Relative Humidity	32-34	
	15	<i>Self-paced</i>	Activity: Cloud in a Jar	35	
	16	Mon, Mar 2	Heat Index and Windchill	36-37	
	17	Wed Mar 4	Air Masses and Fronts	38-39	
	18	<i>Self-paced</i>	Activity: Humidity Lab	40-41	
	19	Mon, Mar 9	Global Weather Patterns	42-43	
	20	Wed, Mar 11	Ocean Currents	44-45	
	21	<i>Self-paced</i>	Activity: Convection Convention	46-49	
	March 16-20: SPRING BREAK				
	22	Mon, Mar 23	ENSO: El Niño-Southern Oscillation	50-51	
	23	Wed, Mar 25	The Weather Forecast	52-53	
	24	<i>Self-paced</i>	Activity: Tropical Storm Quest	54-57	
	25	Mon, Mar 30	Tropical Cyclones	58-59	
	26	Wed, Apr 1	Weather Quiz Show		
	27	<i>Self-paced</i>	Weather & Atmosphere Unit Assessment	60-63	
28	Mon, Apr 6	Understanding Ecosystems	64-65		
ECOLOGY & HUMAN SYSTEMS	29	Wed, Apr 8	Keystone Species	66-67	
	30	<i>Self-paced</i>	Activity: Stackable Food Chain and Food Web	68-71	
	31	Mon, Apr 13	Nutrient Cycles	72-73	
	32	Wed, Apr 15	Succession	74-75	
	33	<i>Self-paced</i>	Activity: Composting	76-79	
	34	Mon, Apr 20	Ecosystem Resilience	80-81	
	35	Wed, Apr 22	Human Geography	82-83	

Unit	Lesson	Date	Topic	Pages
ECOLOGY & HUMAN SYSTEMS	36	<i>Self-paced</i>	Activity: Invasive Species Comic	84-85
	37	Mon, Apr 27	Agriculture	86-87
	38	Wed, Apr 29	Greenhouse Effect & Energy Choices	88-89
	39	<i>Self-paced</i>	Activity: Natural Resource Scavenger Hunt	90-91
	40	Mon, May 4	5 Myths About Climate Change	92-94
	41	Wed, May 6	5 Solutions to Climate Change	95-97
	42	<i>Self-paced</i>	Ecology & Human Systems Unit Assessment	98-101
	43	Mon, May 11	Final Quiz Show	

SUPPLY LIST:

Lesson 3 - Map the Ring of Fire

- Pencil & colored pencils or crayons
- Internet connection or book(s) to use for researching volcanoes and earthquakes

Lesson 6 - Shake, Rattle, Resilient

- A small box
- Cardboard (at least 3x as long as the small box)
- Cylindrical pencils or markers
- Smart phone
- Various household objects

Lesson 9 - Stream Table Study

- Sand and gravel
- Plastic paint tray or a long bin or storage container
- Drill or nail
- Rocks or brick to elevate tray/container
- Cups or an empty gallon jug

Lesson 15 - Cloud in a Jar

Adult supervision recommended

- 4 glass jars with lids
- Ice
- Water
- Matches
- Paper or tape and pen for making labels

Lesson 18 - Humidity Lab

- A small piece of cloth or gauze
- Fan
- Rubber band
- 2 identical thermometers

Lesson 21 - Convection Convention

Adult supervision recommended

- 2 to 4 identical clear cups
- 2 paper cups (will need to be cut)
- Stiff wire taller than the paper cups
- Scissors or exacto knife
- Thin flat piece of plastic
- Food coloring
- Water (some of it heated to be very warm)
- Ice cubes

- Salt
- Tray
- 1 large clear container
- Pencil
- Matches
- Tea candle

Lesson 24 - Hurricane Tracker

- Pencil & colored pencils or crayons
- Internet connection or book(s) to use for researching a historic hurricane

Lesson 30 - Build a Food Web

- Cardboard
- Colored pencils, crayons, or markers
- Yarn
- Tacks or pins
- Scissors
- Gluestick

Lesson 33 - Competing Compost Jars

- 2 identical clear containers
- Lids for the containers with ventilation holes OR 2 pieces of cloth and 2 rubber bands
- Newspaper
- Scissors
- Grass clippings or vegetable scraps such as carrot peels, apple cores, or squash rinds etc
- A small sample of soil, if possible, containing invertebrates such as earthworms, millipedes etc

Lesson 36 - Invasive Species Comic

- Cardboard
- Colored pencils, crayons, or markers
- Scissors
- Gluestick

Lesson 39 - Natural Resource Scavenger Hunt

- Pencil and lesson handout

CONTINENTAL DRIFT

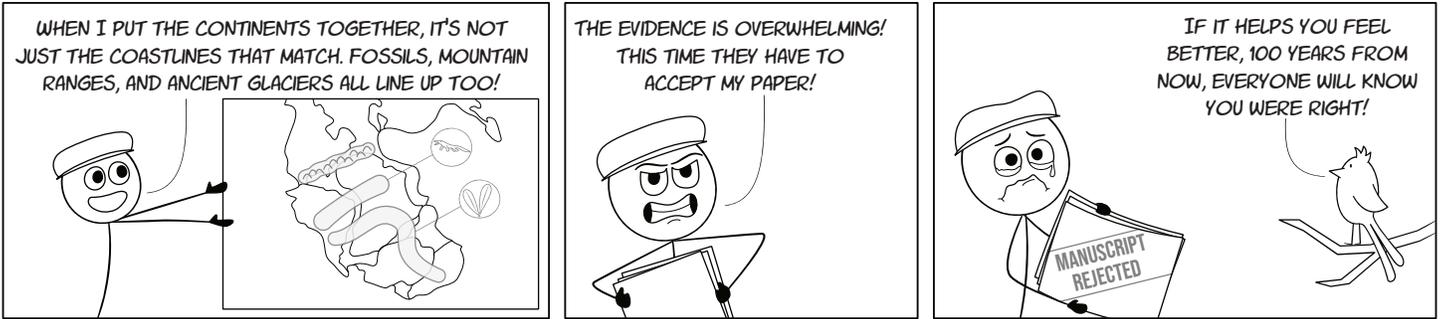


PLATE TECTONICS THE BEDROCK THEORY OF GEOLOGY

HOW IT WORKS

WHAT IT IS

Draw lines to match the terms with the correct description, then label each term on the diagram below:

Crust

Inner Core

Mantle

The "Moho" or Mohorovičić discontinuity

Outer Core

The hottest layer of the planet

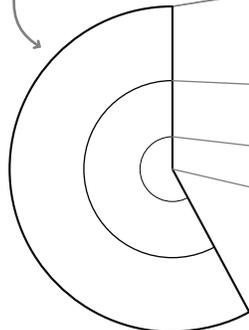
Solid silicate rock that is brittle near its surface

A silicate rock layer that makes up more than 60% of the mass of the Earth

A liquid layer mostly made of iron and nickel

The boundary between crust and mantle; the depth where earthquake waves speed up as they move from less-dense crust into denser mantle

TO SCALE



NOT TO SCALE

Use the descriptions below to identify and color each of the major tectonic plates:

RED Indian Plate
Smallest major plate; formed the Himalayas

PINK North American Plate
This plate is moving over the Yellowstone hotspot

ORANGE South American Plate
Contains the Amazon rainforest

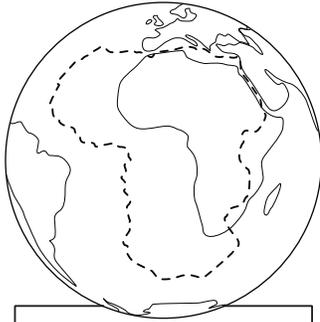
YELLOW African Plate
A plate bordered by rift zones that form deep lakes

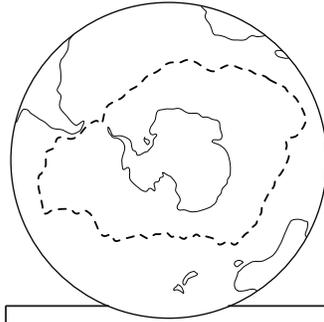
GREEN Australian Plate
Fastest moving continental plate; north at 6.9 cm/yr

LIGHT BLUE Antarctic Plate
A plate with no human cities, only research stations

BLUE Pacific Plate
Largest tectonic plate; primarily oceanic crust

PURPLE Eurasian Plate
This plate contains most of Europe



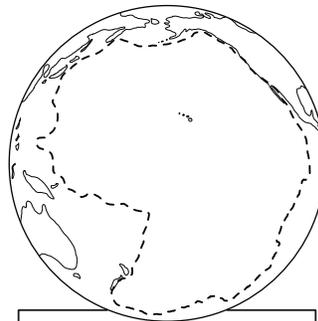


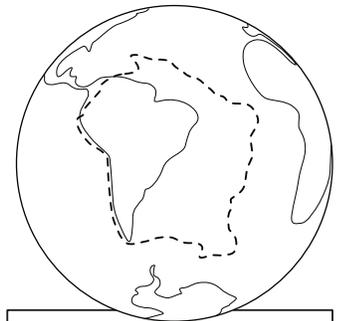












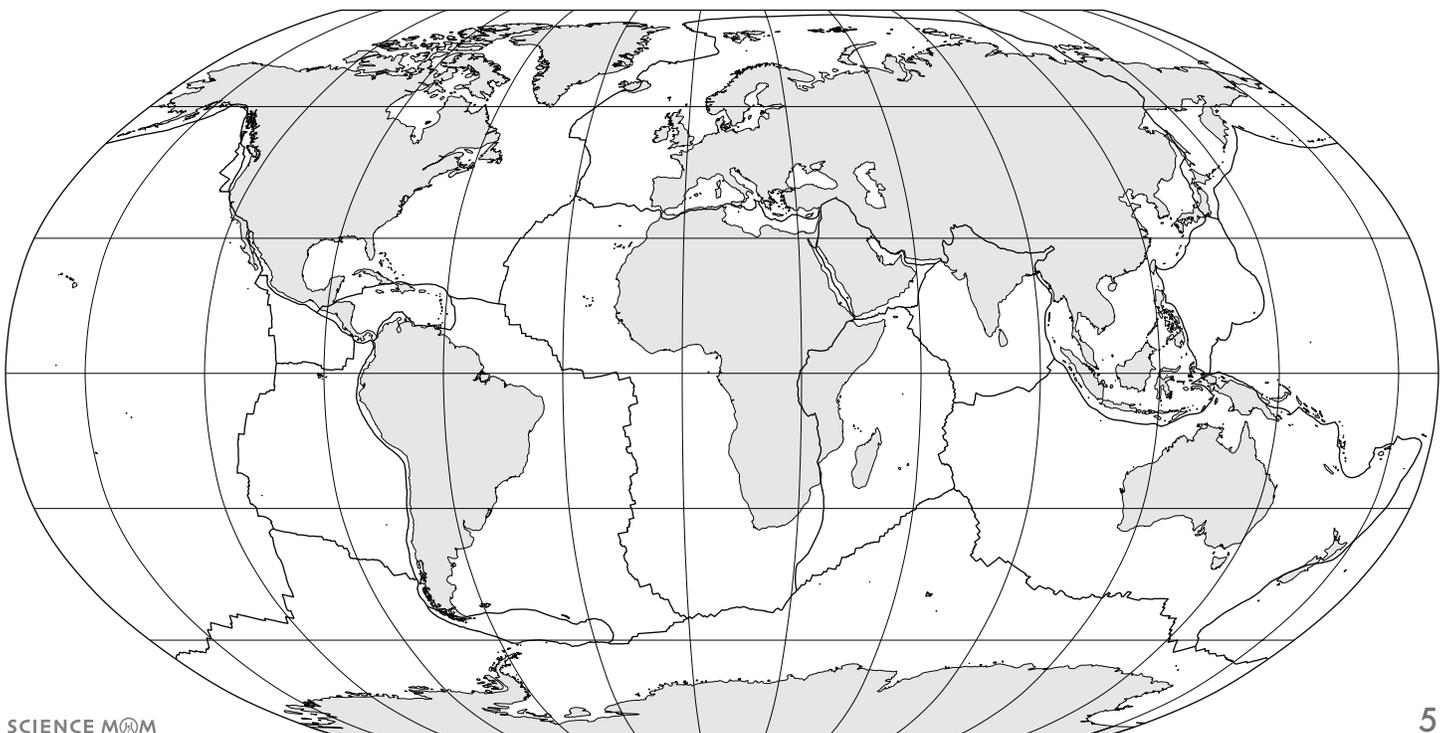
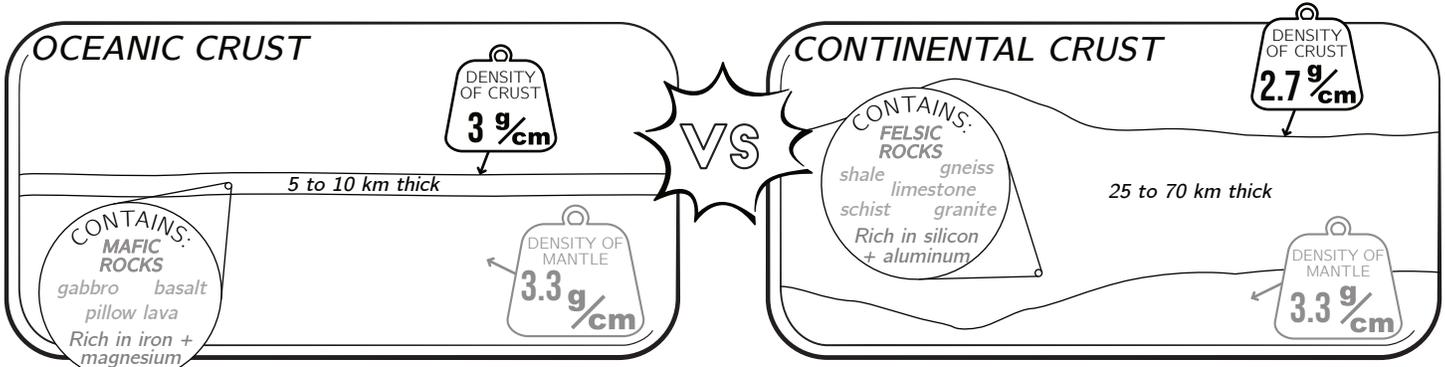
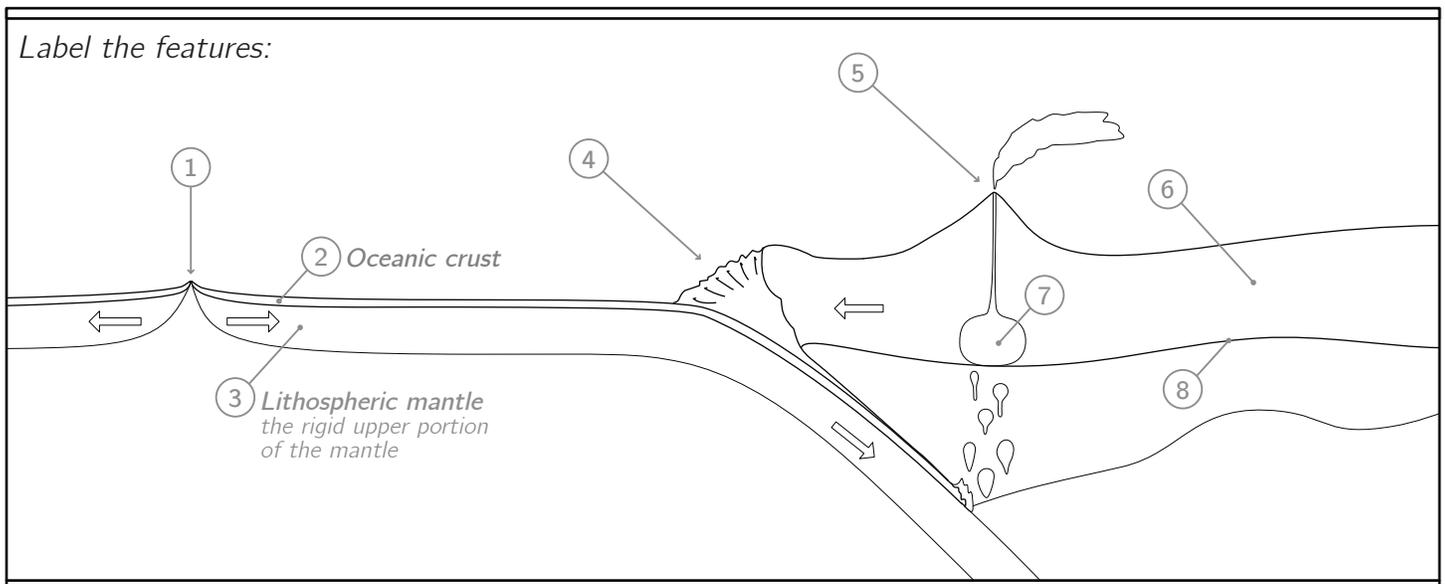


PLATE BOUNDARIES



TYPES OF PLATE BOUNDARIES

<p>Definition:</p> <p>Ex:</p>	<p>Definition:</p> <p>Ex:</p>	<p>Definition:</p> <p>Ex:</p>
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Explain how plate tectonics caused or influenced each event or geologic feature:



COTOPAXI

In 1877, Cotopaxi erupted with a violent explosion that destroyed the town of Latacunga, Ecuador.

The volcano produced enormous pyroclastic flows of hot gas and volcanic material which melted all of the ice cap on the volcano. This caused mudflows or lahars that traveled to the Pacific Ocean, more than 100 km away.



2002 DENALI EARTHQUAKE

This magnitude 7.9 quake lasted for almost 3 minutes. It caused thousands of landslides, fractured glaciers, and displaced roads and streams up to 29 feet from their original location. It even caused sloshing in lakes as far away as Louisiana!



LAKE BAIKAL

Lake Baikal is over 1,600 m deep and contains approximately 20% of Earth's surface water. It is both the largest and oldest freshwater lake in the world, and is getting larger by approximately 4 mm each year. Deep hydrothermal vents release heated, mineral-rich water into the lake.

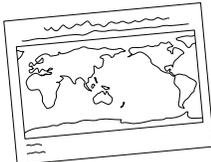


HAWAIIAN ISLANDS

The Hawaiian-Emperor seamount chain is an enormous chain of volcanic islands, atolls, and seamounts that stretch for 6,200 km across the Pacific Ocean. The eastern-most islands contain the most active volcanoes on Earth.

ACTIVITY: A RING OF FIRE

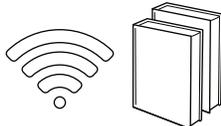
MATERIALS



World map printout from page 11 OR any world map with latitude and longitude



Crayons, colored pencils, or other coloring supplies



Internet connection OR books about volcanoes & earthquakes

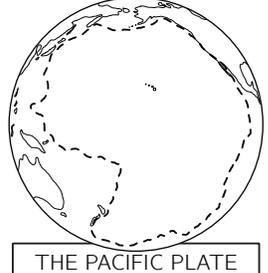
GOALS

- ★ To recognize patterns with how volcano and earthquake locations relate to plate boundaries
- ★ To discover and learn more about the "Ring of Fire"
- ★ Practice researching a topic independently

DIRECTIONS

- 1 Read the charts on page 10 showing the largest volcanoes and earthquakes that have occurred in the past two decades. Use the latitude and longitude coordinates to find the locations of each earthquake and volcano and mark them with different colors on the map.
- 2 Use the completed map and other resources such as books or an internet search engine to answer questions A through F on this page and page 9.

A The zone with highest volcanic and quake activity on Earth is called "The Ring of Fire." Bob says the Ring of Fire circles the entire Pacific plate. Raina says the Ring of Fire is shaped like a horseshoe that's bigger than the Pacific plate. Do the points you plotted on page 11 support Bob's argument or Raina's?



THE PACIFIC PLATE

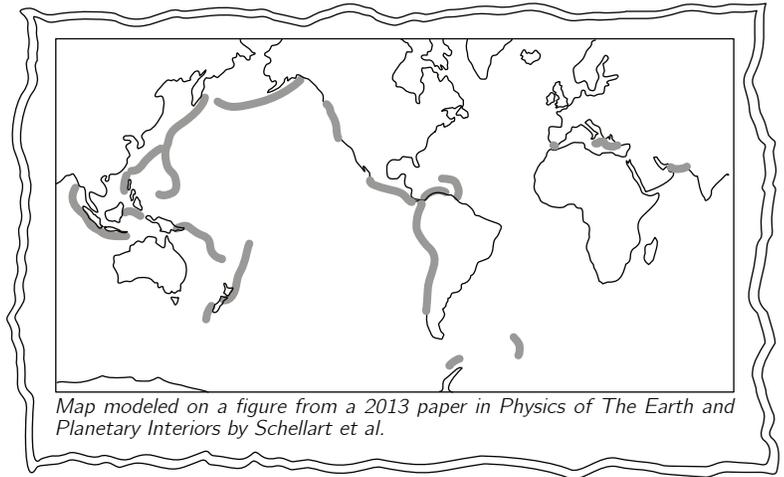
B Why is there is no "Ring of Fire" around the Atlantic Ocean?

C How is volcanic activity at a divergent boundary (like Iceland) different from volcanic activity at a convergent boundary (like Japan)? Which location is typically more dangerous?

D The grey lines in this map show the location of the world's subduction zones.

If you were given the house of your dreams but it had to be built on one of these subduction zones, which location would you choose and why? Would you make any modifications to your dream house due to the location?

If desired, use another paper to illustrate your dream home and describe where it would be.



E Look it up! What percentage of the world's volcanoes and earthquakes occur on the Ring of Fire?

F Between 1900 and 2025, there have been 5 earthquakes with a magnitude of 9 or greater:

- 1952 Severo-Kurilsk earthquake
- 1960 Valdivia earthquake
- 1964 Alaska earthquake
- 2004 Indian Ocean earthquake
- 2011 Tōhoku earthquake

Choose one of these quakes to research. How long did shaking last during the main quake? Did the quake produce tsunamis or landslides? Create a visual of how the landscape/towns looked before and after the quake. You can use 3-D materials such as lego blocks, draw a picture, or find photos from online. If the same quake happened were to happen again in the same area, what disaster preparation steps would you recommend?

FACT OR FICTION? Write your verdict below each statement:

An area with large earthquakes will also experience high levels of volcanic activity

IT'S LIKE NATURE'S OWN BOGO SALE!

Scientists can predict the date and time a volcano will erupt, similar to how they can predict when an eclipse will occur.

ERUPTION COUNTDOWN

05	22	17
DAYS	HOURS	MINUTES

Measured from base to peak, the tallest mountain on Earth is a volcano.

ASH-TOUNDING!

YEAR	VOLCANO	LAT	LONG	VEI or DESCRIPTION
2022	Hunga Tonga–Hunga Ha’apai	-20.55	-175.38	VEI 5; plume reached the mesosphere
2008	Chaitén	-42.83	-72.65	VEI 5; rhyolitic eruption
2011	Puyehue–Cordón Caulle	-40.59	-72.12	VEI 5; widespread ash fallout.
2011	Grímsvötn	64.42	-17.32	VEI 4; ash plume up to 20 km
2019	Raikoke	48.29	153.25	VEI 4; with significant SO ₂ release
2020	Taal	14.0	121	VEI 4; phreatomagmatic eruption
2008	Kasatochi	52.18	-175.51	VEI 4; large SO ₂ and ash release.
2014	Kelud	-7.94	112.31	VEI 4; ash plume to 26 km
2018	Anak Krakatau	-6.1	105.42	VEI 3–4; tsunami
2006	Augustine	59.36	-153.44	VEI 3–4; ash deposits over 200 km away
2014	Ontake	35.89	137.48	VEI 3; Phreatic eruption
2018	Fuego	14.48	-90.88	VEI 3; Produced deadly lahars
2015	Wolf	0.02	-91.35	VEI 2; Extensive lava flows.
2018	Kīlauea (Lower East Rift Zone)	19.42	-155.0	VEI 0; but ~1.4 km ³ lava volume.
2021	Cumbre Vieja	28.57	-17.83	85 day-long eruption; 1 km ³ lava

15 of the largest volcanic eruptions

VEI EXPLAINED

The volcanic explosivity index (VEI) measures the size or scale of an explosive eruption. It assigns a numerical value to the eruption based on volume of ejected material, cloud height, and qualitative descriptions of the eruption

A VEI of 0 or 1 describes an effusive eruption such as a relatively slow and calm lava flow from Kīlauea on Hawai‘i. These are occurring somewhere on Earth almost constantly.

An eruption with a VEI of 5 is a cataclysmic eruption that can send ash over 20 kilometers high and injecting substantial material into the troposphere. These occur roughly every 12 years.

Colossal eruptions with VEIs of 6 occur every 50-100 years. Eruptions with a VEI of 7 only occur every 500 - 1,000 years. The highest value (VEI 8) describes eruptions such as the Yellowstone supervolcano 1.2 mya. Fortunately, these occur more than 50,000 years apart.

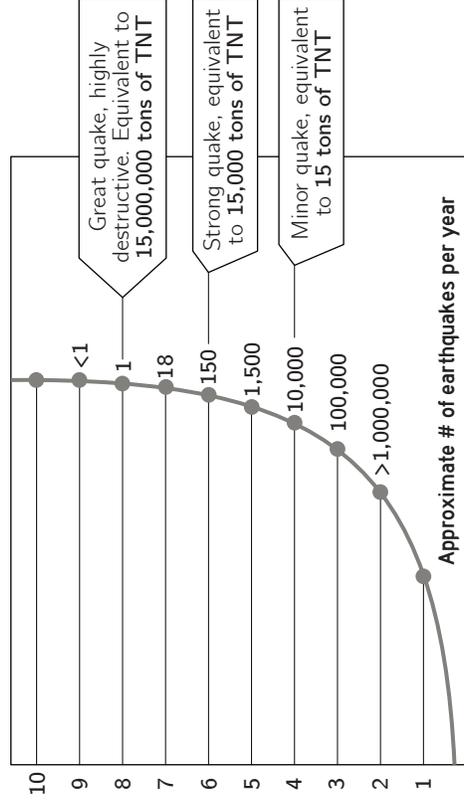
15 of the largest earthquakes from the last 25 years

YEAR & EARTHQUAKE NAME	Mw	LAT	LONG
2011 Tōhoku, or Great East Japan Earthquake	9.1	38.30	142.37
2004 Indian Ocean/Sumatra Earthquake	9.1	3.30	95.98
2025 Kamchatka Earthquake	8.8	52.5	160.24
2010 Chile Earthquake	8.8	-36.12	-72.9
2012 Indian Ocean Earthquakes	8.6	2.33	93.06
2007 Bengkulu Earthquakes	8.4	-4.44	101.37
2017 Chiapas Earthquake	8.2	15.02	-93.90
2014 Iquique Earthquake	8.2	-19.61	-70.77
2018 Fiji Deep Earthquake	8.2	-18.11	-178.15
2021 Chignik Alaska Earthquake	8.2	55.36	-157.89
2021 South Sandwich Islands Earthquake	8.1	-58.38	-25.26
2007 Solomon Islands Earthquake	8.1	-8.47	157.04
2009 Samoa Earthquake	8.1	-15.49	-172.1
2006 Tonga Earthquake	8.0	-20.19	-174.12
2007 Peru Earthquake	8.0	-13.39	-76.6

All lat/long values from USGS

The Moment Magnitude Scale (Mw)

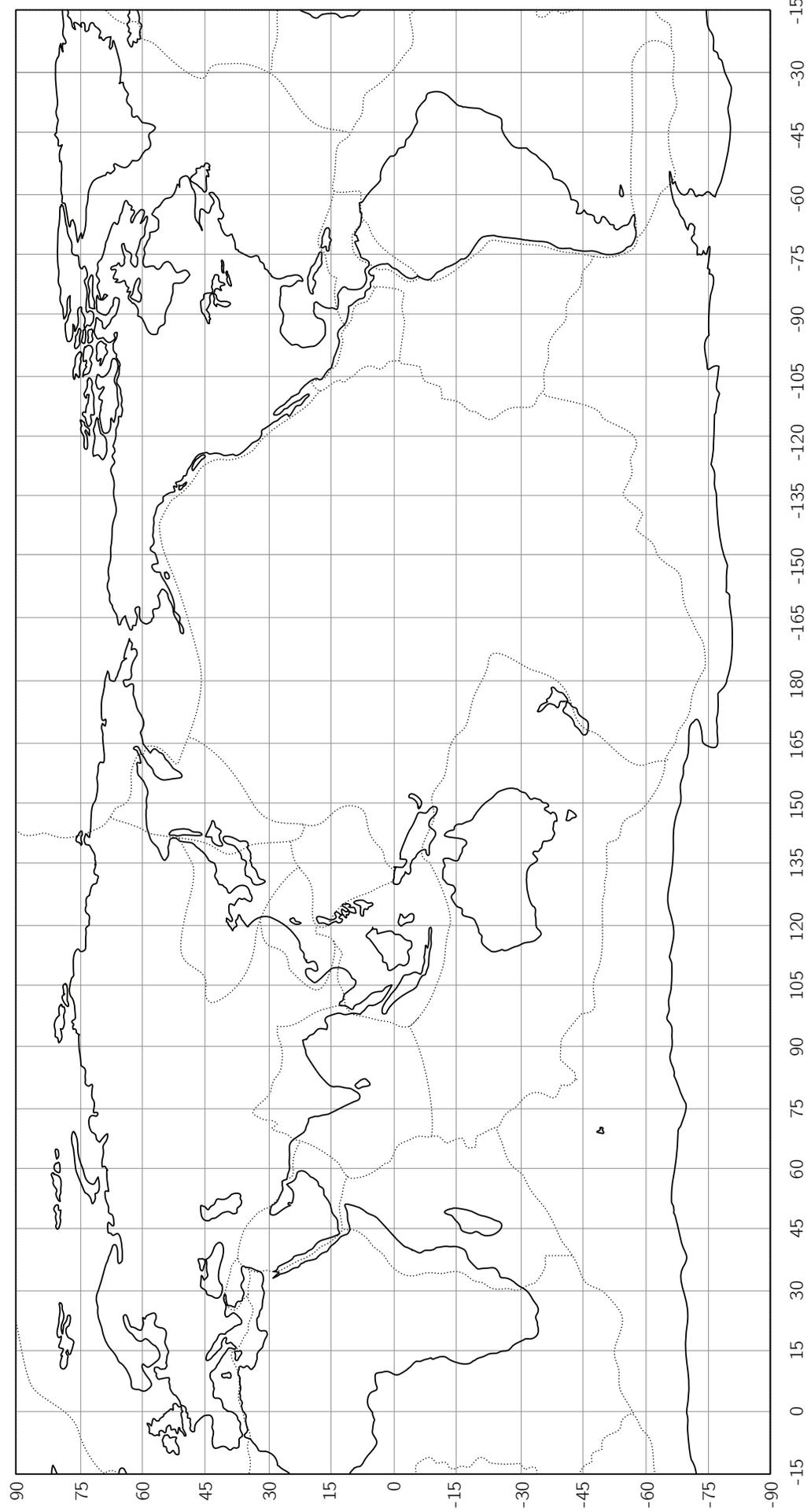
similar to but more accurate than the older Richter scale



10.6 is the highest possible value because at that level, the entire crust of the Earth would break apart.

A PACIFIC-CENTERED WORLD MAP

This is an equirectangular projection - also known as "Plate Carrée" (French for flat square). It is a useful for plotting latitude and longitude but it is NOT accurate for distances and shapes of landmasses. The closer a landmass is to the poles, the more distorted it is.



- Earthquake
- △ Volcanic Eruption

WEATHERING VS TECTONICS



SHAKE BOTTLE TEST

1) SUGAR CUBES + CHALK:

Make a prediction, which material will change in shape more after 1 min of shaking?

SUGAR CUBES

CHALK

RESULT: _____

2) CHALK + AQUARIUM GRAVEL:

Make a prediction, which material will change in shape more after 1 min of shaking?

CHALK

GRAVEL

RESULT: _____

3) AQUARIUM GRAVEL + STEEL BALL BEARINGS:

Make a prediction, which material will change in shape more after 1 min of shaking?

GRAVEL

STEEL

RESULT: _____

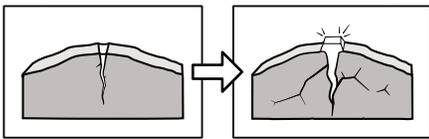
Draw lines to match each type of **weathering** with its corresponding description. Then list examples of each:

Mechanical

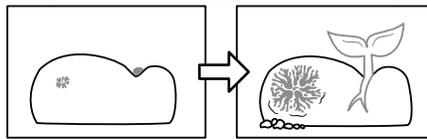
Chemical

Biological

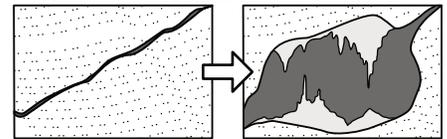
The breaking of a rock into smaller pieces without any chemical change occurring; also called physical weathering



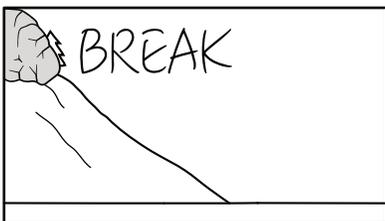
Physical or chemical change to a rock which is caused by living organisms



The chemical composition of a rock is changed through reactions with substances such as water and oxygen

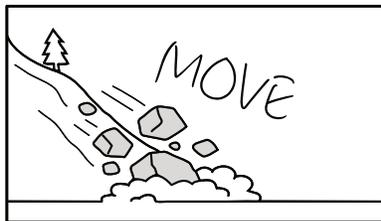


WEATHERING



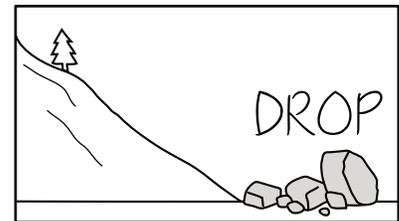
The breakdown of rocks or minerals into smaller pieces

EROSION



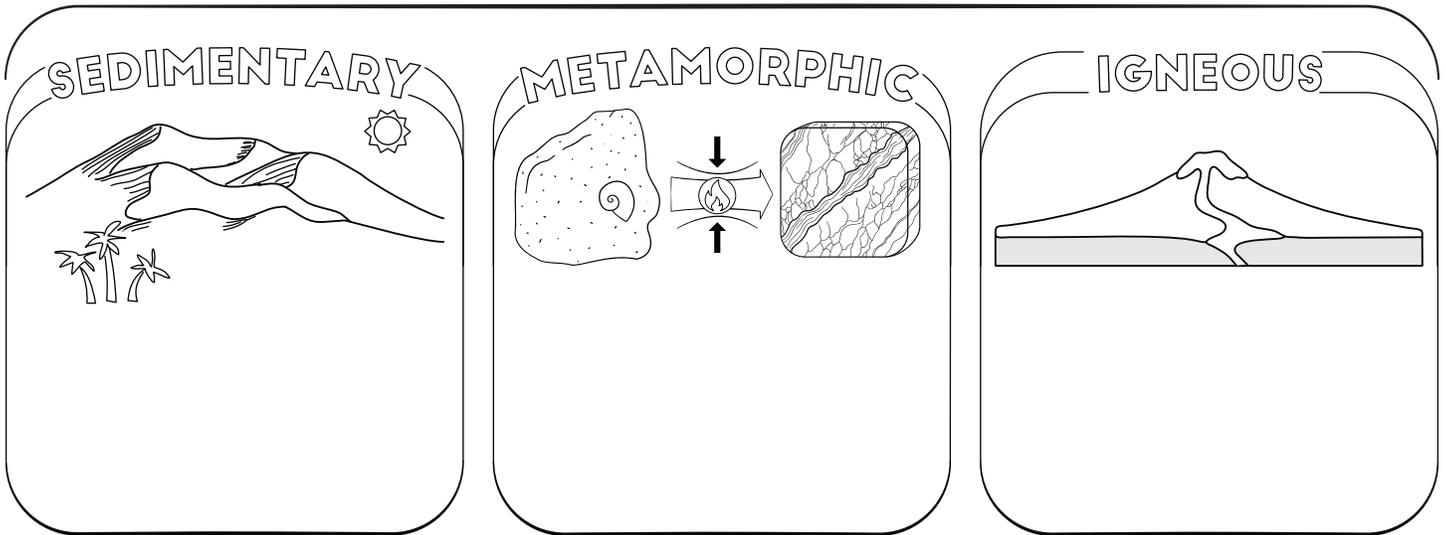
The movement of weathered material from one location to another by natural forces

DEPOSITION



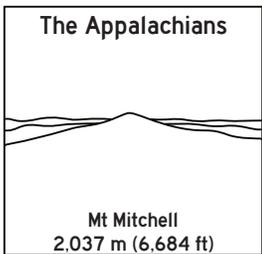
When rock or sediment is deposited or laid down in a new location

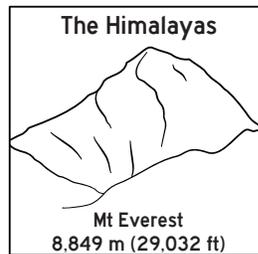
Review: How are the three types of rocks formed?

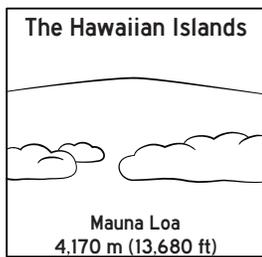


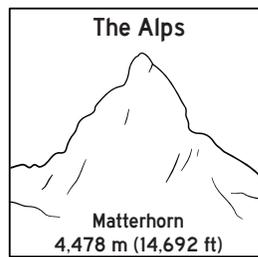
Are these famous mountains growing or shrinking?

For each mountain, take notes on how it was formed, its estimated age, & how its size is changing.





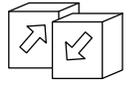
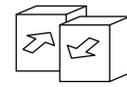
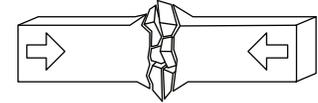
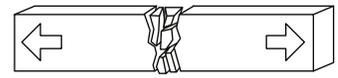




FAULTS AND EARTHQUAKES

Force applied to a rock is called **stress**. It comes in three types:

1. _____ is stress with forces pulling in opposite directions.
2. _____ is stress with forces pushing toward each other.
3. _____ is stress which is transverse, with rocks or regions of rock moving past each other.



If the stress a rock receives is greater than the internal strength of the rock, it will experience **strain**. Strain can deform a rock in three ways:

ELASTIC	DUCTILE	BRITTLE
<p>BEFORE STRAIN DURING STRAIN AFTER STRAIN</p>	<p>BEFORE STRAIN DURING STRAIN AFTER STRAIN</p>	<p>BEFORE STRAIN DURING STRAIN AFTER STRAIN</p>

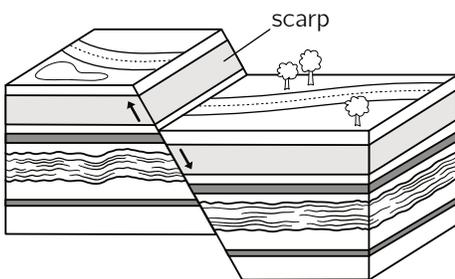
Whether a deformation is elastic, ductile, or brittle depends on a variety of factors such as rate of strain, rock strength, or temperature. Consider each factor below. Would it make a rock more or less likely to break?

<p>HIGHER TEMPERATURE</p> <p><input type="checkbox"/> LESS BRITTLE </p> <p><input type="checkbox"/> MORE BRITTLE</p>	<p>LOWER STRAIN RATE <i>(STRESS APPLIED SLOWLY)</i></p> <p><input type="checkbox"/> LESS BRITTLE </p> <p><input type="checkbox"/> MORE BRITTLE</p>	<p>STRONGER ROCK</p> <p><input type="checkbox"/> LESS BRITTLE </p> <p><input type="checkbox"/> MORE BRITTLE</p>	<p>LOWER TEMPERATURE</p> <p><input type="checkbox"/> LESS BRITTLE </p> <p><input type="checkbox"/> MORE BRITTLE</p>
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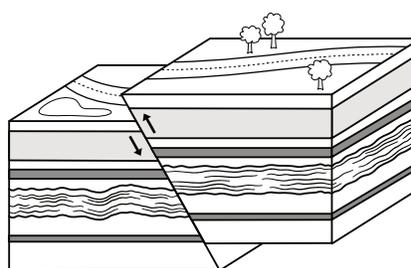
The location where a brittle deformation occurs between two sections of rock moving relative to each other is called a **fault**.

3 TYPES OF FAULTS

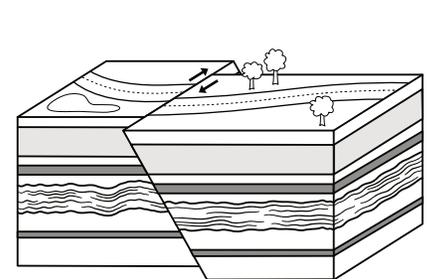
1. NORMAL



2. REVERSE



3. SLIP-STRIKE

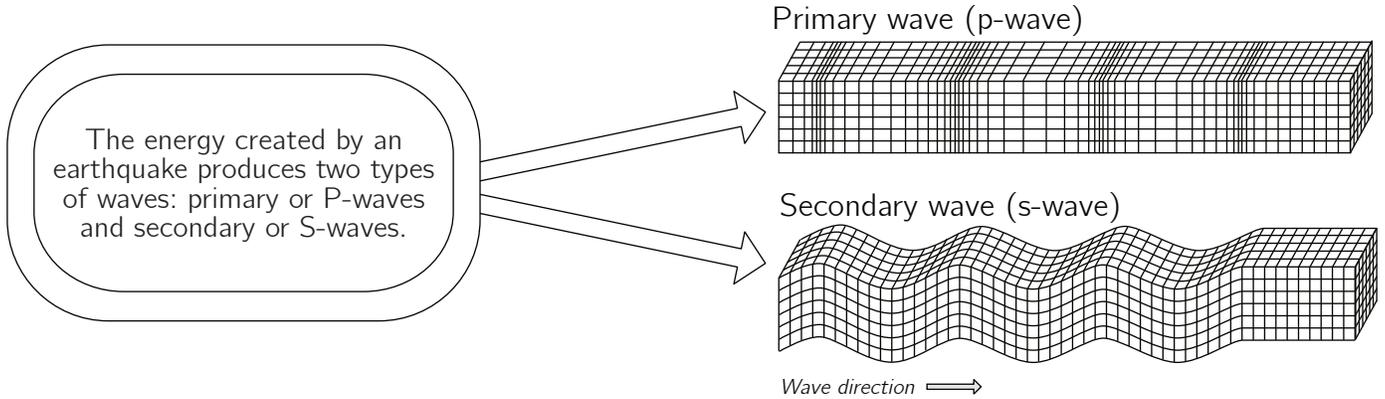
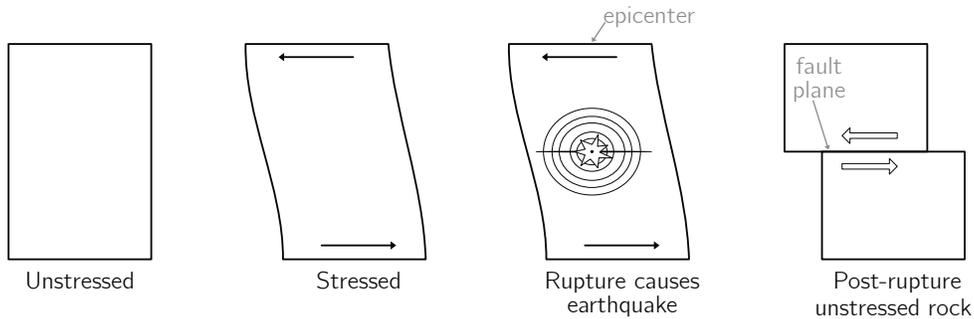


What type of **STRESS** do you think is most often associated with each type of fault?

FILL IN THE BLANKS (WORDS FROM THE BOX MAY BE USED MORE THAN ONCE OR NOT AT ALL)

earthquake energy epicenter fault
focus larger rupture smaller

An _____ is the release of _____ caused by movement of rock along a _____. When applied stress exceeds the strength of the rock, it will _____. The initial point of rupture is called the _____. The surface location above the focus is called the _____. The greater the displacement of rock during an earthquake, the _____ the release of seismic energy will be.



Draw lines to match the following descriptions to either P-waves or S-waves:

Speed: about 6–8 km/s in crustal rock	P-Waves	Usually cause only minor shaking at the surface
Travel through solids only (not liquids or gases)		Motion is shear (side-to-side or up-and-down)
Cause stronger shaking and damage at the surface	S-Waves	Speed: about 3–4 km/s in crustal rock
Travel through solids, liquids, and gases		Motion is compressional (push-pull, like a slinky)

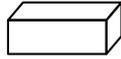
Think about it: If the fastest and least destructive waves (p-waves) reach seismic stations first, can we use that to predict destructive earthquakes? Why or why not?

ACTIVITY: SHAKE, RATTLE, RESILIENT

MATERIALS



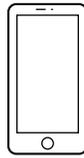
Cardboard (at least 3x as long as the small box)



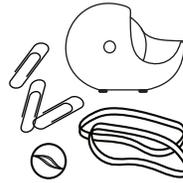
Small box



Cylindrical pencils or markers



Smart phone



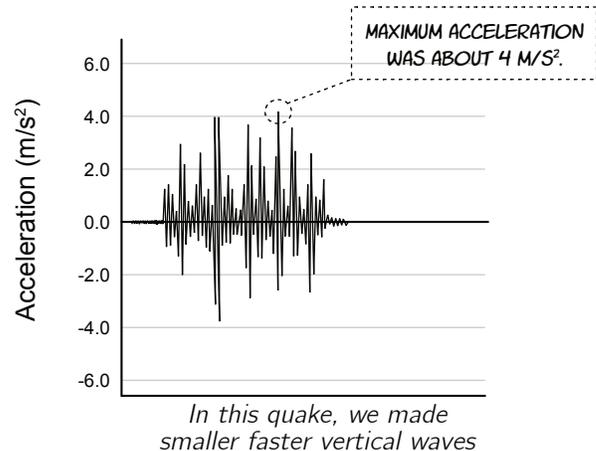
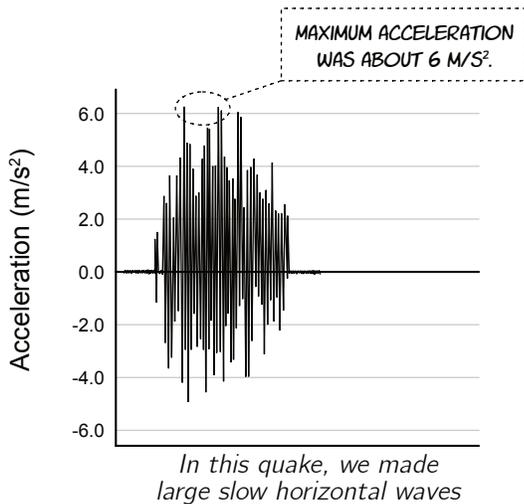
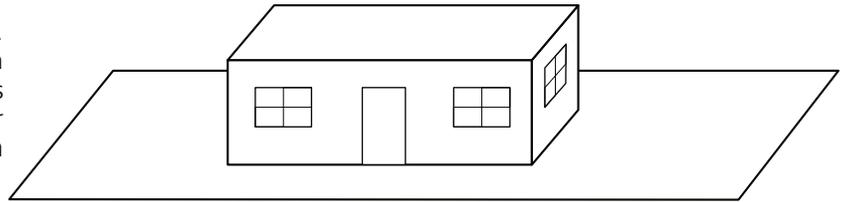
Various household objects

GOALS

- ★ Design and test earthquake-resistant countermeasures.
- ★ Iterate and improve your design.

DIRECTIONS

- ① Place your small cardboard box on top of the larger piece of cardboard. The large piece of cardboard represents the ground and should be at least twice as wide as the small box, which represents a building. If desired, decorate the small box so it looks more like a house. Just be sure it has a flat top or roof so that a phone can rest on top.
- ② Install an accelerometer app on your phone. The free Physics Toolbox Suite by Viera Software has a nice accelerometer which is a free app. Open the linear accelerometer app and start it. Then place the phone on top of the small box.
- ③ Simulate an earthquake by sliding the large piece of cardboard back and forth with steady and predictable movements. **Keep movements small and slow to protect the phone.** Try different speeds and directions and observe how the accelerometer records the movement. You should end up with a pattern something like this:



- ④ **Make a prediction.** Would anchoring the small box to the cardboard with tape be helpful? Would it make the same shaking feel more or less violent? Before attempting it, record your prediction here and explain why or how you think it would make a difference.

⑤ For each earthquake you simulate, note the maximum acceleration in m/s^2 and record it in the chart.

Simulate 5 different earthquake patterns for each iteration, following the movement described on the chart below: slow and large horizontal, fast and small horizontal, slow and large vertical, fast and small vertical, and circular. Try to make the motions the same size and intensity for each iteration.

First iteration: the first series of shaking should be a simple design with the box resting on the cardboard but not attached or secured in any way.

Second iteration: After making a prediction (step 4), anchor or attach the box to the cardboard using tape.

Third iteration: Come up with a plan to help the house experience the same earthquakes with less shaking. Ideally the design would reduce the maximum acceleration recorded for all 5 types of quakes. You could try rollers under the house (cylindrical markers or pencils), rubber bands to create elastic attachment points, or modifying the structure of the house itself. Describe your design:

If desired, you can continue revising your design to see how “earthquake proof” you can get.

	Slow and large horizontal waves 	Fast and small horizontal waves 	Slow and big vertical waves 	Fast and small vertical waves 	Circular motion waves 
Iteration 1 <i>box on cardboard, no attachments or additional structure</i>					
Iteration 2					
Iteration 3					
Iteration 4 (optional)					

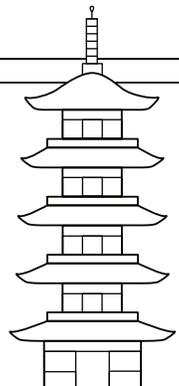
Bring it home: How is the foundation of your home constructed? Built on a slab of concrete? Is it on pylons or stilts? Wheels? Actually floating (boat)? Which of these foundations would be most earthquake proof and why?

EXTENSION

Tokyo experiences dozens of earthquakes each month, and every year they have a larger quake that would cause damage if the buildings weren't earthquake resilient.

How do Tokyo skyscrapers survive large earthquakes without collapsing? Look up *seismic isolation bearings* and *damping systems* to learn more.

Japan is one of the most earthquake-prone countries in the entire world, but it also has the oldest wooden buildings on Earth. The Hōryū-ji Buddhist temple is 1,300 years old! Look up *shinbashira* and *pagoda earthquake resistance* to learn more about how these ancient buildings survived enormous quakes.

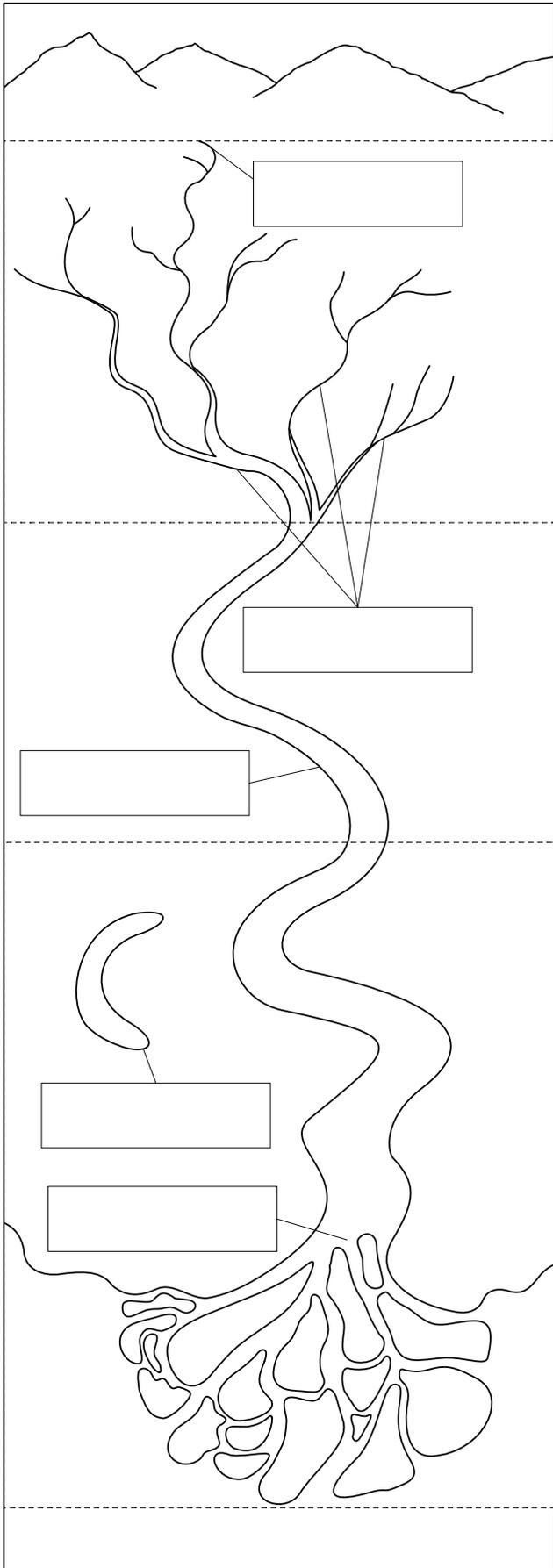


GO WITH THE FLOW

In geology, a **stream** is a body of water on Earth's surface that is flowing within the banks of a natural channel.

In popular culture, a stream may be called a river, creek, brook, rivulet, or waterway depending on its size and location. No matter a stream's size, it will have an impact because every stream moves sediment.

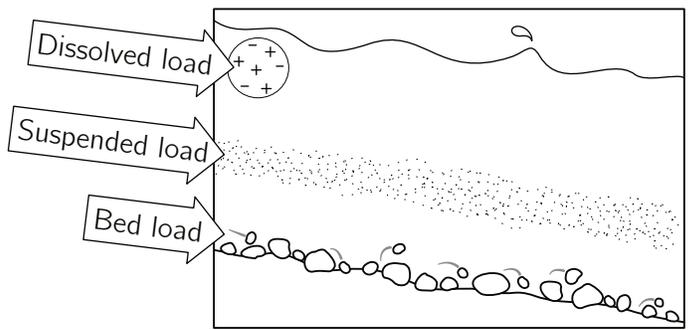
Label the following features of a stream in the adjacent diagram: *oxbow lake*, *mouth*, *source*, *tributaries*, *trunk*. Then, describe the 3 zones of the river and what occurs with sediment in each.



1.

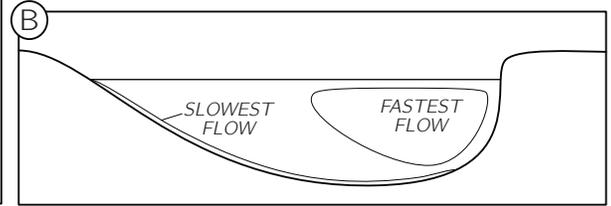
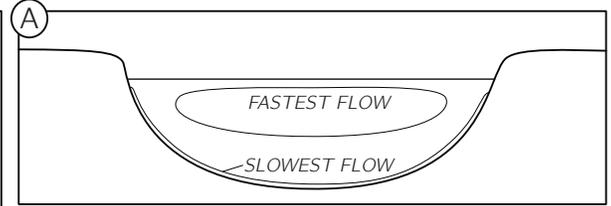
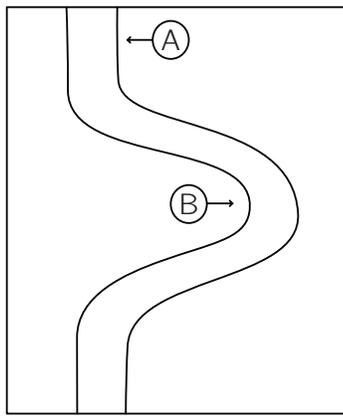
2.

3.

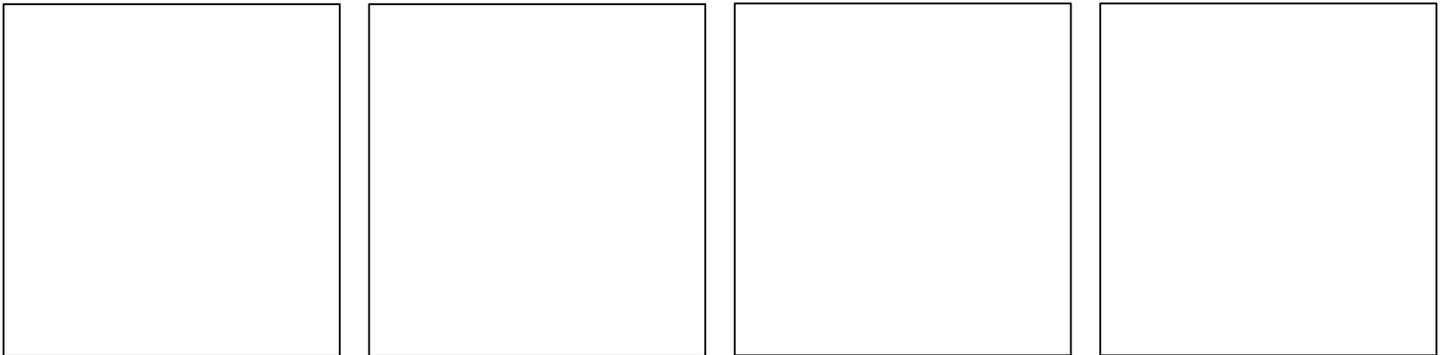


In a straight channel, the fastest flowing water is in the center near the top of the water, where it's furthest away from the friction with the bottom and sides of the channel. The slowest flow will be along the bottom of the channel.

In a bend or meander of a stream, the fastest flow is on the outside curve, producing a **cutbank**. The slowest flow is along the inside where it forms a **point bar** or **sand bar**.



Draw a meander in a river in the leftmost box below. In the other 3 boxes, diagram how the meander changes to form an oxbow lake. Color portions of the stream to show water speed. Use **orange** for slower moving water that is depositing sediment and **purple** for faster-moving water that is actively eroding the river bank.



Would a gold prospector want to stake a claim on a cutbank or a point bar? Why?

The map below shows 4 hydrological basins or watersheds: The Mississippi, Colorado, Great Basin, and Columbia. Label each basin and where it drains. Then note the length & discharge volume of the basin's largest river.



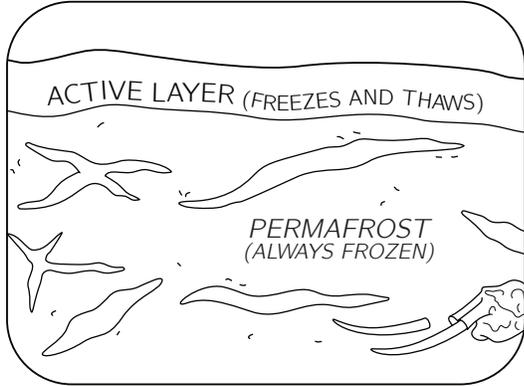
FILL IN THE BLANKS (WORDS FROM THE BOX MAY BE USED MORE THAN ONCE OR NOT AT ALL)

climates cryosphere freshwater land ocean
permafrost regulates rivers 20% 50% 70%

All of the frozen water in ice caps, glaciers, and _____ is known as the _____. _____ of Earth's total _____ is either permafrost or covered in ice. This frozen region impacts every living thing on our planet. The cryosphere is the source of the world's major _____. It contains _____ of Earth's _____. The cryosphere is also a driving force for _____ currents, it reflects sunlight and _____ global weather patterns, and contains detailed records of past _____.

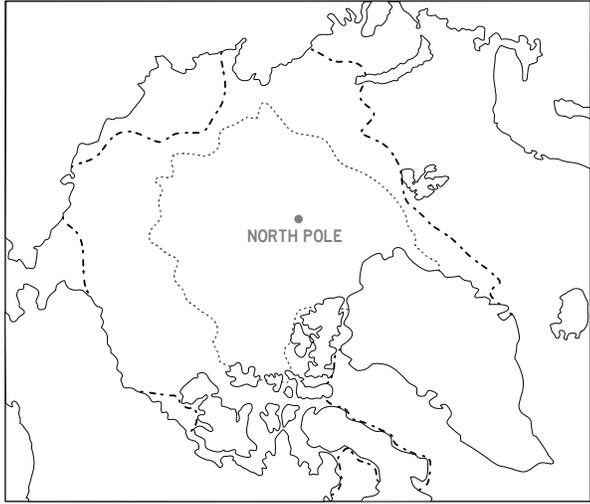
① Permafrost

A subsurface layer of soil that remains frozen year round.



② Ice Caps and Sheets

Ice covering an area less than 50,000 km² is called an "ice cap" while ice covering an area greater than 50,000 km² is called an "ice sheet." A "polar ice cap" or "polar cap" is any amount of ice in the polar region. Earth has polar caps of water ice. Mars has polar caps that are mixture of solid carbon dioxide and water.



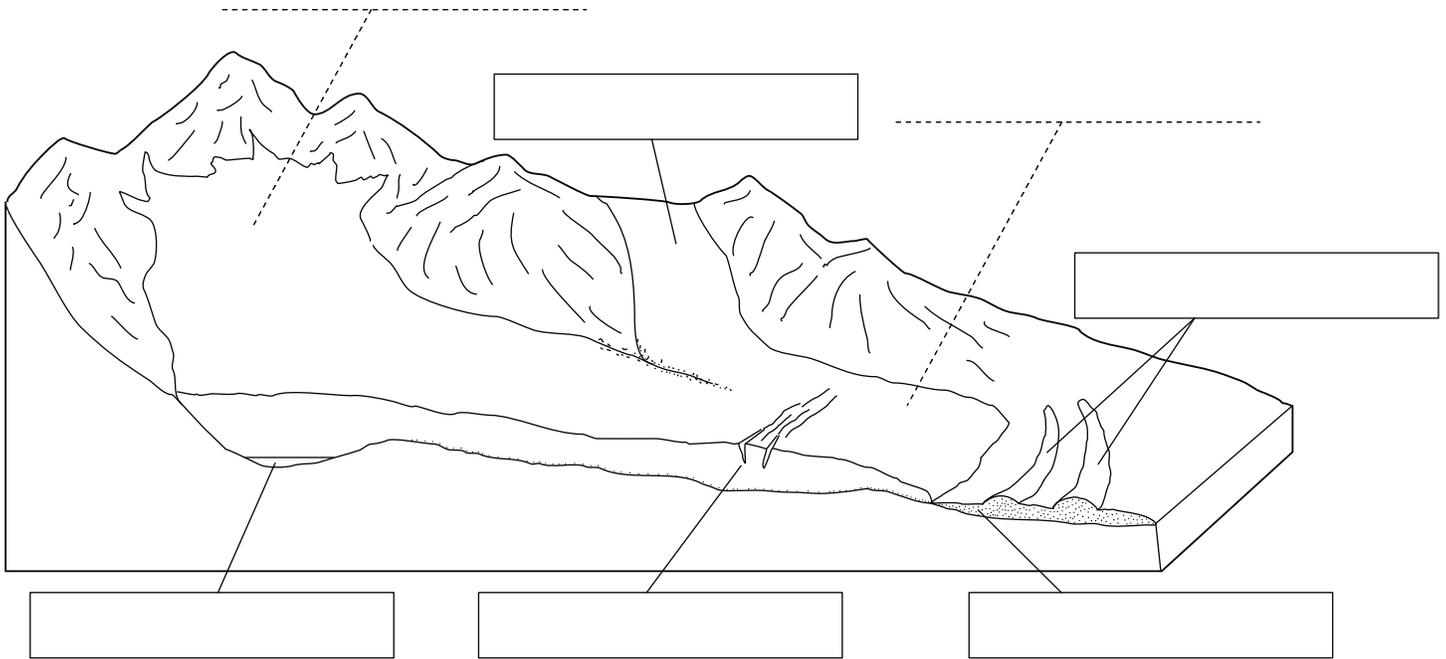
1980 minimum extent of sea ice
 2024 minimum extent of sea ice

Map inspired by data from NASA Scientific Visualization Studio, any errors are mine.

3. Glaciers

A glacier is a body of dense ice that persists from year to year. In other words, it doesn't melt away during the summer. These bodies of ice are so large and heavy that they move downhill like a slow-motion river. Glaciers are powerful engines of erosion that carve U-shaped valleys, cirques, and fjords.

Color the landmass grey or brown and the glaciers white or blue. Label and define the accumulation zone, the ablation zone, tributary glacier, crevasses, subglacial lake, till and terminal moraines.



FACT OR FICTION? Write your verdict below each statement:

A glacier can move up to 4 km per hour.

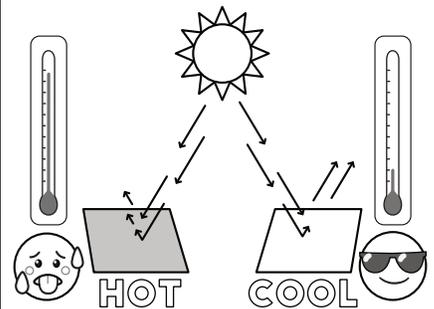
AHHH! IT'S SPEEDING UP!



Every glacier in the world is currently shrinking in size.



Snow reflects about 90% of sunlight while bare ground can absorb as much as 90% of incoming radiation.



ACTIVITY: STREAM TABLE STUDY

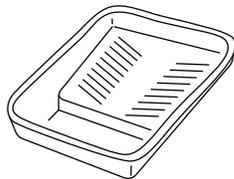
MATERIALS FOR A SMALL STREAM TABLE



Enough sand to fill the paint tray or bin



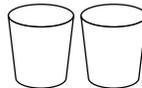
Rocks or bricks to elevate one side of the tray



Plastic paint tray or a long bin



Drill OR a nail



Plastic containers or cups that can have a drainage hole poked in the bottom

GOALS

- ★ Create an artificial stream to observe erosion.
- ★ Identify various stream formations
- ★ Use the scientific method to design an experiment to better understand how sediment is moved

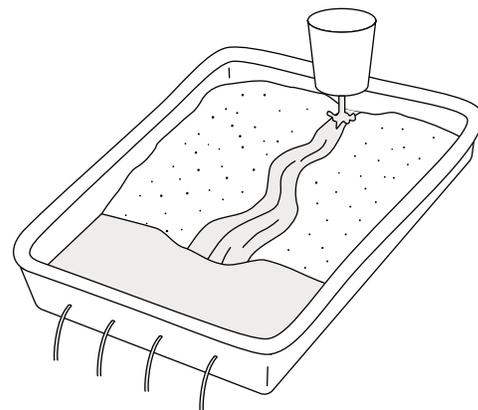
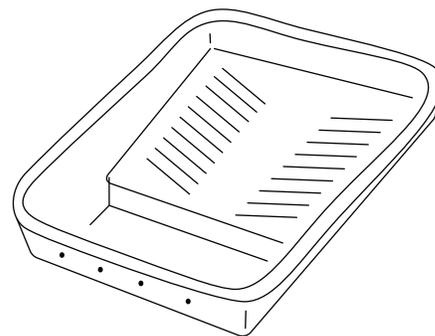


We recommend doing this activity outside!
If completing this activity inside, be sure that you do NOT send any sand or dirt down a sink.



DIRECTIONS

- ① Prepare the sand and water containers: Drill drainage holes in one side of a paint tray or large bin or tray. Place these holes a few cm above the bottom of the tray. Drill a small hole (or use a nail to create a small hole) in the bottom of each container or cup.
- ② Fill the tray partially full of sand. For best results, the sand should be damp, not dry. Shape the sand so that the container is almost completely full at the top end (opposite the drainage holes) and empty of sand near the bottom.
- ③ Place a brick, rocks, or some other object under to top end of the tray so that there is a significant slope.
- ④ Fill the container or cup with water and let it drain over the sand at the top of the tray. As the cup is getting low, refill it with more water or trade out the second cup to keep a continuous trickle of water flowing.
- ⑤ Continue pouring water until a distinct channel forms. Observe your stream channel.
- ⑥ Reset the stream table and then choose one thing to change. It could be the amount or rate of water being added, the slope of the table, or something else. Answer the following:



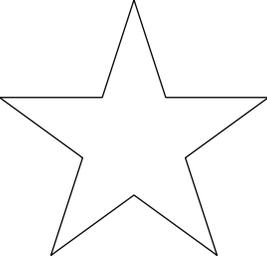
What variable will change?

Your prediction for what will happen:

The result:

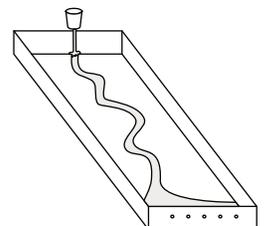
Erosion Bingo

Experiment and play with different variations of the stream table. Mark off each item you were able to observe or simulate. You may need to strategically pack your sand, dig channels, or create dams and levees to get all of these effects. See how many different Bingos you can get!

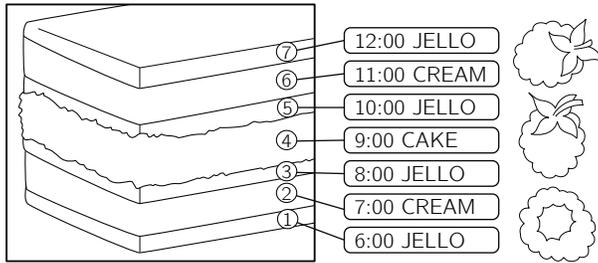
Stream channel gets deeper	Tested different slopes	Stream channel got wider	Built a dam to create a reservoir	Dam failed and reservoir released, causing a flood
Original channel is abandoned and a new channel forms	Delta forms	Sediment is separated by size	Stream bank collapses	Meander forms
Stream goes underground and resurfaces later	Alluvial fan forms		Oxbow lake forms	2 separate channels form
Cut bank observed	Point Bar observed		Build levees to contain a stream	Stream breaks through levees
Ice cubes used to represent glaciers	Different rates of water flow are compared	Landslide observed	Stream washes out objects placed on surface	Stream table put away and all messes cleaned up

OPTIONAL EXTENSION: MAKE A LARGE STREAM TABLE

A larger stream table of 1 to 2 meters in length will show much more impressive stream formations. If you have the resources, you can put together a frame of wood, back it with a board, and then either caulk or paint the corners or secure a drop cloth or plastic sheeting over the top to keep water from leaking out the sides. Create drainage holes and set the large stream table on a slope. You are now ready for hours of exploration!

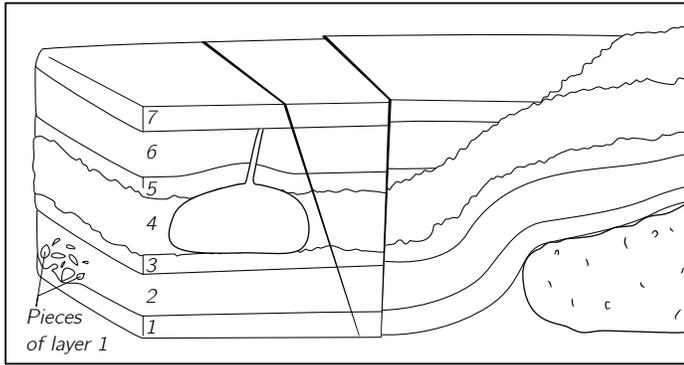


HOW OLD ARE ROCKS?



Math Dad's raspberry jello cake is supposed to be an orderly series of layers, but today his cake was sabotaged!

Math Dad made each layer at regular intervals just like he had on the previous day: Layer 1 was poured at 6 am. Another layer was added every hour until the final layer at noon. But instead of a neat and organized cake, he ended up with a mess! Someone sabotaged the cake by:



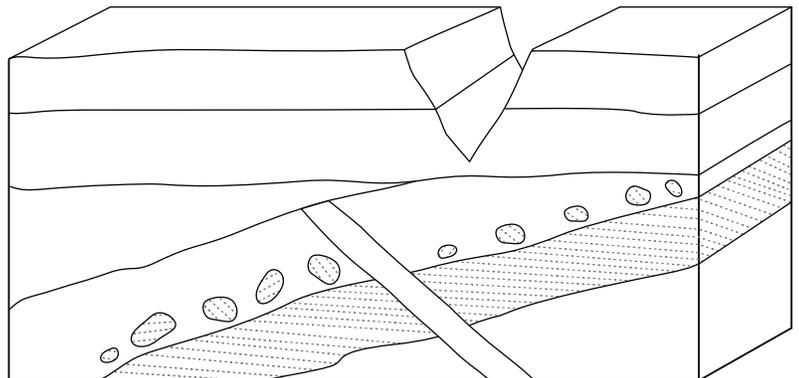
- Cutting the cake with a knife
- Injecting mustard into the cake
- Sliding potatoes under the cake, tilting it.
- Stirring in one corner of the cake

The first layer was poured at 6 am. Use the timestamps for each layer formation to figure out when each act of sabotage occurred. List them in order below and explain how you knew when each event occurred.

Name each principle described below and label the layers or strata in the diagram from oldest (A) to youngest (G).

In an undisturbed sequence of sedimentary strata, the layers on the bottom are oldest and the newest layers are on top.

Deformations like igneous intrusions or faults that cut across rock layers are younger than the rocks they deform.



Strata that are cut by a canyon or other feature remain continuous on either side of the feature.

Layers of rock are originally deposited in horizontal or nearly-horizontal layers.

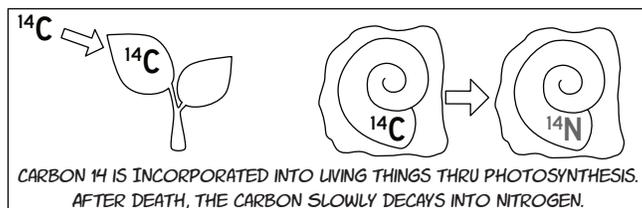
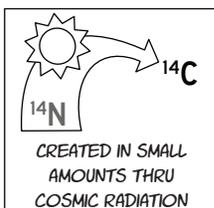
Any rock fragment (inclusion) contained in a host rock is older than the host rock.

Using the principle of stratigraphy to date rocks is called **relative dating**. It can tell us that a rock layer is older or younger than another rock, but it can't tell us the exact age of the rock. The discovery of radioactivity allowed scientists to develop **absolute dating**, which can be used to assign a numerical age to a rock. There are several techniques that can be used for absolute dating. One of the most common is **radiometric dating**, which evaluates the amount of radioactive isotopes in a rock, remain, or historical object.

RADIOMETRIC DATING

An **isotope** is an atom of an element that has a different number of neutrons. ^{12}C is the stable isotope of carbon with 6 protons and 6 neutrons.

Carbon 14 has 8 neutrons. This isotope is radioactive. Over thousands of years, it will slowly undergo radioactive decay, releasing energy and transforming into nitrogen.

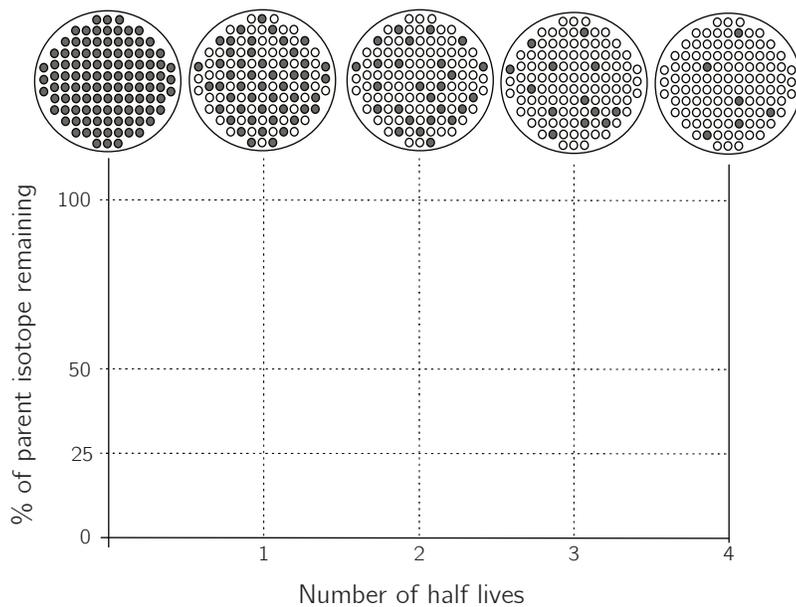


Define and give examples of the following terms:

① Half-life _____

② Parent isotope _____

③ Daughter isotope _____



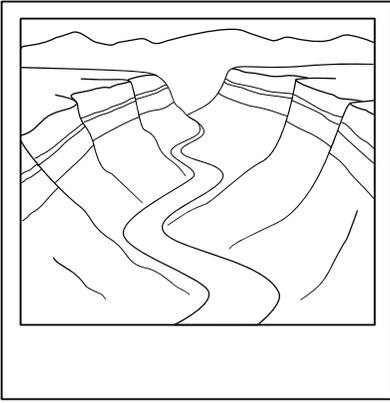
Which rock type (igneous, metamorphic, or sedimentary) are most useful for radiometric dating and why?

A rock has a daughter-parent ratio of 75% ^{40}Ar to 25% ^{40}K . How many half lives have passed?

Approximately how old is the rock?

ELEMENTS	PARENT SYMBOL	DAUGHTER SYMBOL	HALF-LIFE
Samarium-neodymium	^{147}Sm	^{143}Nd	106 billion years
Rubidium-strontium	^{87}Rb	^{87}Sr	50 billion years
Uranium-lead	^{238}U	^{206}Pb	4.5 billion years
Potassium-argon	^{40}K	^{40}Ar	1.3 billion years
Uranium-lead	^{235}U	^{207}Pb	700 million years
Uranium-thorium	^{234}U	^{230}Th	32,760 years
Carbon-nitrogen	^{14}C	^{14}N	5,730 years

GEOLOGIC TIME



In the 1700s, the prevailing theory in geology was called **catastrophism**. It argued that geologic features were caused by sudden dramatic events: a deep canyon was formed when a huge earthquake split the land, fish fossils on mountain tops had been carried there by a tsunami or flood, etc.

Charles Lyell and James Hutton proposed a different idea: **uniformitarianism** or **gradualism**. They argued that *the present was the key to the past*; processes observed today, such as a river removing sediment from a valley, occurred in the same manner and style in the past.

Today, we recognize that the geology of Earth results from a mixture of both uniform and catastrophic forces. But Hutton and others were correct in their assertion that most geologic processes occur over *millions* of years.

List 3 examples of geologic features or events that occurred gradually:

List 3 examples of geologic features or events that occurred suddenly:

FACT OR FICTION? Write your verdict below each statement:

Geologic time divisions were identified almost 100 years before radiometric dating.

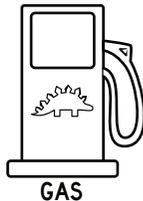
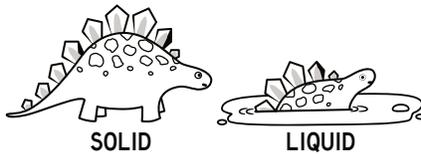
LET'S CALL THESE ROCKS DEVONIAN.

BECAUSE WE'RE IN DEVONSHIRE!

WHY?

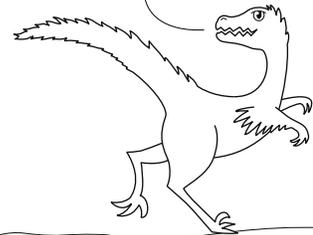


Gasoline is the purified remains of dinosaurs

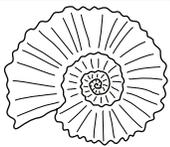


The Cretaceous is the longest period in Earth's geologic history

77 MILLION YEARS, WOO HOO!



Fossils with a relatively narrow time range and wide distribution are called **index fossils** or **dating fossils**. These fossils are useful in correlating rock layers between different regions and reconstructing ancient environments. Label each index fossil below:

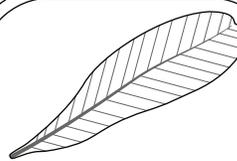


Coiled-shell cephalopods, lived from early Devonian to Cretaceous-Paleogene extinction event

OVER 22,000 SPECIES!



Marine arthropods, lived from Cambrian to end-Permian mass extinction



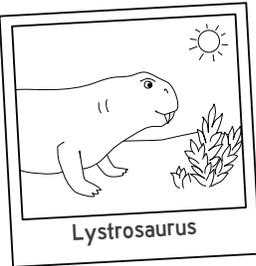
A tree with heavy seeds and oblong leaves, lived during Permian period



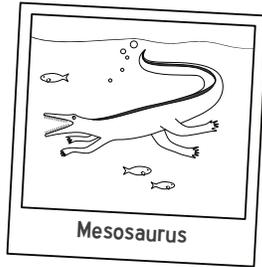
Single-celled aquatic animals with thousands of different prehistoric and modern species

PIECING TOGETHER PANGEA

Use the 4 clues to place Pangea on the geologic time scale on the next page. Can you estimate when the supercontinent existed?



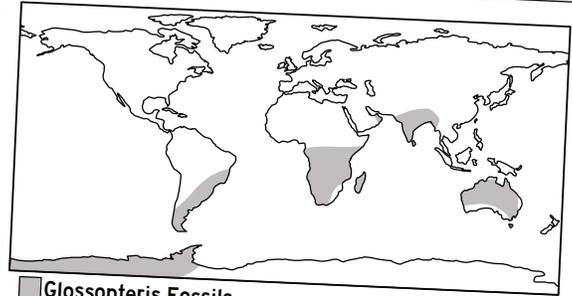
Lystrosaurus



Mesosaurus

FOSSILS OF MESOSAURUS FROM THE PERMIAN HAVE ONLY BEEN FOUND IN TWO REGIONS: SOUTH AMERICA AND SOUTH AFRICA. THIS SMALL REPTILE LIVED IN FRESHWATER RIVERS. IT COULDN'T HAVE SURVIVED A JOURNEY ACROSS THE ATLANTIC OCEAN!

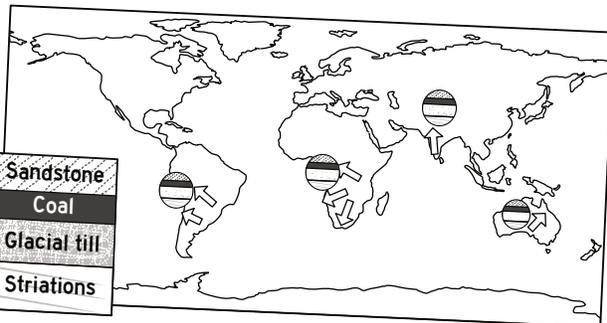
ANOTHER SMALL HERBIVORE CALLED LYSTROSAURUS ALSO LIVED DURING THE PERMIAN PERIOD IN WHAT IS NOW AFRICA, ANTARCTICA, AND INDIA.



Glossopteris Fossils

FOSSILS OF GLOSSOPTERIS ARE FOUND IN AFRICA, ANTARCTICA, AUSTRALIA, INDIA, MADAGASCAR, AND SOUTH AMERICA.

THE WOODY PLANTS GREW UP TO 30 METERS TALL. THE DENSE SEEDS COULD NOT HAVE BEEN TRANSPORTED BY WIND OR FLOATING ON WATER.

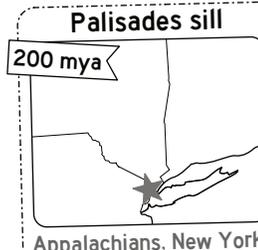


STRATA OF ROCKS IN AFRICA, ANTARCTICA, AUSTRALIA, INDIA, AND SOUTH AMERICA ALL SHARE A DISTINCTIVE SEQUENCE.

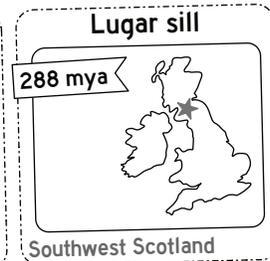
- THE TOP LAYER IS A SANDSTONE.
- THIS LAYER HAS EITHER COAL DEPOSITS OR IS RICH IN GLOSSOPTERIS FOSSILS.
- THE NEXT LAYER HAS GLACIAL TILL.
- CARBONIFEROUS BEDROCK WITH GLACIAL STRIATIONS.

THE GLACIAL STRIATIONS WERE FORMED DURING THE LATE PALEOZOIC ICE AGE, 360 - 255 MILLION YEARS AGO.

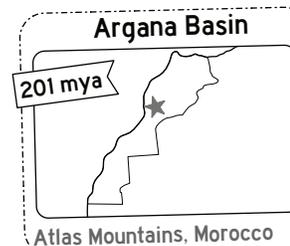
THE STRIATIONS SHOW THE DIRECTION OF GLACIER MOVEMENT AND WERE OF PARTICULAR INTEREST TO SCIENTISTS LIKE ALFRED WEGENER.



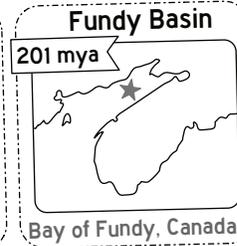
Appalachians, New York



Southwest Scotland



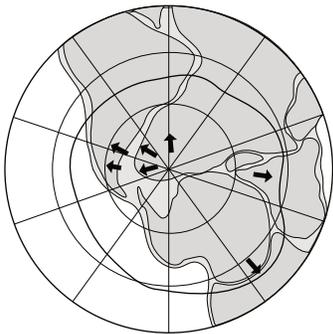
Atlas Mountains, Morocco



Bay of Fundy, Canada

THE APPALACHIAN MOUNTAINS OF NORTH AMERICA, THE SCOTTISH HIGHLANDS, AND THE ATLAS MOUNTAINS OF AFRICA ARE ALL OF SIMILAR AGE AND COMPOSITION.

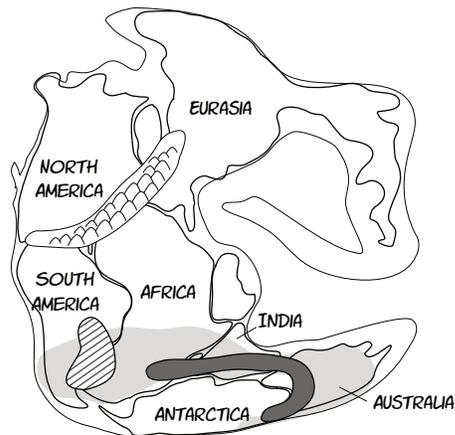
INTRUSIONS OF MAFIC IGNEOUS ROCK INTO THESE ANCIENT MOUNTAINS ARE EVIDENCE OF RIFTING. URANIUM-LEAD RADIOMETRIC DATING FROM ZIRCON CRYSTALS HAVE SHOWN THESE FORMATIONS TO BE BETWEEN 200-288 MILLION YEARS OLD.



In the Carboniferous, an enormous ice cap dominated the Southern Hemisphere during the Karoo or Late Paleozoic Ice Age. Glaciers flowed outward from the ice cap, which was centered over South Africa.

PANGAEA

-  Central Pangean Mountains
-  Glossopteris
-  Lystrosaurus
-  Mesosaurus



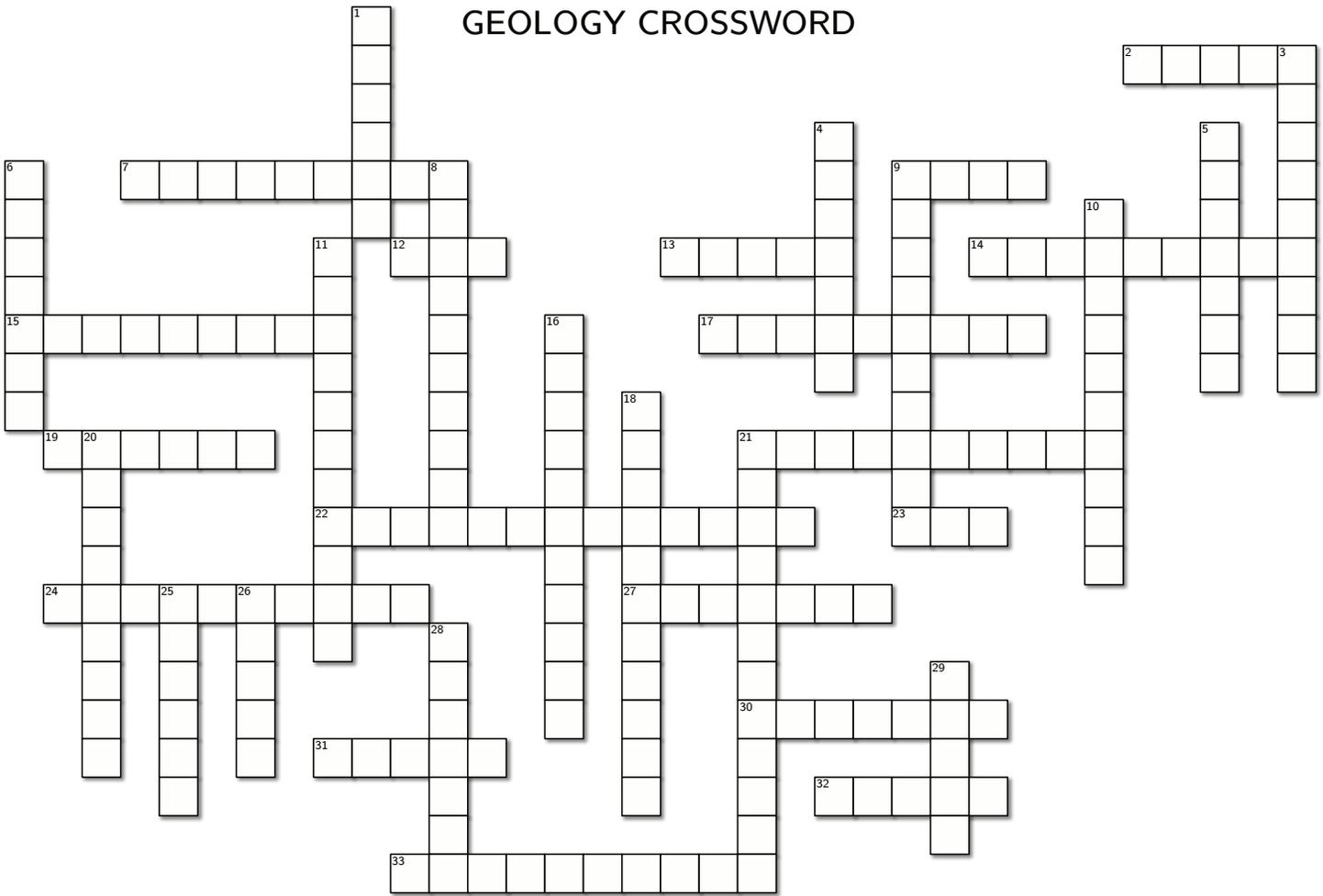
EON	PERIOD	TIME SPAN mya = millions of years ago	DURATION in millions of years
Phanerozoic	Quaternary	2.6-0 mya	2.6
	Neogene	23-2.6 mya	20.4
	Paleogene	66-23 mya	43
	Cretaceous	143-66 mya	77
	Jurassic	201-143 mya	58
	Triassic	252-201 mya	51
	Permian	299-252 mya	47
	Carboniferous	359-299 mya	60
	Devonian	420-359 mya	61
	Silurian	443-420 mya	24
	Ordovician	487-443 mya	44
Proterozoic	Cambrian	539-487 mya	52
	Ediacaran	635-539 mya	96
	Cryogenian	720-635 mya	86
	Tonian	1,000-720 mya	280
	Stenian	1,200-1,000 mya	200
	Ectasian	1,400-1,200 mya	200
	Calymmian	1,600-1,400 mya	200
	Statherian	1,800-1,600 mya	200
	Orosirian	2,050-1,800 mya	250
Archaean	-	4,031-2,500 mya	1531
	-	4,567-4,031 mya	536

GEOLOGY UNIT ASSESSMENT

- 1 Which type of fault is most commonly associated with large, destructive earthquakes?
- A. Normal faults
 - B. Reverse faults
 - C. Strike-slip faults
 - D. Thrust faults with low-angle planes
- 2 Which feature is most important for earthquake-resistant building design?
- A. Using the heaviest possible construction materials
 - B. Building structures as tall as possible to avoid ground shaking
 - C. Using only local materials native to the region
 - D. Incorporating flexible joints and shock-absorbing foundations
- 3 Which piece of evidence for continental drift was based on ancient climate indicators?
- A. Matching fossils of land animals across oceans
 - B. Glacial deposits found in now-tropical regions
 - C. Similar rock formations on different continents
 - D. Matching coastlines of continents across oceans
- 4 Which radiometric dating method would be most appropriate for dating a 50,000-year-old piece of wood?
- A. Potassium-argon dating of associated volcanic rocks
 - B. Carbon-14 dating of the organic material
 - C. Uranium-lead dating of zircon crystals
 - D. Rubidium-strontium dating of the surrounding sediment
- 5 Volcanic island arcs typically form at which type of plate boundary?
- A. Divergent boundaries where plates separate
 - B. Transform boundaries where plates slide past each other
 - C. Convergent boundaries where oceanic plates subduct
 - D. Hot spots in the middle of tectonic plates
- 6 What evidence first convinced scientists that continents had moved over geological time?
- A. The discovery of oil deposits in similar locations on different continents
 - B. The matching of fossils, rock types, and mountain ranges across ocean basins
 - C. The observation of volcanic eruptions along coastlines
 - D. The measurement of different magnetic fields on different continents
- 7 At mid-ocean ridges, new oceanic crust is formed through which process?
- A. Subduction of old oceanic plates beneath continental margins
 - B. Seafloor spreading as magma rises and cools at divergent boundaries
 - C. Transform motion grinding existing rocks into new formations
 - D. Continental collision creating underwater mountain chains
- 8 Mount Rainier in the Cascade Range was formed primarily by which geological process?
- A. Subduction of the Juan de Fuca Plate beneath the North American Plate
 - B. Collision between two continental plates
 - C. Divergent spreading creating a rift valley
 - D. Strike-slip faulting along a transform boundary
- 9 The Himalayas represent which type of mountain-building process?
- A. Oceanic-continental convergence with subduction
 - B. Continental-continental collision with crustal thickening
 - C. Volcanic arc formation above a subduction zone
 - D. Fault-block mountains formed by normal faulting
- 10 Which factor most directly controls whether physical or chemical weathering dominates in a region?
- A. The age of the underlying bedrock
 - B. The elevation above sea level
 - C. The distance from active plate boundaries
 - D. Climate conditions, particularly temperature and moisture

- 11 The active layer in permafrost regions refers to which zone?
- The permanently frozen ground that never thaws
 - The layer of ground that freezes and thaws seasonally
 - The deepest layer of permafrost closest to bedrock
 - The layer of permafrost with the highest ice content
- 12 Chemical weathering is most intense in which type of climate?
- Cold and dry conditions
 - Hot and humid conditions
 - Moderate temperature with low rainfall
 - Extremely cold conditions with high snowfall
- 13 Most of the world's earthquakes and volcanoes occur along which geological features?
- Ancient continental shields and cratons
 - The boundaries between tectonic plates
 - Areas of thick sedimentary rock accumulation
 - Regions with high elevation and steep topography
- 14 Which process dominates in areas where tectonic uplift is very slow?
- Mountain building through continued rock deformation
 - Erosion and weathering wearing down the landscape
 - Volcanic activity creating new landforms
 - Sediment deposition in low-lying areas
- 15 Thawing permafrost contributes to climate change by releasing which greenhouse gases?
- Primarily oxygen and nitrogen
 - Water vapor and ozone
 - Sulfur dioxide and nitrous oxide
 - Carbon dioxide and methane
- 16 Delta formation requires which specific conditions?
- Sediment-laden water entering a standing body of water
 - Fast-moving water in a narrow channel
 - Rocky coastlines with high wave energy
 - Deep water with strong ocean currents
- 17 The principle of superposition states that in undisturbed sedimentary rocks:
- Younger rocks are found above older rocks
 - Older rocks are found above younger rocks
 - All rocks in a sequence are the same age
 - Age cannot be determined from position
- 18 According to the theory of plate tectonics, what drives the movement of lithospheric plates?
- Gravitational pull from the Moon and Sun
 - Convection currents in the underlying mantle
 - Magnetic field reversals at Earth's core
 - Centrifugal force from Earth's rotation
- 19 Transform boundaries are characterized by which type of plate motion?
- Plates moving directly toward each other
 - Plates moving directly away from each other
 - Plates sliding horizontally past each other
 - One plate moving over another at an angle
- 20 Rivers are most effective at eroding landscapes when they have which characteristics?
- Low velocity and high sediment load
 - High velocity and steep gradient
 - Constant temperature and clear water
 - Wide channels and shallow depth
- 21 Which mountain range was NOT formed by continent-continent collision?
- The Alps
 - The Appalachians
 - The Himalayas
 - The Rocky Mountains
- 22 Which unit represents the longest division of geological time?
- Period
 - Era
 - Eon
 - Epoch

GEOLOGY CROSSWORD



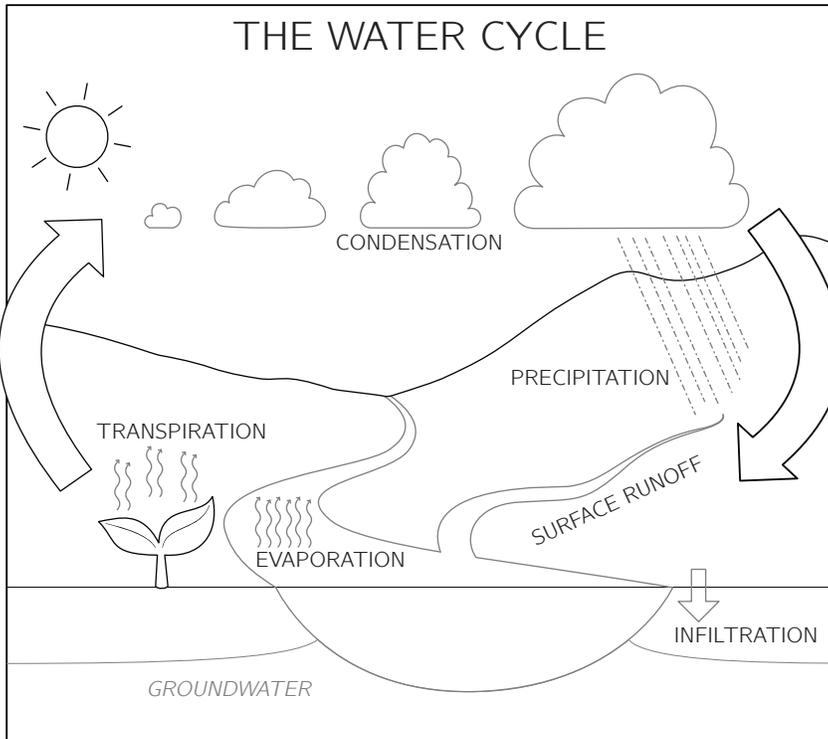
ACROSS

- 2 The thin, solid outermost layer of the Earth.
- 7 A curved lake formed when a river meander is cut off from the main channel.
- 9 The dense, hot center of Earth made mostly of iron and nickel.
- 12 A division of geologic time smaller than an eon, lasting tens to hundreds of millions of years.
- 13 A crack in Earth's crust where blocks of rock have moved past each other.
- 14 A plate boundary where two tectonic plates move away from each other.
- 15 A plate boundary where two plates slide horizontally past each other.
- 17 The principle that rock fragments contained in a layer are older than the layer itself.
- 19 A division of geologic time smaller than an era, lasting millions of years.
- 21 A plate boundary where two tectonic plates move toward each other.
- 22 The principle that in undisturbed rock layers, older rocks lie beneath younger rocks.
- 23 The largest division of geologic time, spanning hundreds of millions of years.
- 24 Permanently frozen ground found in cold climates that remains frozen year round.
- 27 The process of wearing away and transporting rock and soil by natural forces.
- 30 A pulling force that stretches rock in opposite directions.
- 31 A large section of Earth's lithosphere that moves across the mantle.
- 32 A triangular deposit of sediment at a river's mouth where it enters standing water.
- 33 The breaking down of rocks into smaller pieces by physical or chemical means.

DOWN

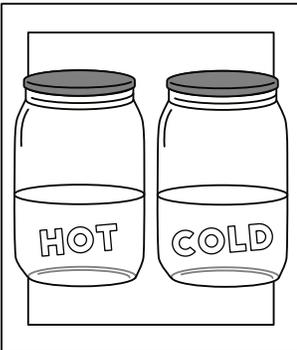
- 1 A dome-shaped mass of ice.
- 3 A smaller stream or river that flows into a larger river.
- 4 A material that is able to bend or deform without breaking under stress.
- 5 Rock formed from the cooling and solidification of molten magma or lava.
- 6 A material that is able to return to its original shape after stress is removed.
- 8 A sudden shaking of the ground caused by movement along a fault.
- 9 All frozen water on Earth including ice, snow, and permafrost.
- 10 The process of sediment settling out and being laid down in a new location.
- 11 A pushing force that squeezes or shortens rock from opposite directions.
- 16 Rock formed when existing rocks are changed by heat and pressure underground.
- 18 Rock formed from compressed layers of sediment deposited over time.
- 20 The point on Earth's surface directly above an earthquake's focus.
- 21 The principle that a geologic feature cutting through rock is younger than the rock.
- 25 The thick layer of hot rock between Earth's crust and core.
- 26 The underground location where an earthquake's energy is first released.
- 28 A material that breaks or fractures easily when stress is applied.
- 29 The end of a river where it empties into a larger body of water.

RELATIVE HUMIDITY



What forces cause water to move through this cycle?

COOL FACT
 Water vapor stays in air for average of 10 days before falling back to Earth as rain or snow



A SIMPLE BUT POWERFUL EXPERIMENT:

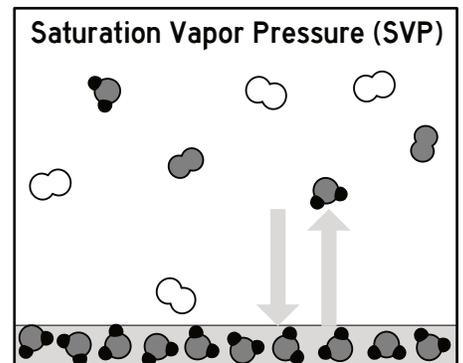
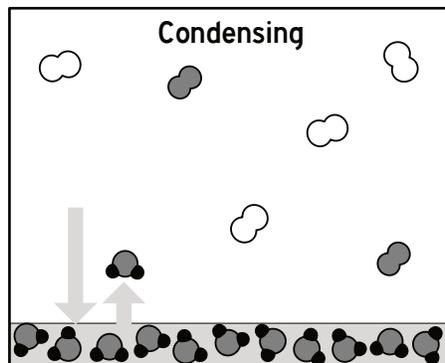
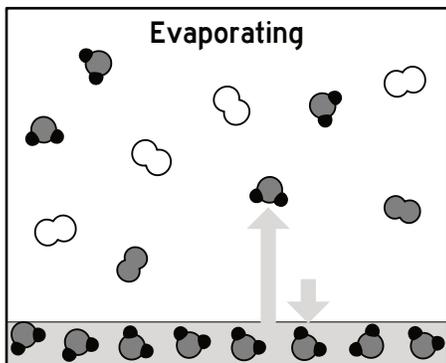
Two identical jars are filled with equal amounts of water. But in one jar, the water is cold. In the other jar, the water is hot. Which jar will have air with higher humidity?

My prediction: _____

What happened: _____

REMEMBER: Air is mostly made of gas molecules moving at hundreds of meters per second. At the temperatures we experience naturally on Earth, nitrogen, oxygen, and argon will always remain in a gaseous state. But water vapor can change to a liquid state (condense) or a solid state (deposit). *At each temperature, there's a limit to how much water vapor can be in the air.* If more water vapor is added, the molecules will interact with each other to form droplets (condensing) or ice/frost (depositing).

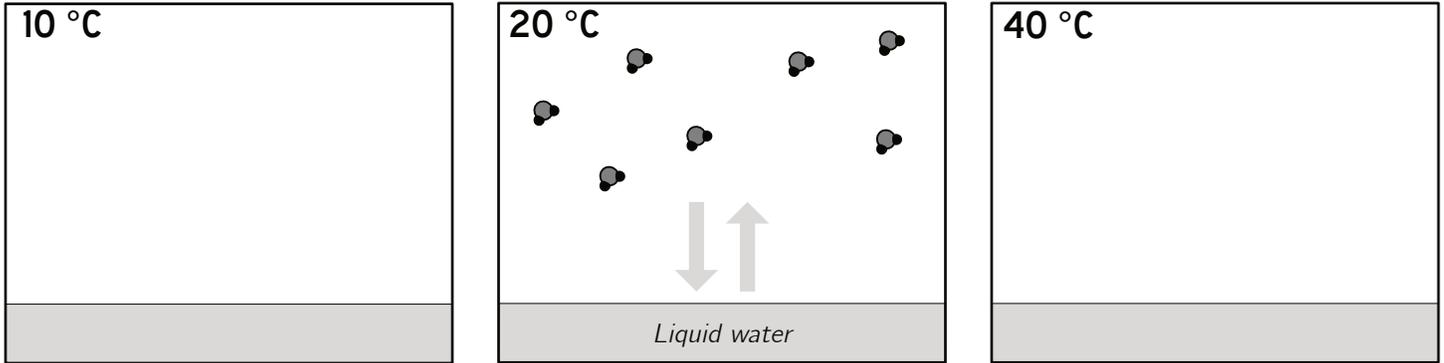
The maximum amount of water vapor that can be in the air at a given temperature is called the **saturation vapor pressure** or SVP. In this state, the rate of water molecules evaporating equals the rate of any molecules condensing.



The box in the middle with the 20 °C label represents a parcel of air over liquid water at saturation vapor pressure (SVP). It contains the maximum amount of water vapor that can be in the air at 20 °C (68 °F). At this state, there is equilibrium between evaporation and condensation.

What will happen to the amount of water vapor in the air if the temperature increases or decreases?

Draw arrows representing evaporation and condensation in the boxes labeled 10 °C and 40 °C. Then draw whether there would be more or fewer water molecules in the air:



IN YOUR OWN WORDS:

Why can hot air “hold” more water vapor?

Absolute vs Relative Humidity

There are two primary ways humidity is measured: Absolute or specific humidity and relative humidity. Label the definition below and then make notes of where it is used and how it is measured.

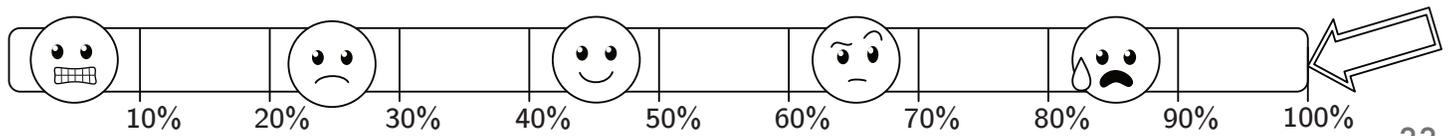
<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> <p>_____</p> </div> <p>The actual amount of water vapor in the air</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> <p>g/m³ or g/kg</p> </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> <p>WHERE USED</p> </div> <div style="border: 1px solid black; padding: 5px;"> <p>HOW MEASURED</p> </div>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> <p>_____</p> </div> <p>How saturated the air is with moisture; the percent of actual water vapor pressure vs the saturation vapor pressure (SVP)</p> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> <p>%</p> </div> <div style="border: 1px solid black; padding: 5px; margin-bottom: 5px;"> <p>WHERE USED</p> </div> <div style="border: 1px solid black; padding: 5px;"> <p>HOW MEASURED</p> </div>
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HUMIDITY & COMFORT

A brochure for an HVAC unit says indoors spaces feel comfortable at 30-60% humidity. Below 30% humidity, the air will feel uncomfortably dry. Above 70%, the air will feel muggy and the home will have issues with mold growth.

What type of humidity is the brochure referring to? _____

The **temperature** where air reaches 100% humidity is called: _____



CONSIDER THE TEMPERATURES:

The rectangles below represent the *water-holding capacity* of an air parcel as temperature increases.

Scenario 1: At each temperature, color half of each rectangle to show the air contains exactly half of the maximum amount of water vapor it *could* contain.

0°C (32 °F) 10°C (50 °F) 20°C (68 °F) 30°C (86 °F) 40°C (104 °F)

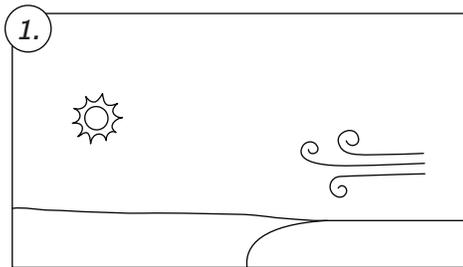
Describe how absolute humidity and relative humidity (RH) change in Scenario 1:

Scenario 2: Inside each rectangle, color a block of the same size to show that the total amount of water vapor remains the same at each temperature.

0°C (32 °F) 10°C (50 °F) 20°C (68 °F) 30°C (86 °F) 40°C (104 °F)

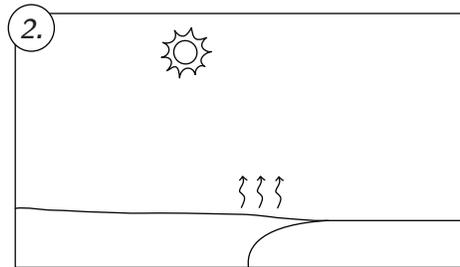
Describe how absolute humidity and relative humidity (RH) change in Scenario 2:

Afternoon Thunderstorm



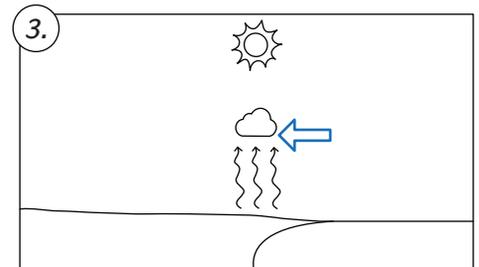
1. The Sun warms air over the land. How does this affect its capacity to hold water? (circle one)

INCREASE DECREASE NO CHANGE

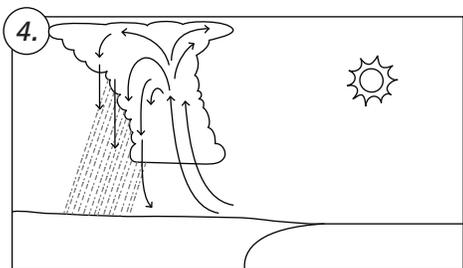


2. As hot moist air rises, it cools. How does this affect its **relative humidity**?

INCREASE DECREASE NO CHANGE

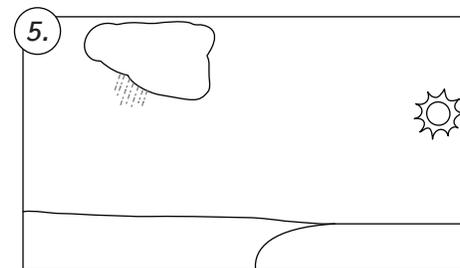


3. Clouds begin to form as the moist air condenses. Draw an arrow in the above box to show where the air temperature reaches the **dew point**.



4. Updrafts bring warm moist air to the thunderhead while downdrafts send rain to the ground. Is the downdraft air warmer, cooler, or the same temperature as the surface?

WARMER COOLER SAME



5. When the updrafts stop, the storm dissipates. A small anvil-top of the cloud persists for a few hours.

Where does the water go that was in the anvil-top cloud remnant?

COOL FACT:
 AT ANY GIVEN MOMENT, THERE ARE ABOUT 2,000 THUNDERSTORMS OCCURRING AROUND THE WORLD

THUNDERSTORM INGREDIENTS:

- ✓ WATER VAPOR
- ✓ UNSTABLE AIR
- ✓ LIFT

COOL FACT:
 A LARGE CUMULONIMBUS CLOUD MAY STRETCH OVER 10 MILES HIGH AND CONTAIN ENOUGH WATER TO FILL HUNDREDS OF OLYMPIC-SIZE SWIMMING POOLS!

ACTIVITY: CLOUD IN A JAR

MATERIALS



4 glass jars with lids
(for best results, use metal lids)



Ice



Water (and ability to heat it to different temperatures)



Matches



Paper or tape and a pen or pencil for making labels

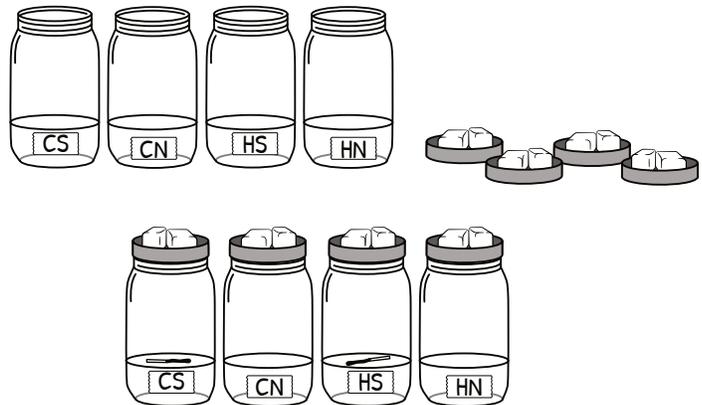
GOALS

- ★ Gain a better understanding of humidity and cloud formation
- ★ Practice scientific method and reasoning

Note: This experiment moves quickly, so make sure to prepare all of your materials before beginning the experiment! Also, be sure to have a parent/guardian's assistance when using matches.

Directions:

- ① Make predictions about whether temperature or aerosol/smoke will impact cloud formation.
- ② Label each jar with either a paper in front of the jar or a small piece of tape. Write out the descriptions or use the abbreviations CS, CN, HS, and HN for:
 - Cold water + smoke
 - Cold water + no smoke
 - Hot water + smoke
 - Hot water + no smoke
- ③ Place the 4 lids upside down next to the jars and fill or top each lid with some ice.
- ④ Add cold water to two of the jars so that each jar is 1/4 full. Swirl the water around for 5 to 10 seconds so the glass comes to a similar temperature as the water.
- ⑤ Add hot water to the other two jars until each of them is 1/4 full. Swirl the water around a little bit so the glass comes to a similar temperature as the water.
- ⑥ Place the lids with ice on the jars that have no aerosols/smoke.
- ⑦ Light a match and drop it into the cold water + smoke jar. For best results, hold the match at the top of the jar for 2-3 seconds before dropping it into the water. Place the ice lid on top of the jar immediately after dropping it.
- ⑧ Light another match and drop it into the Hot water + smoke jar, using the same technique.
- ⑨ Observe the 4 jars and record whether clouds or condensation are seen.



Prediction for the effect of water temperature:

Circle one:

Warmer water will *decrease* cloud formation

Warmer water will *increase* cloud formation

Water temperature will have no impact on cloud formation

Prediction for the effect of aerosols:

Circle one:

Aerosol particles will *decrease* cloud formation

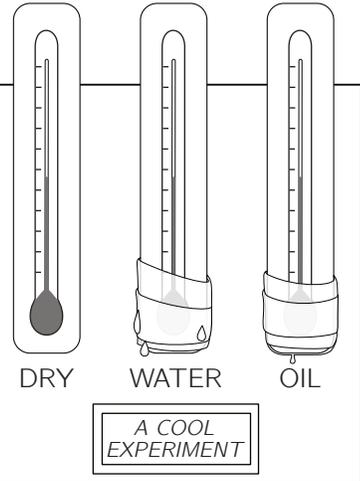
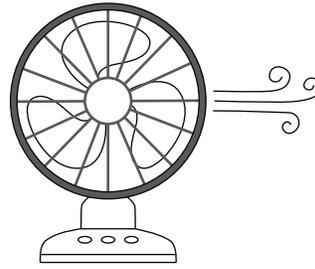
Aerosol particles will *increase* cloud formation

Aerosol particles will have no impact on cloud formation

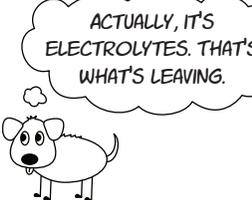
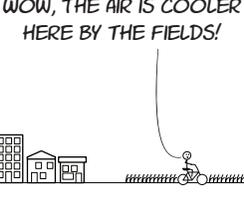
Results:

HEAT INDEX AND WINDCHILL

A fan is placed in front of 3 thermometers. One is dry, the others are wet with water or oil. Which thermometer(s) will show a drop in temperature and why?



Put a checkmark by each phenomenon you've observed or experienced before:

 <p><input type="checkbox"/> A PERSON SWEATING</p>	 <p><input type="checkbox"/> A DOG PANTING</p>	 <p><input type="checkbox"/> BRIDGE ICE</p>	 <p><input type="checkbox"/> URBAN HEAT EFFECT</p>	 <p><input type="checkbox"/> COLD AFTER SWIM/SHOWER</p>
---	---	--	--	--

How does water evaporating affect air temperature? (color or circle one)

<input type="checkbox"/> ↑ TEMPERATURE	<input type="checkbox"/> ↓ TEMPERATURE	<input type="checkbox"/> NO CHANGE TO TEMPERATURE
--	--	---

What are the hottest and coldest outside air temperatures you've seen?

Would it have felt different if it was windy on those days? What if humidity was near 100%?

FILL IN THE BLANKS (WORDS FROM THE BOX MAY BE USED MORE THAN ONCE OR NOT AT ALL)

above	apparent	average	dangers
humidity	different	below	

The "feels like" or _____ temperature in the weather forecast can sometimes be very _____ than the actual temperature! When temperatures are _____ 27 °C (81 °F), _____ and temperature are used to calculate the **heat index** or humidex and estimate how hot the air would feel to the _____ person. When temperature are _____ 10 °C (50 °F), the **wind chill index** is used to help warn people about the _____ of cold weather.

HEAT INDEX

A heat index is a scale that models *human-perceived temperature*. It is meant to describe what the temperature *feels like* to the average person. It assumes shady conditions, no wind, and no physical activity. Different countries and organizations use different formulas to calculate a heat index or “feels like” temperature.

What similarities and differences do you notice between the 2 indexes below? What is significant about the risk for temperatures which are lower vs higher than 37 °C (98.6 °F)?

NATIONAL WEATHER SERVICE HEAT INDEX (USA)

	80 °F 26.7°C	84 °F 28.9°C	88 °F 31.1°C	92 °F 33.3°C	96 °F 35.6°C	100 °F 37.8°C	104 °F 40°C	108 °F 42.2°C
40	80	83	88	94	101	109	119	130
45	80	84	89	96	104	114	124	137
50	81	85	91	99	108	118	131	
55	81	86	93	101	112	124	137	
60	82	88	95	105	116	129		
65	82	89	98	108	121	136		
70	83	90	100	112	126			
75	84	92	103	116	132			
80	84	94	106	121				
85	85	96	110	126				
90	86	98	113	131				
95	86	100	117					
100	87	103	121					

Caution / Extreme Caution / Danger / Extreme Danger

ISGlobal HEAT INDEX (SPAIN)

	27 °C 80.6 °F	29 °C 84.2 °F	31 °C 87.8 °F	33 °C 91.4 °F	35 °C 95 °F	37 °C 98.6 °F	39 °C 102.2 °F	41 °C 105.8 °F
40	27	29	31	34	37	41	46	54
45	27	29	32	35	39	43	49	62
50	27	30	33	36	40	45	60	66
55	27	30	33	37	42	54	64	70
60	28	31	34	39	44	61	67	74
65	28	31	35	40	55	64	71	78
70	29	32	36	42	61	68	75	82
75	29	33	38	53	64	71	78	86
80	30	34	39	60	67	74	82	90
85	30	35	47	63	70	77	85	93
90	31	36	57	65	73	80	89	97
95	31	39	61	68	76	84	92	101
100	32	48	63	71	78	87	95	105

Caution / Extreme Caution / Danger / Extreme Danger / Too severe for human survival

- 80-90: **Caution.** Fatigue possible with activity/prolonged exposure
- 90-103: **Extreme Caution.** Heat stroke possible
- 103-124: **Danger.** Heat stroke likely
- >125: **Extreme Danger.** Heat stroke highly likely

- 27-32: **Caution.** Fatigue possible with activity/prolonged exposure
- 33-40: **Extreme Caution.** Heat stroke possible
- 41-51: **Danger.** Heat stroke likely
- 52-92: **Extreme Danger.** Heat stroke highly likely
- >93: **Deadly.** Beyond human resistance to heat

WINDCHILL

The wind chill temperature is how cold people and animals will *feel* when they are outside. Wind draws heat away from the body. The lower the wind chill temperature, the higher the risk of hypothermia or frostbite.

Affects how _____ something cools, not how cold it can get.

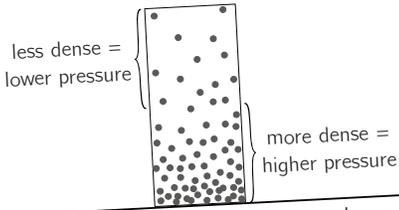
Especially for animals. For inanimate objects, windchill just shortens how much time it takes for them to cool.

If the outside temperature is -5 °C (23 °F) and the windchill is -30 °C (-22°F), how cold can a pipe become that is exposed to the wind?

Our comfort depends on humidity and air movement, and so does the weather!

AIR MASSES AND FRONTS

BAROMETRIC PRESSURE



Air pressure within the atmosphere of Earth. At sea level, it is approx. 1 atm, 29.9" Hg, or 1,013 millibars

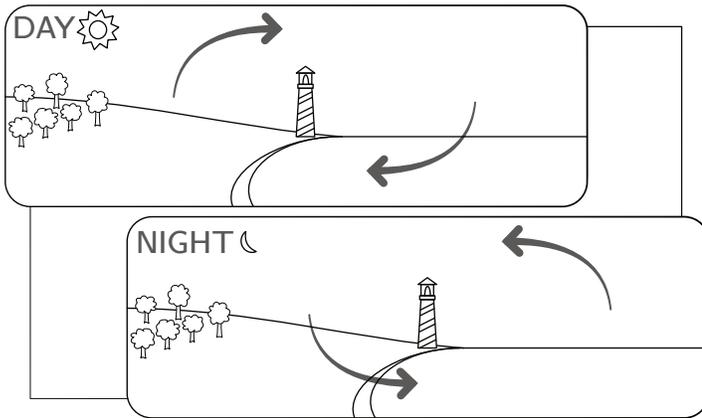
Air pressure is the force caused by the weight of air above a point or object. The Stern Auditorium at Carnegie Hall is 5 stories tall and seats 2,804 people. How much do you think the air in that room weighs? Take a guess!* Then record the actual average value.

MY GUESS

ACTUAL VALUE

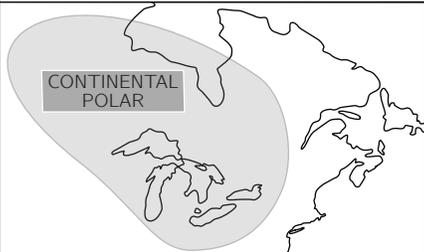
*Use kilograms. There are 2.2 pounds in 1 kg.

Air pressure decreases with elevation because at high elevations there is less overlying air. **But it also changes with the weather!** To understand how pressure relates to storm systems and rain, it helps to understand wind, air masses, and the boundaries between them (fronts).



What is wind and why does it blow?

AIR MASS



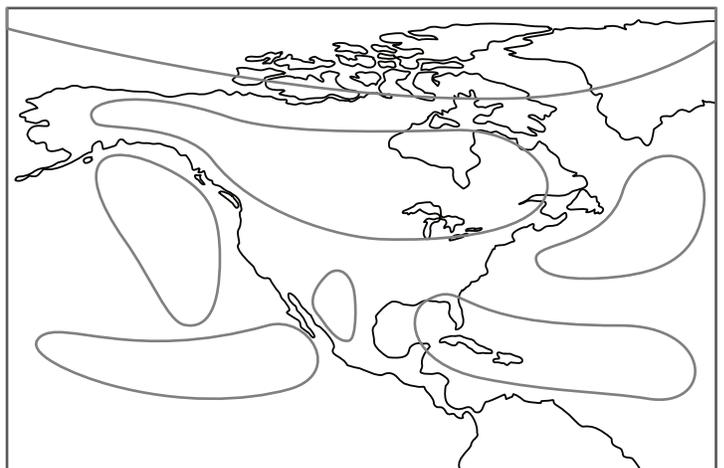
A large volume of air with a consistent temperature, pressure, and moisture content

Air masses are named and classified according to their *source regions* and whether they form over *land or sea*.

Source regions from coldest to warmest are: **Arctic (A)**, **polar (P)**, or **tropical (T)**.

Air masses over the ocean have higher humidity and are called **Maritime (m)**. Air masses originating over land have drier air and are called **continental (c)**.

Fill in the abbreviations on the key below. Then color and label the air masses that dominate weather in North America:



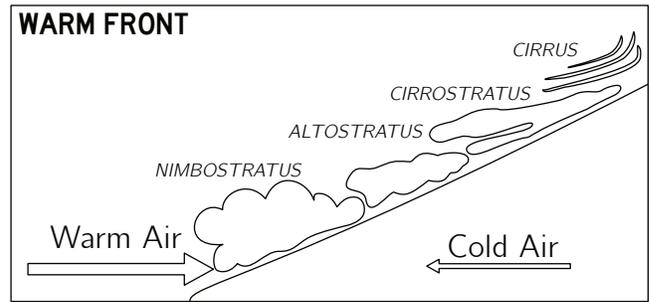
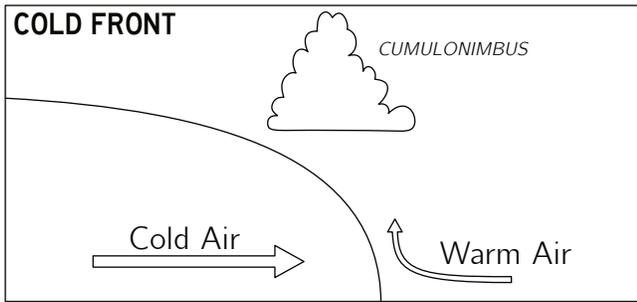
mP:

mT:

cA:

cP:

cT:



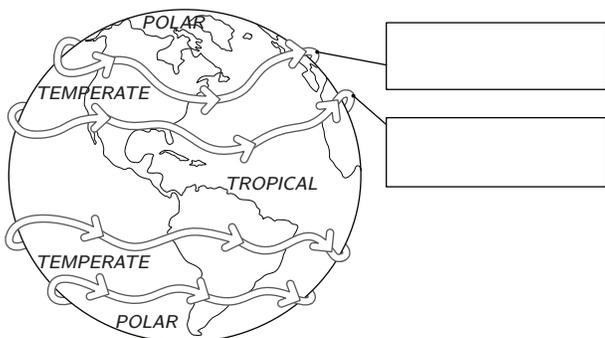
When air masses of different temperatures collide with each other, the boundary between them is called a **front**. Most often, the front is named for the leading edge: in a cold front, the cold air is overtaking a mass of warm air. In a warm front, the warmer air is overtaking the mass of cold air. In both cases, the warm air will rise up and over the denser cold air, but the shape of the front and the weather associated with it are quite different!

WARM vs COLD: Draw lines to match each definition or characteristic to its corresponding front:

A mass of colder air moves into an area where warmer air is present.		Steeply-sloped boundary. Clouds with strong vertical development.
Pressure often rises sharply after front passes		Represented by a line of triangles
Associated with more turbulent weather and gusty wind		Can bring rain or snow
Associated with stratiform clouds		Moves more slowly than the other type of front
Brings a drop in humidity after passage	Represented by a line of semicircles	

JET STREAMS

Earth has several different currents of high-altitude air moving at high speed. These currents form at the boundaries of air masses and are called jets or jet streams. They are dynamic with paths that often meander. The Polar Jet Streams (often called just “jet stream”) are the most impactful on weather and aviation.

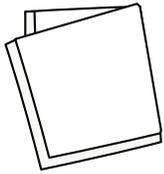


Basic Jet Stream Facts:

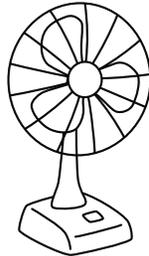
- Layer of atmosphere:
- Altitude:
- Wind speed:
- Depth and Width:
- Direction:

ACTIVITY: HUMIDITY LAB

MATERIALS



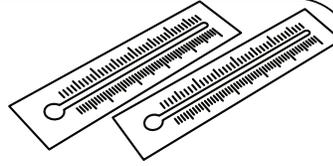
A small piece of cloth, gauze, or wet paper towel



Fan



Rubber band



Thermometers
Ideally, use 2 identical thermometers, but the experiment can also be done with 1 thermometer

GOALS

- ★ Use a psychrometer to measure relative humidity
- ★ Explain the relationship between temperature and the atmosphere's capacity to hold water vapor

DIRECTIONS USING 2 THERMOMETERS

- 1 Wrap one thermometer's bulb with the damp cloth and secure it with a rubber band. The cloth should be fully wet but not dripping. Leave the other thermometer dry.
- 2 Place both thermometers side by side in the same location.
- 3 Turn on the fan so that both bulbs are in the moving air for 2–3 minutes.
- 4 Record both temperatures (wet and dry).
- 5 Calculate the wet-bulb depression by subtracting the wet-bulb temperature from the dry-bulb temperature.
- 6 Use the Table on the next page to find the relative humidity. Find your dry-bulb temperature in the left column and your temperature difference across the top row. The number where the row and column meet is your relative humidity (%).

DIRECTIONS USING 1 THERMOMETER

- 1 Place the thermometer in its location for at least 5 minutes to let it stabilize. Then record the temperature. (This is the dry-bulb temperature.)
- 2 Wrap the bulb of the thermometer with the piece of damp cloth and secure it using a rubber band. Make sure the cloth is snug and fully wet, but not dripping.
- 3 Hold or position the thermometer so that air from the fan blows directly across the damp cloth for about 2–3 minutes. (If using a digital thermometer, give it enough time to stop changing.)
- 4 Once the temperature stops dropping, record it as your wet-bulb temperature.
- 5 Calculate the difference and use the table to find the humidity as outlined in steps 5 and 6 above.

Weather Forecast Connection

Meteorologists use the *wet bulb temperature* all the time! It's an important part of every weather forecast.

It used to be gathered by hand with sling psychrometers: two thermometers side by side, one wet and one dry, attached to a rope that the meteorologist would swing around their head like a lasso!

Nowadays, humidity data can also be gathered by electronic instruments that sense how water vapor alters the electric field or thermal conductivity of different substances.

But many weather stations still have a water-fed wick that keeps a thermometer wet. It's simple and reliable.

EXAMPLE

Dry-bulb temperature = 24°C

Wet-bulb temperature = 19°C

$$24^{\circ}\text{C} - 19^{\circ}\text{C} = 5^{\circ}\text{C}$$

On the chart, locate the the row with the dry-bulb temperature and the column with the wet bulb depression. The overlap reads 62.

The relative humidity is 62%

Dry-Bulb Temperature (°C)	Wet Bulb Depression (Dry-Bulb Temp minus Wet-Bulb Temp)										
	0	1	2	3	4	5	6	7	8	9	10
0	100	81	63	45	28	11					
2	100	83	67	51	36	20	6				
4	100	85	70	56	42	27	14				
6	100	86	72	59	46	35	22	10			
8	100	87	74	62	51	39	28	17	6		
10	100	88	76	65	54	43	32	24	13	4	
12	100	88	78	67	57	48	38	28	19	10	2
14	100	89	79	69	60	50	41	33	25	16	8
16	100	90	80	71	62	54	45	37	29	21	14
18	100	91	81	72	64	56	48	40	33	26	19
20	100	91	82	74	66	58	51	44	36	30	23
22	100	92	83	75	68	60	53	46	40	33	27
24	100	92	84	76	69	62	55	49	42	36	30
26	100	92	85	77	70	64	57	51	45	39	34
28	100	93	86	78	71	65	59	53	47	42	36
30	100	93	86	79	72	66	61	55	49	44	39

Relative Humidity %

Dry-Bulb Temperature (°C)	Wet Bulb Depression (Dry-Bulb Temp minus Wet-Bulb Temp)														
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	100	81	63	45	28	11									
2	100	83	67	51	36	20	6								
4	100	85	70	56	42	27	14								
6	100	86	72	59	46	35	22	10							
8	100	87	74	62	51	39	28	17	6						
10	100	88	76	65	54	43	22	24	13	4					
12	100	88	78	67	57	48	38	28	19	10	2				
14	100	89	79	69	60	50	41	33	25	16	8	1			
16	100	90	80	71	62	54	45	37	29	21	14	7	1		
18	100	91	81	72	64	56	48	40	33	26	19	12	6		
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5	
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20

Explore Further

Now that you know how to measure relative humidity, compare different places or situations:

1. Indoors vs. Outdoors: How does humidity change between the living room and outside?
2. Before and After a Shower: How much does the humidity rise in your bathroom?
3. While Cooking Pasta: How does boiling water affect the humidity in your kitchen?

Record your data in the table below.

Location/Time	Dry-Bulb (°C)	Wet-Bulb (°C)	Difference	Relative Humidity (%)

Bonus Challenge: Make a Mini Swamp Cooler!

A swamp cooler is a device that cools air through evaporation, just like your wet-bulb thermometer did.

Materials:

Electric Fan, Cardboard Box (big enough to fit the fan), Damp cloth or towel, Tape or rubber bands

Steps:

1. Cut a hole in the front of the box just large enough for the front of your fan to blow through.
2. Hang or tape the damp cloth over the back opening of the box.
3. Turn on the fan!
4. Air gets pulled through the wet cloth, water evaporates, and the air coming out the front feels cooler.

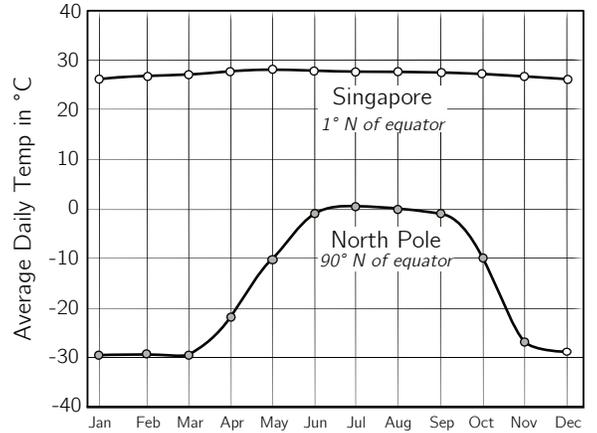
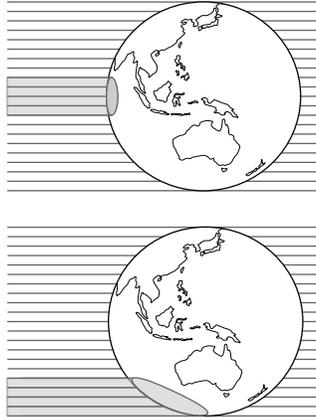
Measure the temperature of the air before and after it passes through your mini swamp cooler. Can you detect a cooling effect?

GLOBAL WEATHER PATTERNS

Incoming radiation from the Sun is much more intense over the equator than the poles.

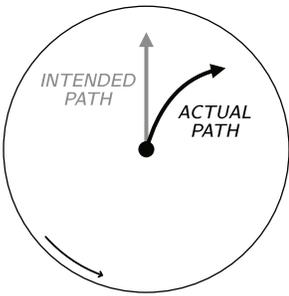
The Sun is directly overhead at the equator on the equinox. But at 60° N it only rises 30° over the horizon. The light spreads out to cover a much larger area, which reduces the intensity of the heat.

This differential heating is a key driving force of weather systems on our planet.



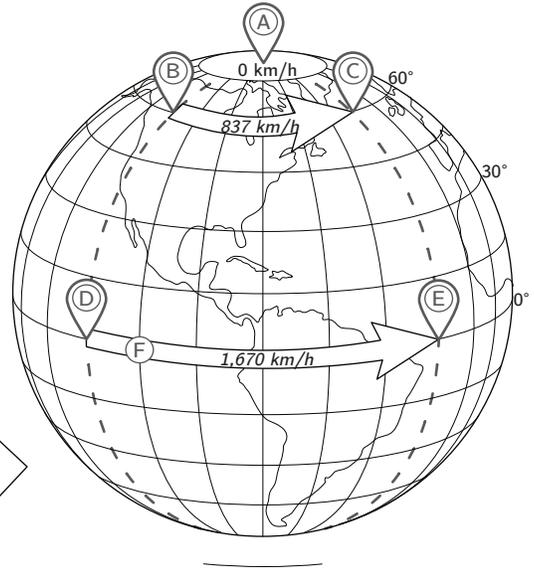
THE CORIOLIS EFFECT

As Earth rotates, different latitudes move at different speeds. To an observer in space, a person standing on the North Pole wouldn't appear to move - they would only rotate. A person standing at the equator, on the other hand, would be moving east at 1,670 km/h!

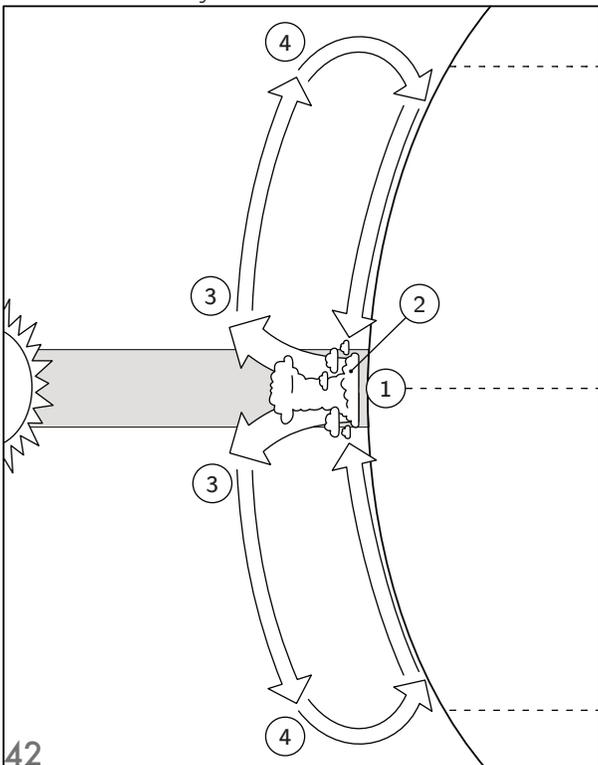


This has an important impact on air or water moving from one latitude to another. As a mass of air travels in a straight path, the Earth continues to rotate, which makes the path appear to curve.

A mass of air travels north from point F on the globe. Draw the path it will take.



Label the Hadley cells and latitude lines below:

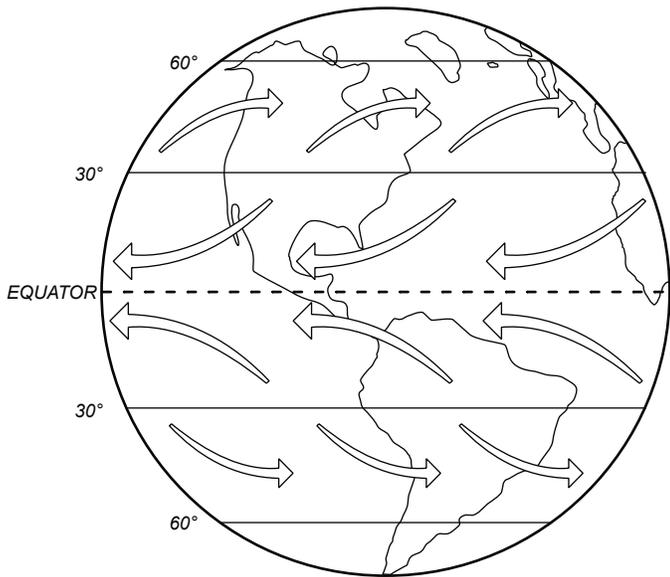


1. More intense solar radiation at the equator causes:

2. The band of large clouds near the equator is called:

3. At the top of the troposphere the air:

4. This air travels out to about 30° and then:



Westerlies:

Trade Winds (Easterlies):

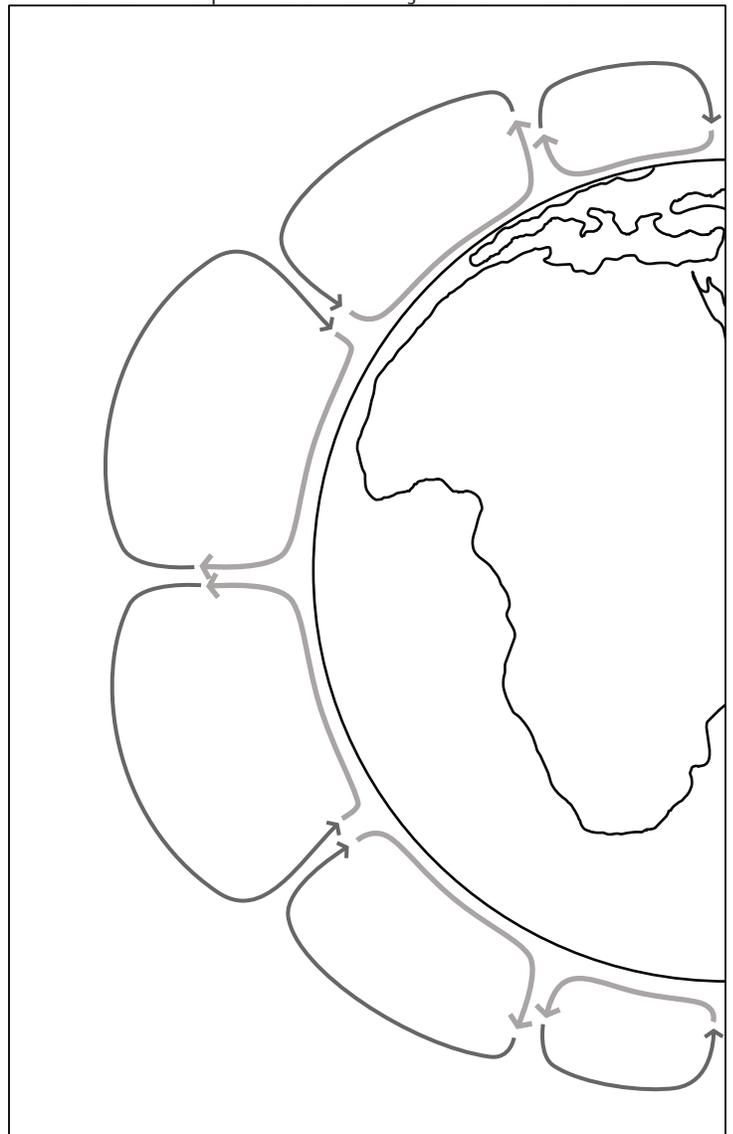
What drives the Hadley cells?

What drives the polar cells?

What causes or drives the Ferrel cells?

Why are so many of the world's deserts at 30°?

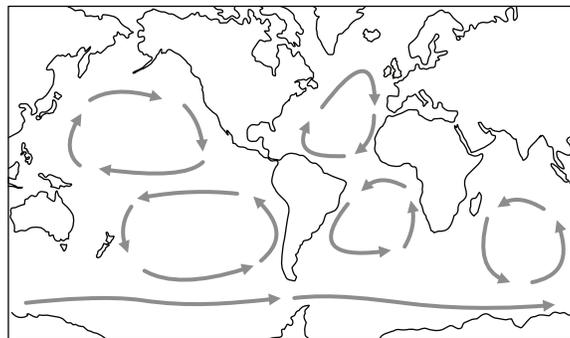
Label the atmospheric cells and jet streams below:



OCEAN CURRENTS

A large system of rotating ocean currents is called a gyre. There are 5 major subtropical gyres:

1. North Pacific Gyre
2. South Pacific Gyre
3. North Atlantic Gyre
4. South Atlantic Gyre
5. Indian Ocean Gyre



Label each gyre on the map, then answer the questions below:

Which gyre moves cold water north along the coast of South America?

Which gyres contain a garbage patch?

Which gyre contains the Sargasso Sea?

Which gyres rotate clockwise? _____

Which gyres rotate counterclockwise? _____

A LITTLE SPIN

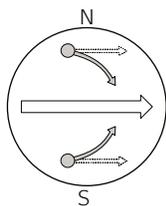
Because of the Earth's rotation, all large-scale air and water currents are influenced by the Coriolis effect.

Draw arrows in the diagrams to the right and label the direction of rotation for the pressure systems in each hemisphere.

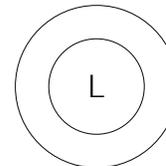
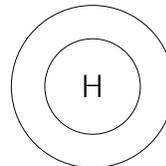
Remember, air or water will flow **OUT** of a high pressure system but **INTO** a low pressure system.

Also, in the **Northern Hemisphere**, moving objects deflect to the **right**.

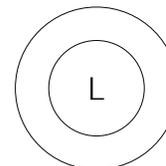
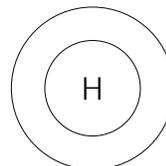
In the **Southern Hemisphere**, moving objects deflect to the **left**.



Northern Hemisphere

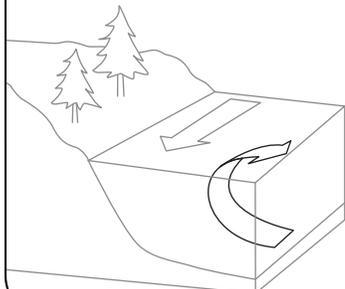


Southern Hemisphere

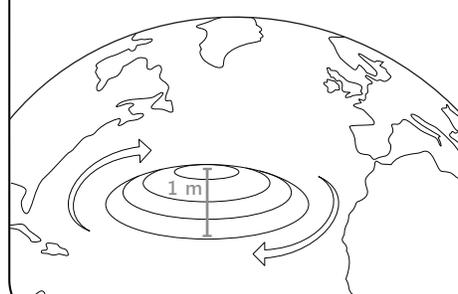


FACT or FICTION? Write your verdict below each statement:

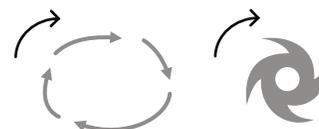
Prevailing winds along a coast will move warm surface water away and pull up cold deep water



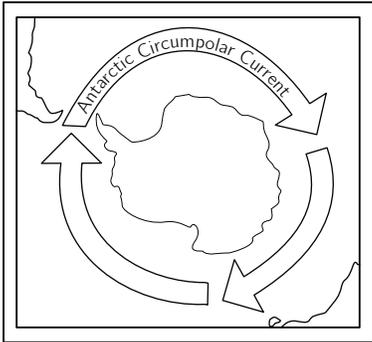
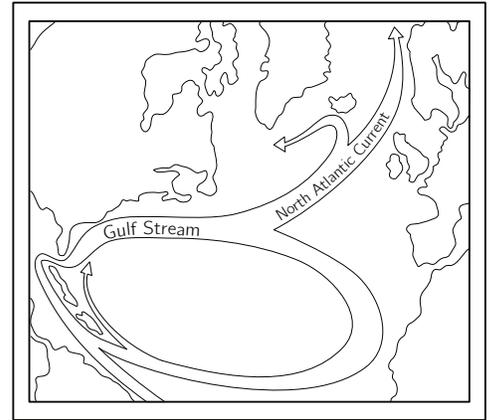
The water in the center of a gyre is about 1 meter (3 ft) higher than average sea level



Gyres and hurricanes in the same hemisphere will always rotate the same direction



Gulf Stream and North Atlantic Current

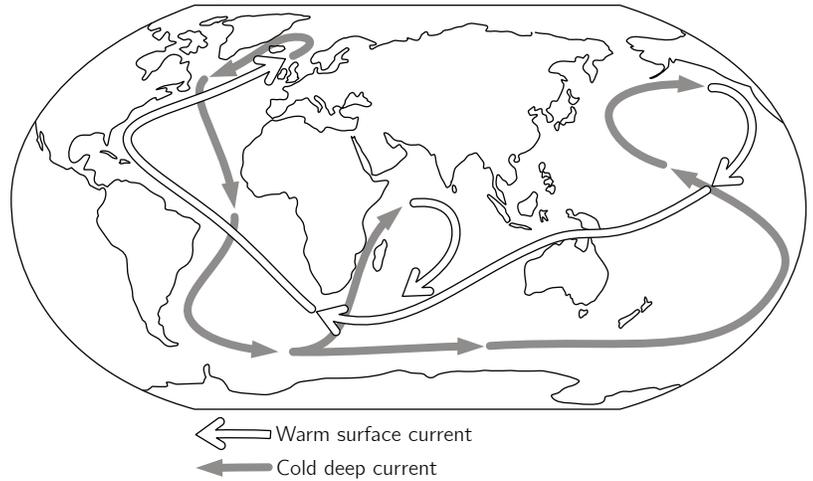


ACC (Antarctic Circumpolar Current)

Thermohaline Circulation

The Global Conveyor Belt

This simplified graphic shows the overall motion rather than every current



What are the driving forces of this global circulation?

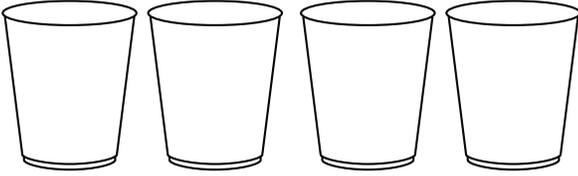
What effects does it have on weather & ecosystems?

ACTIVITY: CONVECTION CONVENTION

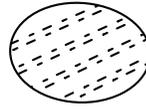
DIRECTIONS

This project has 4 different investigations that explore the concept of convection. For each activity, first **write a prediction** describing what you expect to occur. Then, after the activity is complete, record your results and answer any questions.

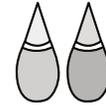
MATERIALS



Two to four clear cups of the same size.
Jars also work.



One or two thin pieces of flat plastic



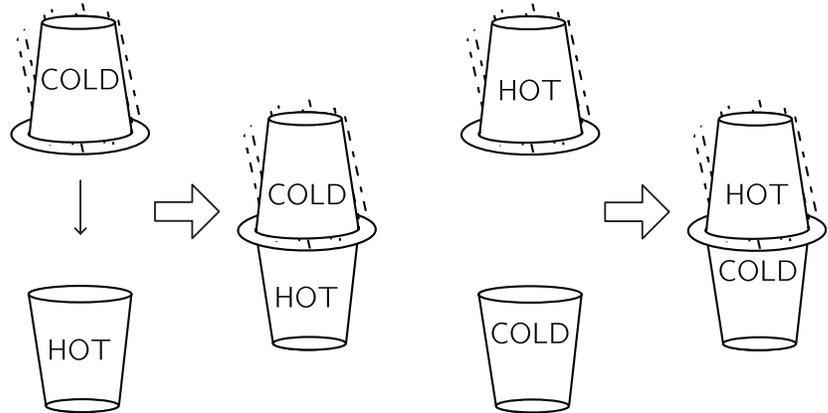
Blue and yellow food coloring



Tray

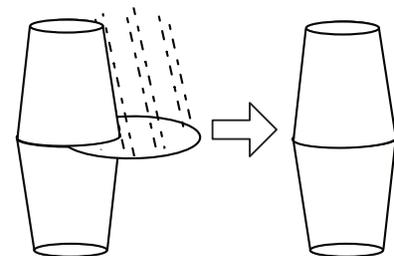
① Hot and Cold Water Cups

1. Do the experiment on a tray or outside to protect against spills.
2. Fill up two cups or jars with **cold** water that has been dyed **blue**.
3. Fill up the other two cups or jars with **warm** water that has been dyed **yellow**.
4. Make sure each cup is filled to the brim.
5. Cover one of the blue cups and one of the yellow cups carefully with a flat disk of plastic.
6. Press one hand on top of the plastic cover and invert the cup. The plastic disk should stay on the cup as you place it over a cup of the opposite color as shown.

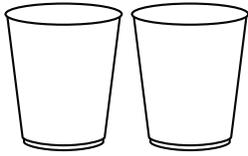


What do you expect to happen when the flat plastic barriers are carefully and slowly removed? Will the water mix, if so, how? **Record your prediction:**

7. Gently and slowly slide the disc out from between each set of the two cups so that both colors of water are connected. It helps to have 2 people for this step: one person holds the cups or jars steady while the other removes the disk.
8. **Record your observations:**



MATERIALS



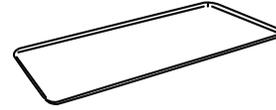
2 identical clear cups or jars



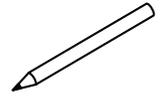
1 tsp salt



4-8 Ice cubes



Tray



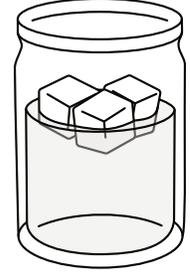
Pencil and paper or marker to make a label

② Fresh vs Salty Ice Melt

1. Do the experiment on a tray to protect against spills.
2. Fill the jars more than halfway with water of the same temperature.
3. Stir a teaspoon of salt into one of the jars until it dissolves. Some salt may remain undissolved on the bottom of the cup. This is okay. Label or mark the jar with salt
4. Place an equal number of ice cubes in each jar
5. In which jar do you expect the ice to melt the fastest? **Circle your prediction and briefly explain why you made it:**



SALT



NO SALT

Ice cubes melted at the SAME RATE

Ice cubes melted faster in FRESH WATER

Ice cubes melted faster in SALT WATER

6. Record your results:

Tip for success:

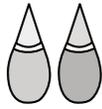
Watching ice melt can be a slow process – but if you leave and do something else, you might miss seeing the result!

Use the *timelapse* feature on a phone to record a video of the ice melting.

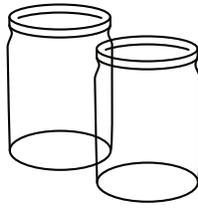
MATERIALS



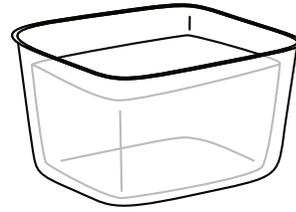
Tray



Red and blue food coloring



2 jars

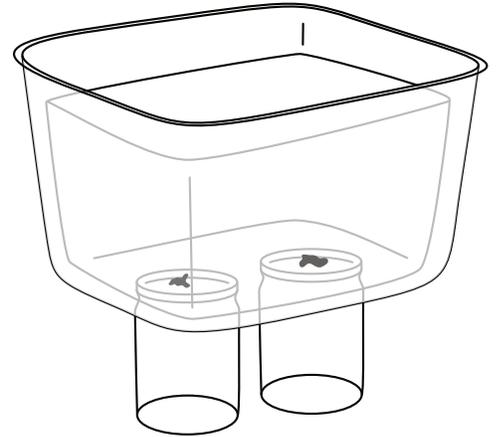


Large clear plastic container filled with water. Ideally not more than about 2 liters (0.5 gallons) because it will end up balanced on top of the jars

③ Convection in Water

A container of water will have food coloring to mark the movement of water. The red food coloring will be placed over a jar with hot water and the blue food coloring will be placed over a jar with ice-cold water. What do you predict will happen? Describe or draw a picture of how you expect the water to behave. Then complete the experiment and record your results.

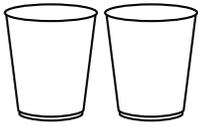
Prediction:



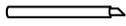
Instructions:

1. Do the experiment on a tray OR outside.
2. Check your container and jars to see if the container can safely balance on top of the jars. If needed, get additional jars or supports for the container.
3. Fill the 2 jars which will be used to support the large container. One jar should contain very hot or almost boiling water and the other jar should contain ice-cold water.
4. Fill up the large container with room temperature or cool water.
5. Carefully place the container on top of the 2 jars.
6. Carefully and slowly place a few drops of red food coloring at the bottom of the container just above the hot jar. Then add a few drops of blue food coloring above the cold jar. Try not to disturb the water too much as you add the coloring.
7. Observe.
8. Record your results:

MATERIALS



2 paper cups



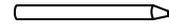
Exacto knife



Tape



Stiff wire taller than the cup



Pencil

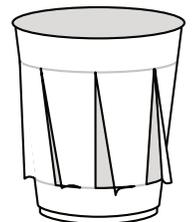
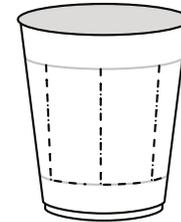


Candle that will fit in a paper cup

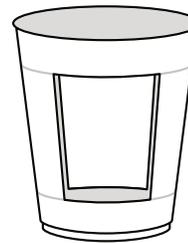
④ Convection in Air

ADULT SUPERVISION REQUIRED

1. Use the pencil to mark lines around each cup at about 20% and 80% of the height.
2. Cut 6 to 8 lines straight down from the top pencil mark to the bottom.
3. Near the bottom of each cut, make a horizontal cut that goes about $\frac{3}{4}$ of the way to the next vertical line.
4. Open up and crease triangular flaps as shown in the illustration.
5. On the other cup, cut out a window on each side of the cup between the top and bottom lines. This cup will be the one that holds the candle.
6. Carefully tape the wire on the candle-holding cup so that the tip of the wire is directly over the center of the cup. Getting the wire to the right angle can take some patience. Bend the wire if needed.
7. Place the candle inside the window.
8. Place the cup that has 6 to 8 flaps upside down on top of the wire. Check the placement. If the top cup does not rest so that it is fairly centered above the bottom cup, remove it and readjust the wire.
9. What do you expect to happen when you light the candle?
Make a prediction:



Step 4



Step 5



10. Light the candle and observe the cups.

11. Record your results:



Step 8

CAUTION:

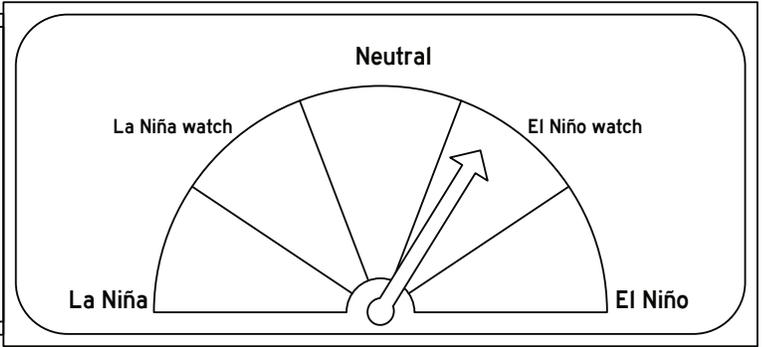
Observe the candle the entire time it is lit and then blow it out when you are done. Never leave fire unattended!

ENSO: EL NIÑO-SOUTHERN OSCILLATION

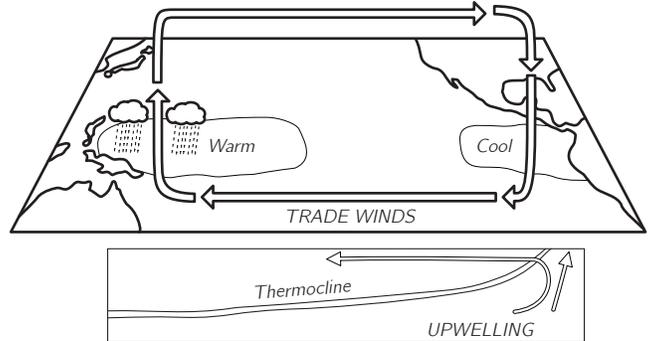
What ocean-atmosphere phenomenon can influence everything from droughts in Australia to salmon runs in Alaska and hurricanes in the Atlantic?

ENSO! This natural cycle alternates between two states called "El Niño" and "La Niña."

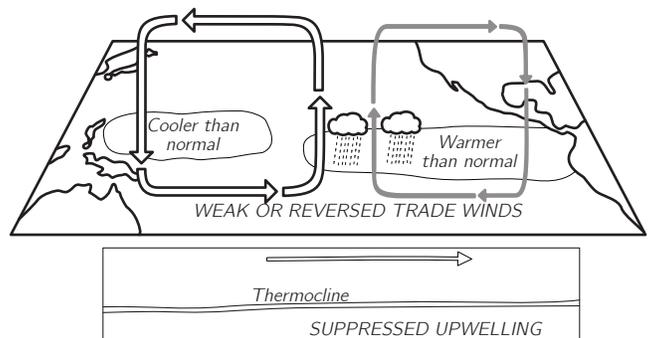
Before examining those extremes, it's important to look at the neutral or average state of temperature and pressure in the Pacific Ocean.



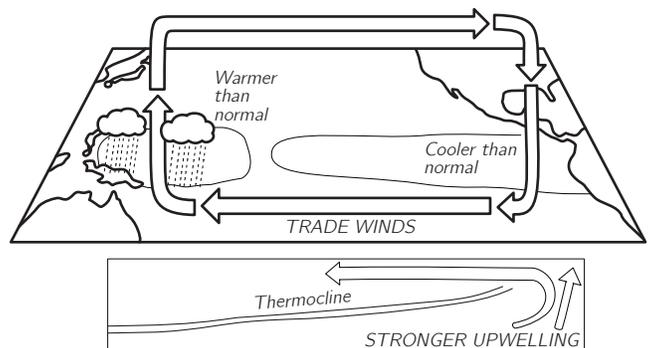
NEUTRAL



EL NIÑO



LA NIÑA



Global Impacts

Match each impact to show whether it's associated with El Niño or La Niña.

Flooding and mudslides
in Peru and Ecuador

Droughts and
wildfires in Australia

Flooding in
Indonesia

Wetter winters in
southern US

More frequent
Atlantic hurricanes

EL NIÑO

LA NIÑA

If ENSO is driven by changes in the Pacific Ocean basin, what about the other ocean basins that interact with the trade winds? Do you think there are similar patterns in the Atlantic or Indian oceans?

Show What You Know!

DESCRIBE NEUTRAL AND WATCH CONDITIONS, THEN FILL IN THE BLANKS TO ACCURATELY DESCRIBE LA NIÑA AND EL NIÑO.

Neutral: _____

Watch: _____

La Niña: Sea surface temperatures (SST) in the equatorial Pacific are at least 0.5 °C _____ than average and expected to persist _____ there are atmospheric changes such as:

- _____ trade winds
- _____ pressure and _____ rainfall over Indonesia
- _____ pressure and _____ rainfall in the eastern Pacific

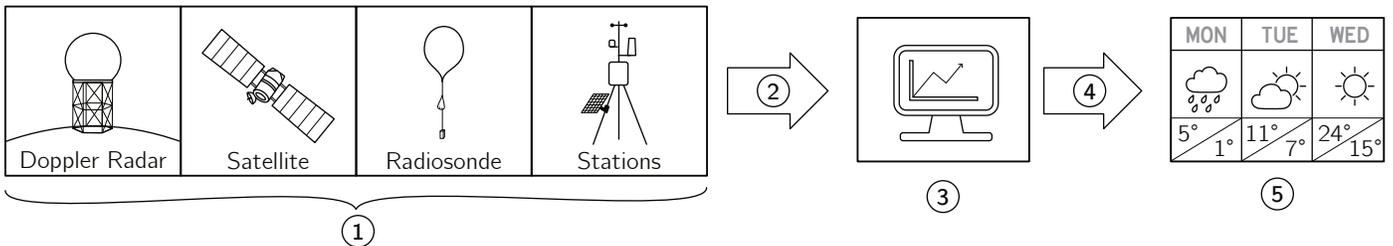
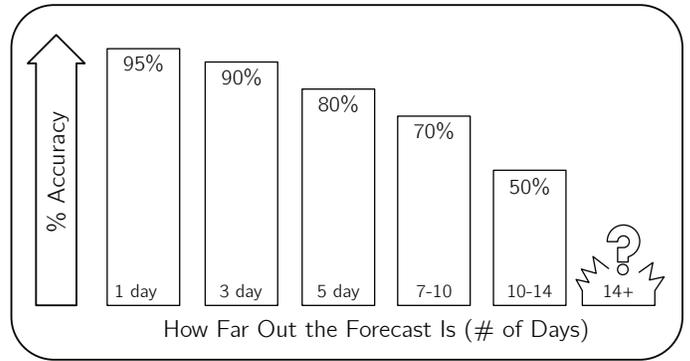
El Niño: SST in the equatorial Pacific are at least 0.5 °C _____ than average and expected to persist _____ there are atmospheric changes such as:

- _____ trade winds
- _____ pressure and _____ rainfall over Indonesia
- _____ pressure and _____ rainfall in the eastern Pacific



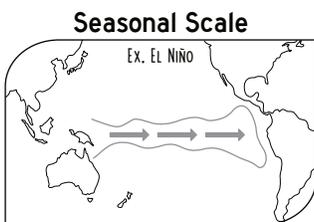
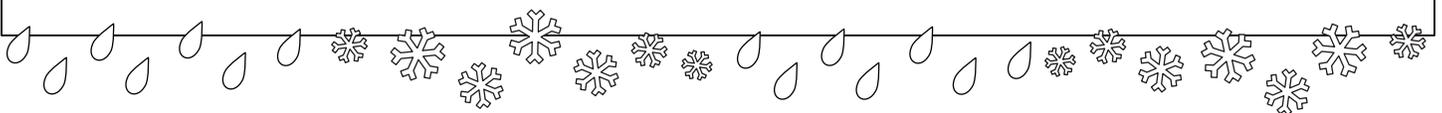
THE WEATHER FORECAST

Why is tomorrow's weather forecast more reliable than next week's forecast? Explain why the weather forecast get less reliable the further in the future we try to predict:



Describe the steps of making the weather forecast. Are there any notable challenges or limits?

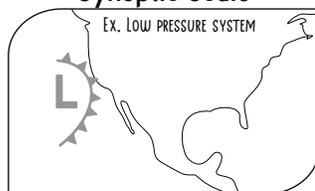
1. Observe current conditions: _____
2. Assimilate data: _____
3. Run multiple models: _____
4. Process and verify results: _____
5. Communicate: _____



Seasonal Scale

Ex. El Niño

Time: weeks to months
Size: hemisphere to global



Synoptic Scale

Ex. LOW PRESSURE SYSTEM

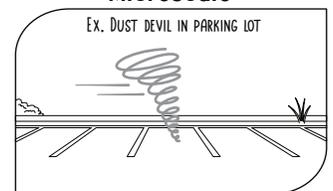
Time: 1-7 days
Size: >1,000 km wide



Mesoscale

Ex. SEA-BREEZE

Time: hours
Size: approx. 2 to 200 km wide



Microscale

Ex. DUST DEVIL IN PARKING LOT

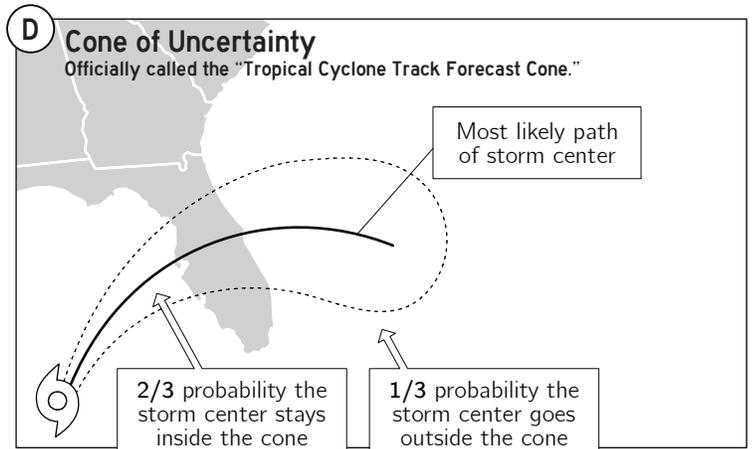
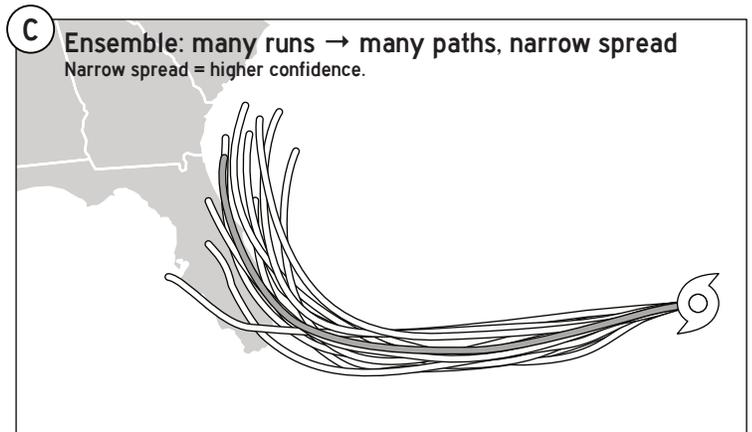
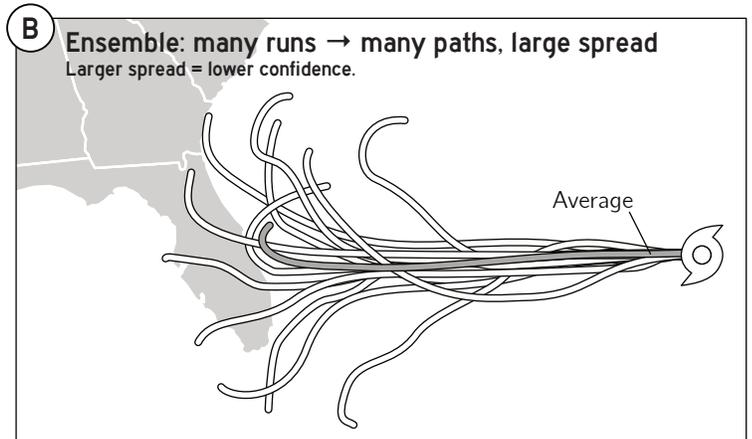
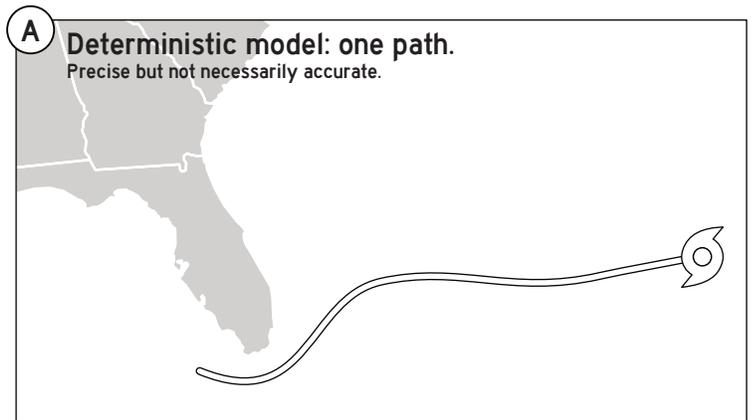
Time: minutes
Size: <1 km wide

A **deterministic model** takes the observations of the current atmosphere and produces one outcome. This can be a useful estimate, but we don't see the inherent uncertainty.

An **ensemble** runs the model many times with small changes to initial conditions and the physics formulas. Even with thousands of datapoints from radar, satellites, weather balloons and stations, we don't know the *exact* atmospheric conditions. Small initial errors grow over time, so realistic nudges to the initial data gives a better idea of future conditions.

The "spaghetti map" spread of an ensemble run is like an uncertainty signal. A large spread (B) indicates less certainty while a narrow spread (C) shows a higher confidence in the forecast.

Ensemble runs can be used to calculate percent chances. For example, if 8/20 models show rain in a given time interval, then that's about a 40% chance of rain.



Draw a forecast cone for maps B and C.

Bob is in Melbourne, Florida. Evaluate the forecast maps for storms B, C, and D.

Which has the potential to be the most dangerous to Bob, and why? Assume each storm is the same size and strength when making landfall.

The forecast calls for a **60% chance of rain tomorrow in Chicago. What does this mean?**

- 60% of Chicago will experience rain tomorrow.
- Rain will occur for 60% of the day.
- There is a 60% chance that Chicago will have measurable rain at some point tomorrow.
- Every model shows rain occurring tomorrow.
- Approximately 6/10 models predict rain.

ACTIVITY: TROPICAL STORM QUEST

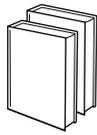
MATERIALS



Pages 52-55 of these notes



Internet connection OR books about hurricanes



Crayons, colored pencils, or other coloring supplies

GOALS

- ★ Compare hurricane paths to warm water belts and prevailing winds
- ★ Identify formation thresholds and typical track patterns of hurricanes
- ★ Research and communicate the impacts of one historical storm.

Large tropical storm systems revolving around an area of low pressure with winds over 119 kph (74 mph) are called **tropical cyclones**. When they form in the Atlantic or East Pacific, we call them **hurricanes**. In the West Pacific, we call them **typhoons**. In the South Pacific or Indian ocean, we usually call them **cyclones**. But they're the same type of storm!



DIRECTIONS

Examine the map on page 53 which shows the path of 10 cyclones. Lightly color the warm water bands. Shade 30° and 28° C areas red, 26° areas orange, and 24° areas yellow. Use the key on the map to note how the storm symbols change as the cyclones move. Then answer the following questions:

- A Of the 10 storms mapped on page 53, how many formed between 5° and 15° latitude?

- B Do any of these storms cross the equator? Why do you think that is? Take a guess!

- C Which direction do most storms move soon after their initial formation? Is the motion more like the trade winds (east to west) or the westerlies (west to east)?

- D Pick 3 storms with paths that curve away from the equator. For each one, estimate the latitude and write it down. Based on these examples, at roughly what latitude would you expect a future storm to turn?

- E What happens to storm strength when the center of the storm moves over land? (circle one)

Weakens
Strengthens
Stays similar/no change
- F Based on your mapping, label each statement below as either true or false:

Storms strengthen over warm water and weaken over cooler water

Storms intensify when they pass over cooler water that is less than 24°C

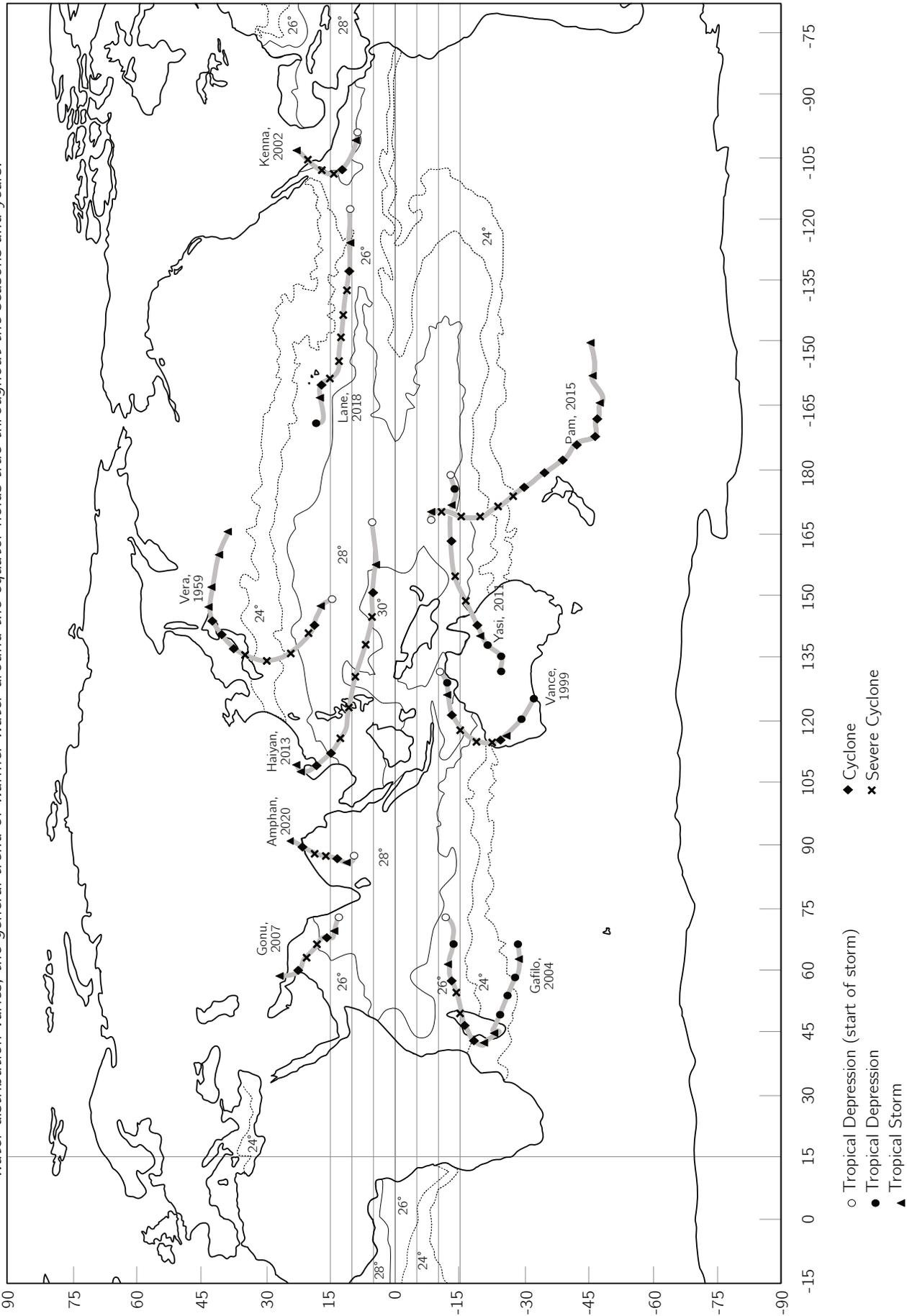
Severe cyclones can form in both the Northern and Southern hemispheres

Most storms are initially formed between 20° and 30° latitude

Most tropical storms begin on the equator

WARM WATER + CYCLONES

Note: The warm water distribution on the map may not match warm water distribution for the dates of the individual storms. This map shows ocean waters 24°C and warmer, drawn based on data from NOAA for November of 2025. Although warm water distribution varies, the general trend of warmer water around the equator holds true throughout the seasons and years.



Examine the map on page 55 showing the tracks of 3 famous storms: Debbie (1961), Mitch (1998), and Katrina (2005). The map also has November sea surface temperatures warmer than 24°C. Lightly color the warm water bands. Then answer the following questions:

- | | |
|-----|---|
| ○ | Tropical Depression (start of storm) |
| ● | Tropical Depression |
| ▲ | Tropical Storm |
| ◆ | Cyclone (equivalent to a category 1 or 2 hurricane) |
| ✕ | Severe Cyclone (category 3 hurricane or higher) |
| --- | Extratropical Storm |

G Note the latitude of where each of the 3 storms formed. Is the latitude of storm formation in the Atlantic similar to or different from the latitude of storm formation observed on the previous map? (circle one)

Similar latitude of formation for Atlantic storms

Different latitude of formation for Atlantic storms

Not enough data. More storm tracks needed to form an opinion

H How much of each storm's track lies over latitudes that contain the warmest water bands? What correlations do you notice between storm strength and water temperature?

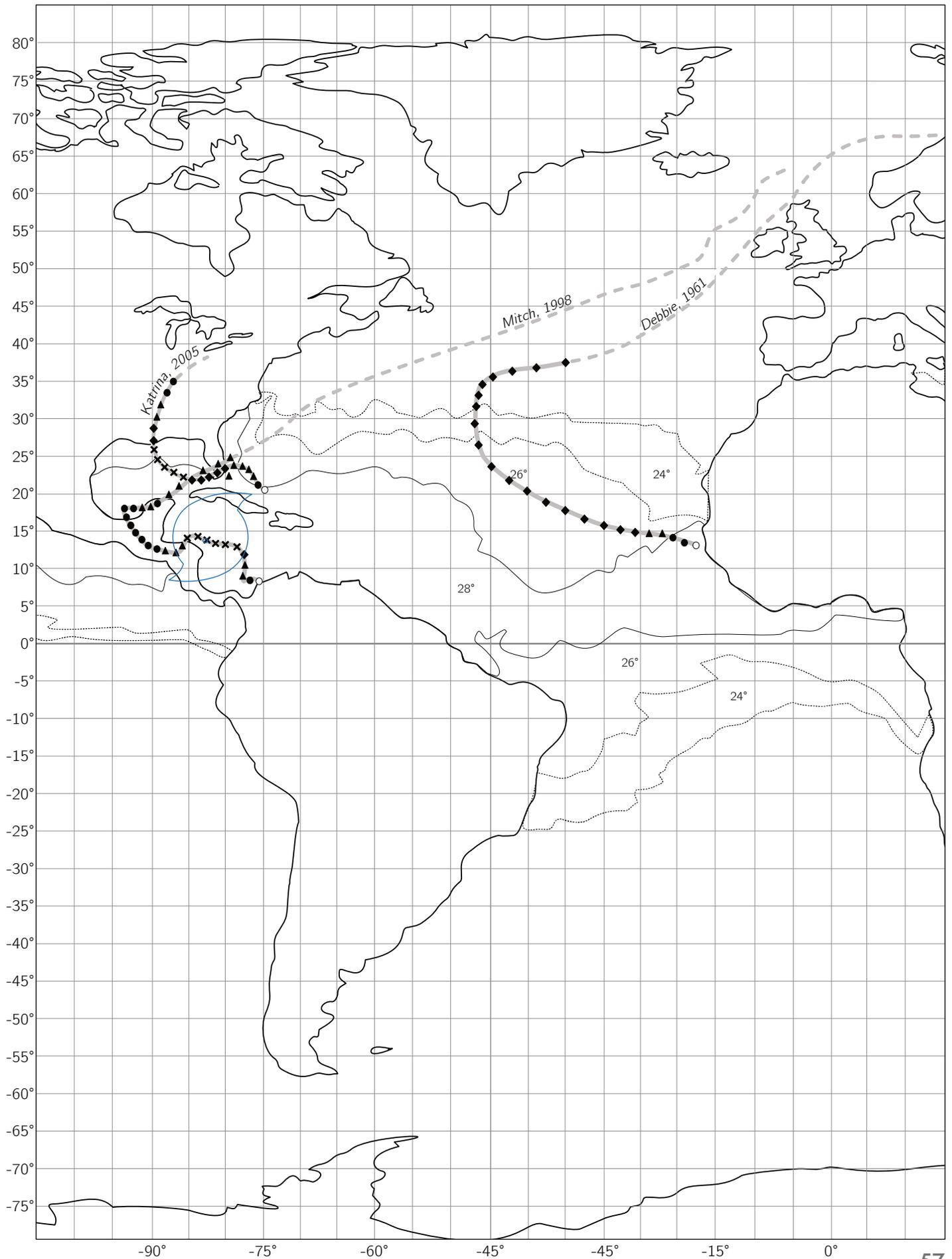
I Debbie was classified as an extratropical storm when it hit Ireland in the fall of 1961, but that doesn't mean it wasn't dangerous! Debbie brought winds with gusts of 183 km/h (114 mph), tore roofs from houses, and toppled tens of thousands of trees and power lines. Offshore waves reached heights of 14 m (46 ft). How far from the equator (in terms of latitude) do you think an Atlantic storm can bring dangerous winds and rain?

J Between 1970 and 2020, there were 325 named hurricanes (cyclones) in the Atlantic. Of those storms, 324 formed north of the equator and only 1 formed south of the equator. Study the location and shape of the warm water bands, ocean, and landmasses on the map.

- Describe two differences you observe between the North Atlantic and South Atlantic that might affect cyclone or hurricane formation.
- Using those differences as evidence, write an explanation for why Atlantic cyclones/hurricanes are more common in the North Atlantic but virtually unknown in the South Atlantic.

K Choose one of the storms from the map or Sandy (2012), Helene (2024), or Melissa (2025). Use a reliable source such as The National Hurricane Center, NOAA Historical Hurricane Tracks, or books about the storm to write a short research essay on the storm that addresses the following:

- When/where the storm formed
- Peak intensity and rating or category
- The total duration of the storm (from tropical depression to remnant)
- Human impact (casualties, evacuations, how many people affected)
- Infrastructure damage and economic costs
- What advice would you give a person in that location if the same storm were to occur again? In other words, what could people do *individually* to prepare?
- What could people do *collectively* with structures, laws, or planning to help a second storm be less destructive?

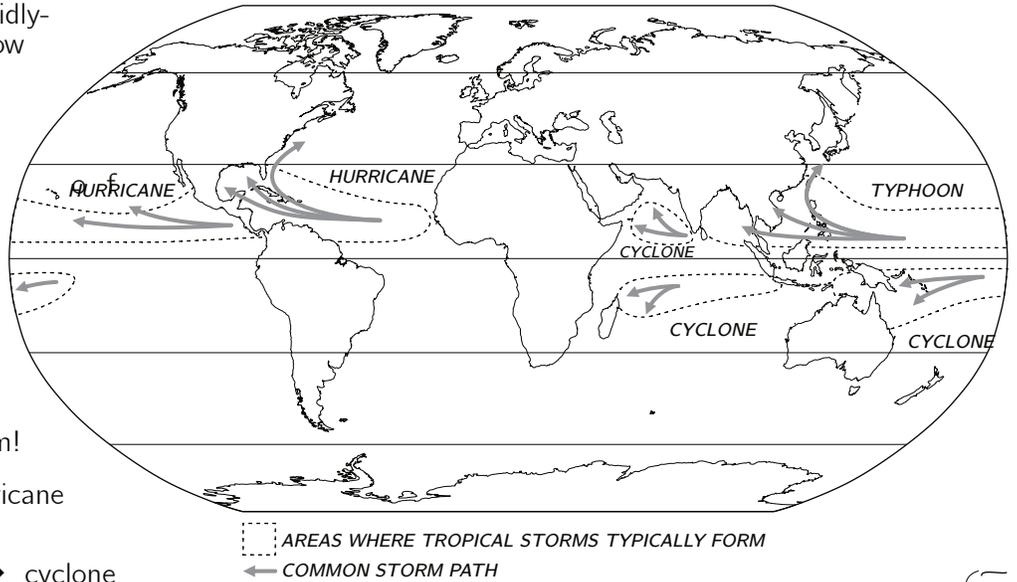


TROPICAL CYCLONES

Tropical cyclones are giant rapidly-rotating storm systems with a low pressure area in the center.

They impact millions of people each year and are among the most destructive all natural disasters.

These storms occur in the Pacific, Atlantic, and Indian ocean basins. Because they are monitored by different agencies, they have different names and rating systems. But they're all the same type of storm!



- 🌀 Atlantic / East Pacific → hurricane
- 🌀 West Pacific → typhoon
- 🌀 Indian Ocean/South Pacific → cyclone

Ingredients of a tropical cyclone:



Low vertical wind shear _____



Lots of water vapor _____



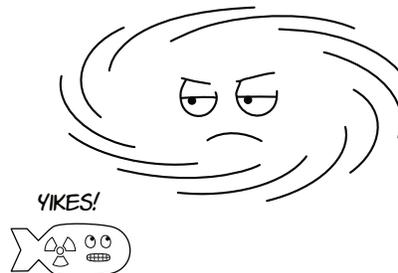
Warm water (surface temperatures of 27°C (80°F) or greater) _____

FACT or FICTION? Write your verdict below each statement:

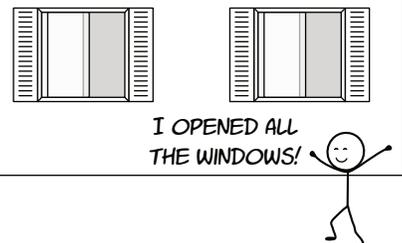
Hurricanes usually form directly on the equator because it's the hottest part of the ocean.



A hurricane releases as much energy as 1,000 nuclear bombs

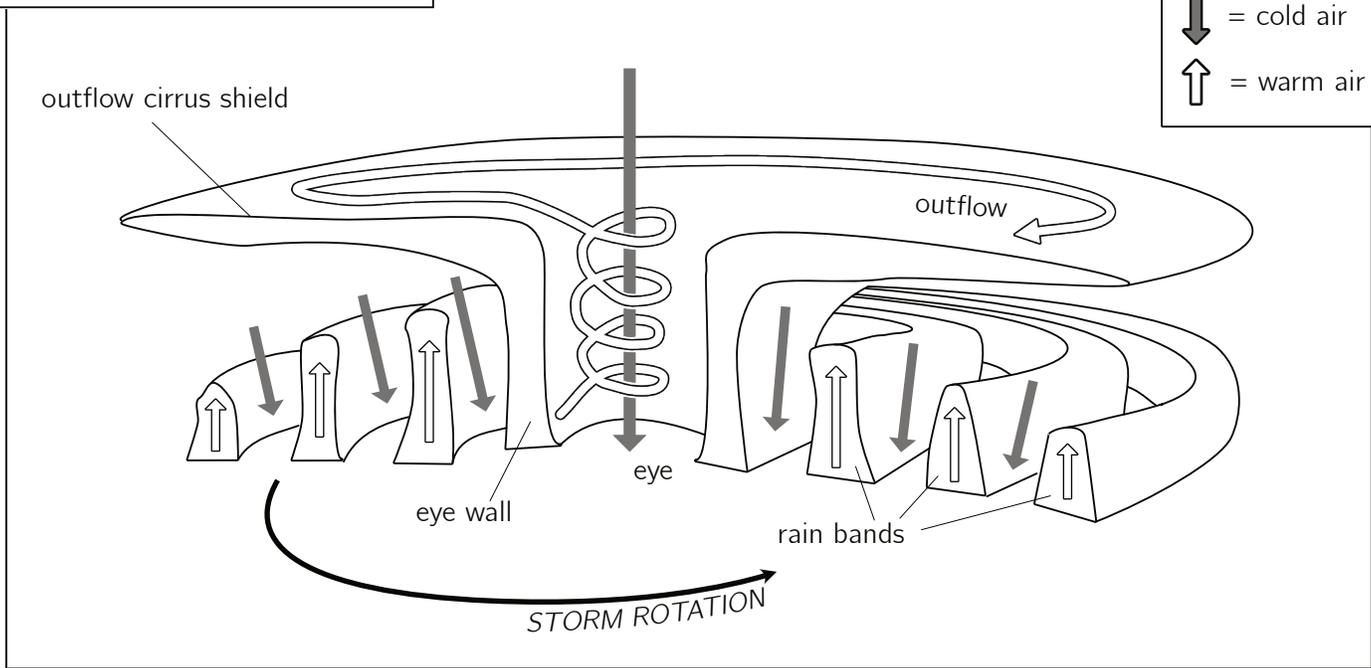


Opening windows during a hurricane equalizes pressure and prevents structural damage.



Anatomy of a Cyclone

↓ = cold air
↑ = warm air



A **heat engine** is any device that takes heat energy from something hot and turns a small fraction of that energy into “work”— such as motion or electricity etc. Tropical cyclones are a natural heat engine. Warm ocean water is their energy source. They move that heat to the upper atmosphere and, in the process, convert heat energy into wind, waves, and rain.

Make notes about each factor below and how it contributes to the destructive impacts of a tropical cyclone:

SIZE _____

RAIN _____

WIND _____

TORNADOS _____

STORM SURGE _____

THE SAFFIR-SIMPSON HURRICANE WIND SCALE

Describes how severe a storm is expected to be.

63-118 km/h	119-153 km/h	154-177 km/h	178-208 km/h	209-251 km/h	252+ km/h	
34-73 mph	74-95 mph	96-110 mph	111-129 mph	130-156 mph	157+ mph	
TROPICAL STORM	1	2	3	4	5	6?

HURRICANE



Some scientists are arguing that the Saffir-Simpson scale should be expanded to include a category 6 hurricane.

Look up an argument in favor of expansion and one against it.

Do you agree or disagree?

WEATHER & ATMOSPHERE UNIT ASSESSMENT

- ① When the air temperature equals the dew point, what is most likely to happen?
- The amount of water vapor in the air will increase
 - Relative humidity will decrease
 - Condensation: clouds or fog will form
 - Wind speed will increase
- ② Which statement about dry bulb/wet bulb temperature is true?
- Wet bulb temperature will always be lower than or equal to dry bulb temperature
 - When people refer to the temperature of the air, they're using the wet bulb temperature
 - The dry bulb temperature depends on the humidity of the air
 - A large difference between dry bulb/wet bulb readings indicates high humidity
- ③ What is the purpose of smoke in the "Cloud in a Jar" activity?
- It warms the air and helps it rise
 - It provides something for water vapor to condense on
 - It increases the jar's air pressure
 - It remove water vapor from the air
- ④ The heat index combines air temperature with:
- Barometric pressure
 - Cloud cover
 - Humidity
 - Wind speed
- ⑤ When a fast-moving cold front meets a mass of warm air, what is most likely?
- A band of nimbus clouds that produces steady, long-lasting rain
 - A wide arc of cirrus clouds with no precipitation
 - Cumulonimbus clouds with severe weather including heavy rain
 - Clear skies
- ⑥ Which direction does a hurricane in the Northern Hemisphere spin?
- Clockwise
 - Counterclockwise
 - It can spin in either direction
 - There is not enough information to tell
- ⑦ The Coriolis effect exists because Earth:
- Orbits the Sun
 - Is tilted at 23.5°
 - Has uneven heating between land and ocean
 - Rotates on its axis
- ⑧ The Hadley cell features:
- Rising air near 30° latitude and sinking at the Equator
 - Rising air near the Equator and sinking around 30° latitude
 - Rising air near the 30° latitude and sinking air at 60° latitude
 - Rising air near 60° latitude and sinking air near the poles
- ⑨ The Gulf Stream is an example of a western boundary currents of an ocean gyre. These western currents are typically:
- Cold and slow
 - Cold and fast
 - Warm and slow
 - Warm and fast
- ⑩ The thermohaline circulation of the ocean is driven most directly by:
- Earth's rotation
 - Differences in water density
 - The movements of tides
 - Rainfall patterns
- ⑪ Which of these describes El Niño?
- Stronger trade winds and a warmer eastern Pacific
 - Stronger trade winds and a cooler eastern Pacific
 - Weaker trade winds and a warmer eastern Pacific
 - Weaker trade winds and a cooler eastern Pacific
- ⑫ What is it called when a forecaster compares several model runs that start with slightly different initial conditions?
- Backcasting
 - Deterministic modeling
 - Ensemble forecasting
 - Nowcasting

13 Fill in the blanks for each of the facts about humidity below:

Humidity in Death Valley, California, during a summer day is usually around _____

A sense of smell works _____ in a humid environment than it does in a dry environment

Humidity in the Amazon rainforest is usually around _____

When it is raining, the humidity at ground level will most often be _____ 100%.
Circle the correct option:
LOWER THAN HIGHER THAN EQUAL TO

14 If surface pressure is falling quickly over several hours, which of these weather conditions are most likely to occur?

- A. Calm winds and clear skies
- B. Overcast conditions with no precipitation
- C. A storm system bringing rain, hail, or snow
- D. Strong winds but no change in temperature or precipitation

15 Which condition(s) could cause a hurricane to weaken and downgrade to a tropical storm? Mark all that apply:

- A. Passing over warm surface water that is at least 27° C (81° F)
- B. Passing over cool surface water that is 20 °C (68 °F)
- C. Passing over land
- D. High vertical wind shear
- E. Low vertical wind shear

16 Which statement is true about the dew point?

- A. The higher the dew point, the muggier the weather feels
- B. It often increases at night and decreases during the day
- C. It is the same as relative humidity
- D. When dew point is close to the air temperature, humidity is low

17 The subtropical jet stream typically sits:

- A. Near the Equator at 0°
- B. Near 30° latitude
- C. Near 60° latitude
- D. Over the poles at 90°

18 During La Niña winters, Australia is more likely to experience:

- A. Floods
- B. Droughts
- C. Average or normal weather

19 A sea breeze most often develops on warm, sunny days because:

- A. Land heats faster than ocean
- B. Ocean heats faster than land
- C. Upwelling near the coast creates wind
- D. The Coriolis effect moves air near the coast

20 Which tool is used to detect the motion and intensity of rain within a storm?

- A. Weather satellite
- B. Radiosonde on a weather balloon
- C. Anemometer
- D. Doppler radar

21 Relative humidity doubles in a parcel of air but the temperature remains the same. Which statements are true? (mark all that apply)

- A. Dew point decreased
- B. Dew point increased
- C. There is now more water vapor in the air
- D. There is now less water vapor in the air
- E. More cooling is needed to reach saturation
- F. Less cooling is needed to reach saturation

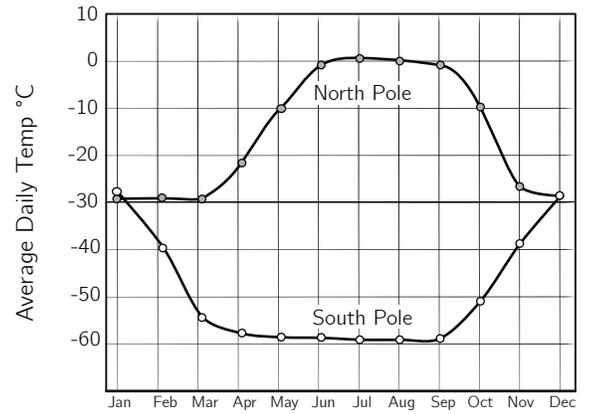
22 What type of weather is typically associated with a warm front?

- A. Intense thunderstorms
- B. Steady precipitation with layered clouds
- C. Clear skies and high pressure
- D. Hurricanes

23 If the polar jet stream shifts south over Toronto, what conditions would the city expect:

- A. Warmer, calmer conditions
- B. Colder, stormier conditions
- C. No change in weather patterns
- D. A reduction in temperature but no change in atmospheric pressure

24 Explain why the South Pole is colder than the North Pole.



25 Why does wind tend to curve to the right in the Northern Hemisphere?

26 Can the dew point ever be higher than the air temperature? Why or why not?

27 Each box below shows an old traditional saying or bit of lore that was used at some point to predict rain. Evaluate each one based on what you know about weather. Do you think any of them would work? Why or why not?

PINECONES THAT WERE OPEN CLOSE AGAIN	DRAGONFLIES FLY NEAR THE GROUND	ARTHRITIC JOINTS ACHES AND HURTS	COWS ARE LYING DOWN
		<p>THERE'S A STORM COMING, I CAN FEEL IT IN MY KNEES!</p>	

28 List each layer of the atmosphere and write a fact about each:

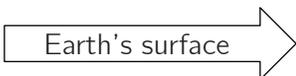


5: _____

4: _____

3: _____

2: _____



1: _____

- 29 Relative humidity doubles in a parcel of air but the temperature remains the same. Which statements are true? (mark all that apply)
- A. Dew point decreased
 - B. Dew point increased
 - C. There is now more water vapor in the air
 - D. There is now less water vapor in the air
 - E. More cooling is needed to reach saturation
 - F. Less cooling is needed to reach saturation

- 30 What does a forecast cone ("cone of uncertainty") for a hurricane represent?
- A. The area that will have hurricane-force winds
 - B. The predicted size of the storm's impact
 - C. The potential track of the storm's center, which grows less certain with time
 - D. The area that can expect flooding

- 31 A meteorologist sees that 12 of 20 ensemble members show rain in Victoria tomorrow afternoon. What's the simplest interpretation of how likely it is to rain in Victoria tomorrow?
- A. 12% chance of rain
 - B. 20% chance of rain
 - C. 40% chance of rain
 - D. 60% chance of rain

- 32 Why don't hurricanes form on the equator?
- A. The water is too warm
 - B. There isn't enough humidity
 - C. The convection is too strong at the equator
 - D. There isn't enough Coriolis force at the equator to create the needed spin

- 33 What is the Intertropical Convergence Zone or ITCZ?
- A. A band of sinking air that circles the equator
 - B. A front between polar and tropical air
 - C. A belt where the trade winds converge, air rises, and thunderstorms are common
 - D. The latitude where deserts are found

- 34 Why does the Intertropical Convergence Zone or ITCZ migrate north and south over the year?
- A. Because Earth rotates on a tilted axis
 - B. Because of changes in the distance between the Earth and the Sun
 - C. Because of El Niño
 - D. Because of fluctuations in the jet stream

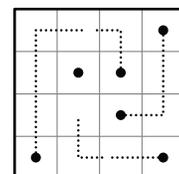
35

PIPE FLOW MATCHING - UNIT 2

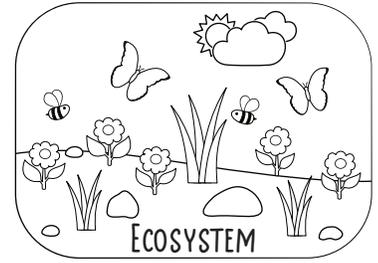
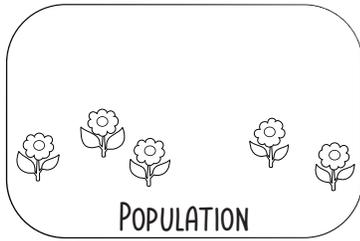
	B	1			E
					3
		4			
		A			
		2			D
C					5

Match each unit with the quantity being measured by joining them with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

- | | |
|-----------------|----------------------------|
| 1. Anemometer | A. Measures wind direction |
| 2. Thermometer | B. Measures temperature |
| 3. Hygrometer | C. Measures air pressure |
| 4. Barometer | D. Measures humidity |
| 5. Weather vane | E. Measure wind speed |



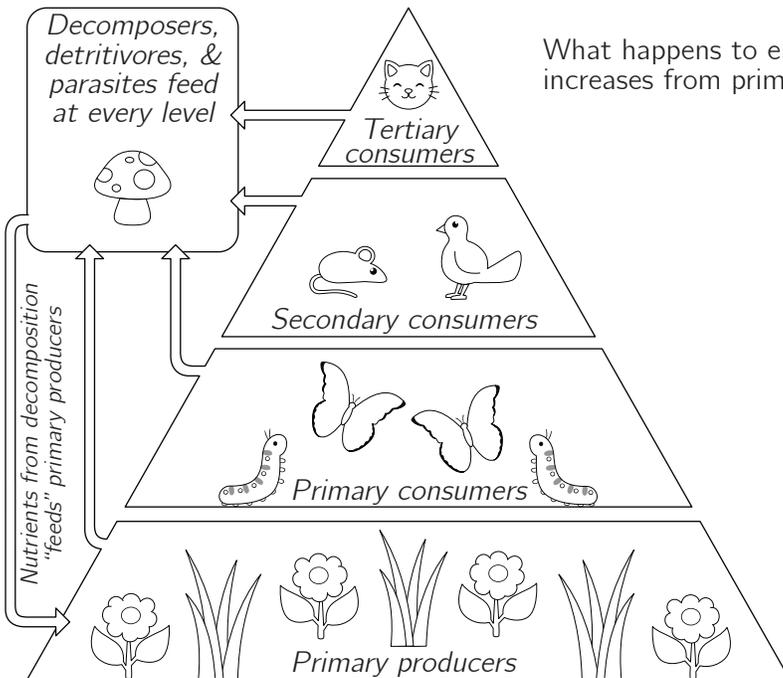
UNDERSTANDING ECOSYSTEMS



FILL IN THE BLANKS (WORDS FROM THE BOX MAY BE USED MORE THAN ONCE OR NOT AT ALL)

10% 25% 50% 75% biomass consumers
ecosystem energy producers pyramid trophic

Sunlight is the _____ source that powers almost every _____ on Earth. _____ such as plants use sunlight to create _____ which is consumed by organisms of different _____ levels: the primary, secondary, and tertiary _____ and decomposers. Only about _____ of the _____ in one level is transferred to the next. An ecological _____ shows visually how each trophic level needs to be supported by a larger "base" of organisms below it.



What happens to energy, biomass, and population size as trophic level increases from primary producers to tertiary consumers? Why?

The synthesis of organic compounds from carbon dioxide is called **primary production**.

Gross Primary Productivity (GPP) in your own words:

Net Primary Productivity (NPP) in your own words:

ECOSYSTEM IN A JAR



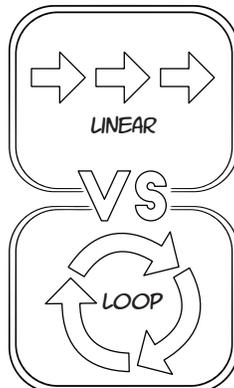
What eats what

- Aphids** eat plants
- Beetles** eat aphids, snails, and springtails
- Centipedes** eat aphids, snails, and springtails
- Dot snails** eat fungi and detritus (dead organic matter such as leaf litter, excrement and the remains of animals)
- Fungi** digest detritus
- Plants** use energy from sunlight to fix CO₂ into organic molecules
- Snake** eats beetles and centipedes
- Springtails** eat fungi and detritus

List the energy source, carbon source, and ecological role of each organism in the terrarium:

Organism	Source of energy	Source of carbon	Ecological role
Aphids			
Beetles			
Centipedes			
Dot snails			
Fungi			
Plants			
Snake			
Springtails			

Is the flow of energy in the terrarium more linear or loop-like? Why?



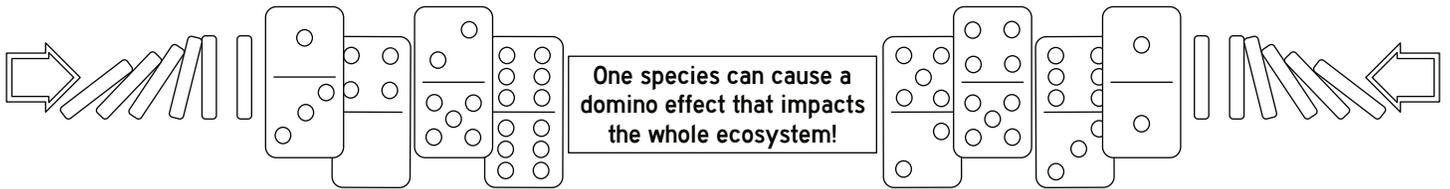
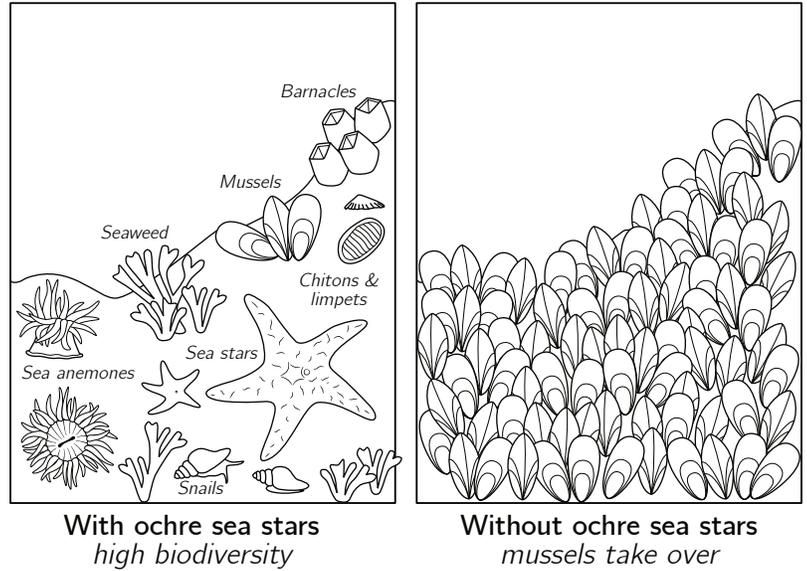
Is the flow of carbon in the terrarium more linear or loop-like? Why?

KEYSTONE SPECIES

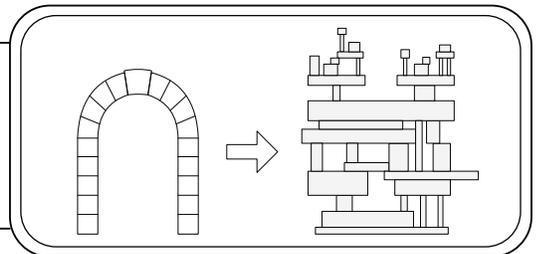
In 1969, the ecologist Robert Paine studied the effect of the ochre sea star (*Pisaster ochraceus*) on tide pools in Washington state. He found that when sea stars were removed from a pool, black mussels established a monoculture.

He called the ochre sea star a **keystone species**. (A keystone block in an arch keeps the entire arch from collapsing.)

Explain Paine's keystone species hypothesis in your own words:



The real world is complicated! An ecosystem isn't as simple as an arch with a central support block. It's more like a complicated tower of interlocking blocks. Kind of similar to playing the game a block stacking game where players take turns removing a block. Taking out any block can contribute to instability, but when a "keystone block" is removed the entire tower collapses.



PREDATORS

MUTUALISTS

Mutualism vs Symbiosis

Both describe mutually beneficial interactions between two or more species.

If the species are living in close physical contact for long period of time, we tend to call it *symbiosis*.

If the organisms live separately from each other, we tend to call it *mutualism*.

ECOSYSTEM ENGINEERS

Some scientists think the term *keystone species* has become too vague, overused, and misapplied. Others argue that it's still a helpful way to communicate the importance of certain species, especially for conservation.

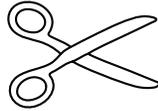
What do you think? Should scientists keep using the term keystone species, refine it, or replace it with a different term? Use at least one example to support your perspective.

ACTIVITY: STACKABLE FOOD CHAIN & FOOD WEB

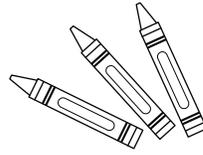
MATERIALS



At least 4 pieces of paper
(construction paper works well,
but any type of paper will work)



Scissors



Coloring supplies

GOALS



Research a food chain



Learn more about food webs

DIRECTIONS

① Choose an ecosystem

Choose a system and a primary producer from among the options below *or* propose your own.

MARINE

Primary producers from a coastal kelp forest:
phytoplankton, bull kelp,
or giant kelp

RIPARIAN

Primary producers from a mountain stream:
Filamentous green algae or aquatic mosses

DEEP SEA

Primary producers from a hydrothermal vent:
Chemosynthetic bacteria

DESERT

Primary producers from the Mojave Desert:
Joshua tree, creosote bush,
cholla cacti, or prickly pear

GRASSLAND

Primary producers from the North American Prairie:
Buffalo grass, western sunflower, or milkweed

FOREST

Primary producers from the Appalachian Forest:
oak, willow, maple, or American persimmon

② Fill in the table

Choose 2 to 5 organisms beside your primary producer that live in the same ecosystem. Fill in the table below to be sure that each organism both eats and is eaten by another organism in the food chain.

Organism <i>common name and scientific name</i>	What do I eat? <i>for producers, list their energy source</i>	Who eats me? <i>if none, label top predator</i>	1 interesting fact about the organism

③ Put your organisms in order

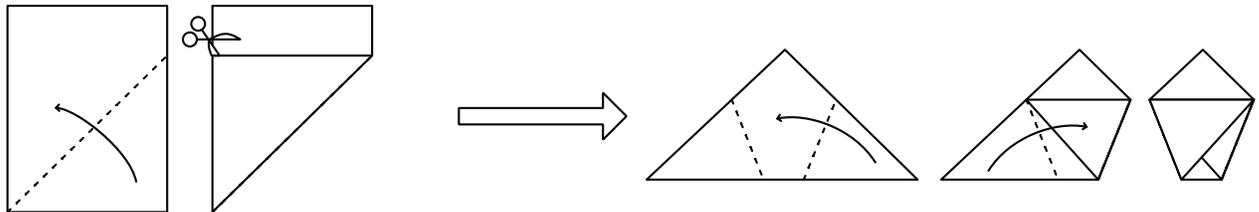
Write down your food chain in the box, double checking that each of the following are true:

- ✓ One producer at the beginning
- ✓ All organisms share the same ecosystem
- ✓ Each arrow goes food → eater
- ✓ Ends with a top predator (no one in your chain eats it)

FOOD CHAIN

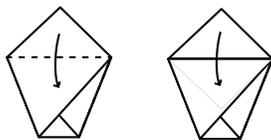
④ Make the nesting cups

Cut the pieces of paper so that they are squares where each square of paper is about 1 inch larger in diameter than the previous one. Then fold each square according to the following steps to make your paper nesting cups:

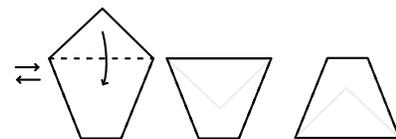


A) Cut the paper to form a square. Drag one corner of the paper to the opposite edge and crease it to make a right triangle. Cut off the exposed edge.

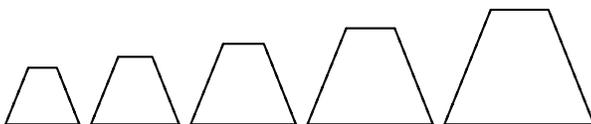
B) Make Dracula fold his arms. Put the right angle on top. Then drag one corner to be about 60% of the way up the opposite side and crease the paper. Repeat with the opposite side so that the sleeves are folded across the body.



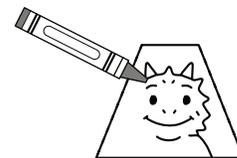
C) Tuck the front head flap. Fold the top triangle down and tuck it inside the front sleeve by opening up a slit in the sleeve and sliding the tip of the triangle in and working the rest of the triangle in. Crease the edge.



D) Tuck the back head flap. Flip it over to the opposite side and then tuck the remaining top triangle backwards into the big gap on the inside. Rotate 180°, and your doll is ready..

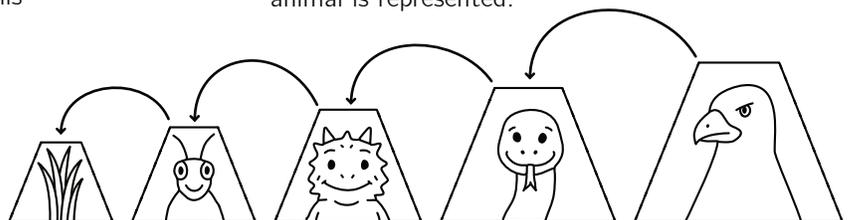


E) Repeat. Make a nesting doll for each animal in your food chain. Use a different size square for each one so that the dolls can nest inside each other.



F) Label and/or decorate. Draw a face or make a picture on each doll to make it clear which animal is represented.

G) Nest the dolls! Demonstrate each step of the food chain by having your food chain members devour each other from smallest to biggest



EXTENSION

Look up the plants and animals that live near you! Can you make a stackable food chain for the ecosystem you live in?

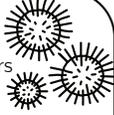
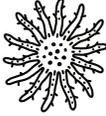
- ⑤ Use the organisms below to create a food web representing a kelp forest in a temperate coastal ecosystem. Keep in mind that in the real world, the web is even more complicated! There are 500+ macroscopic species and many thousands more if we include all of the known microfauna and microbes.

We have selected 15 organisms for this activity. Read each box below to learn a little about the organisms. Then write each organism's name in the empty boxes on the next page so every arrow points from something that could be eaten to something that could eat it.

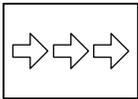
OR you could draw your own food web for these organisms on a separate piece of paper. Just remember that the arrows should show energy moving from food → eater.

TIP: Producers have only outgoing arrows; apex predators (Orca, Bald eagle) have only incoming arrows; mid-level consumers have both. If two cards could fit one box, re-read their diets and predators to find the better match.

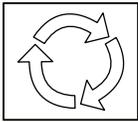
After filling in the food web, label the producers, primary consumers, secondary consumers, tertiary consumers, and apex predators.

<p>Crabs Armor-Plated Snackers</p>  <p>They even have teeth in their stomach (a gastric mill) to grind food after snapping it up.</p> <p>Eats: Mussels</p>	<p>Phytoplankton Tiny Sun Snackers</p>  <p>Microscopic drifters that make about half of Earth's oxygen while powering the whole ocean food chain.</p> <p>Eats: — (energy from sunlight)</p>	<p>Seals/Sea Lions Whiskered Torpedos</p>  <p>Hyper-sensitive whiskers can track the ripples of a fish's swim like underwater fingerprints.</p> <p>Eats: Herring, Salmon, Squid</p>	<p>Sea Birds Feathered Divers Club</p>  <p>Murres can dive to depths of over 100 m.</p> <p>Eats: Herring, Mussels</p>
<p>Zooplankton Night-Shift Elevators</p>  <p>They ride the world's largest daily migration, zooming up at night to feed and down by day to hide.</p> <p>Eats: Phytoplankton</p>	<p>Orca Pod Professors</p>  <p>The ocean's apex dolphins have family dialects and hunting "cultures" passed down through generations.</p> <p>Eats: Seals/Sea Lions, Salmon, Squid</p>	<p>Giant Kelp Underwater Redwoods</p>  <p>Giant kelp can grow up to 2 feet (≈60 cm) per day! It forms enormous underwater "forests" that shelter hundreds of species.</p> <p>Eats: — (energy from sunlight)</p>	<p>Salmon River Seekers</p>  <p>Born in streams, they grow at sea then smell their way home to the exact river where it began.</p> <p>Eats: Herring, Squid</p>
<p>Mussels/Barnacles Super-Glue Crew</p>  <p>Barnacle "cement" and mussel byssal threads stick underwater better than many glues humans make.</p> <p>Eats: Phytoplankton</p>	<p>Bald Eagles Sky Pirates</p>  <p>With amazing vision and huge talons, it can snatch fish from the surface or steal a meal from other birds.</p> <p>Eats: Salmon, Sea Birds</p>	<p>Herring School of Shimmer</p>  <p>Massive, glittering schools confuse predators with mirror-bright sides and lightning-fast turns.</p> <p>Eats: Zooplankton</p>	<p>Sea Urchins Five-Tooth Lawn Mowers</p>  <p>Their jaw, "Aristotle's lantern," is a five-toothed scraper that can mow kelp like a tiny buzz saw.</p> <p>Eats: Kelp</p>
<p>Squid Jet-Pack Ninjas</p>  <p>With three hearts and jet propulsion, squid can blast away while inking a smoke-screen escape.</p> <p>Eats: Zooplankton</p>	<p>Sea Stars Stomach-Flip Specialists</p>  <p>They evert their stomachs over prey to digest it outside their bodies, and many can regrow lost arms.</p> <p>Eats: Mussels, Sea Urchins</p>	<p>Sea Otters Pocket-Rock Chefs</p>  <p>They carry a favorite rock in a forearm "pocket" to crack urchins, and their fur is the densest on Earth.</p> <p>Eats: Sea Urchins, Sea stars, Crabs</p>	

NUTRIENT CYCLES

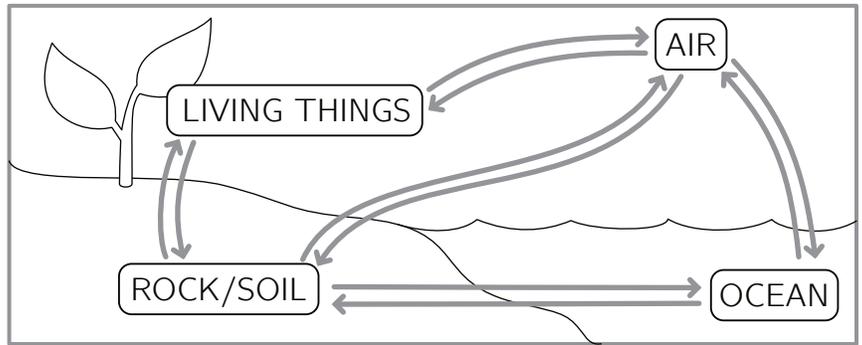


Energy in an ecosystem flows from producers to consumers. It's a unidirectional flow.



Atoms in an ecosystem are reused over and over; they flow in a cycle from one reservoir or pool to another.

On Earth, important reservoirs of nutrients for ecosystems include rock, ocean, air, and living things.



Carbon

Test what you already know about carbon by marking each statement as true or false:

The total amount of carbon on Earth today is the same as it was 300 MYA.

80% of the mass in food is from carbon.

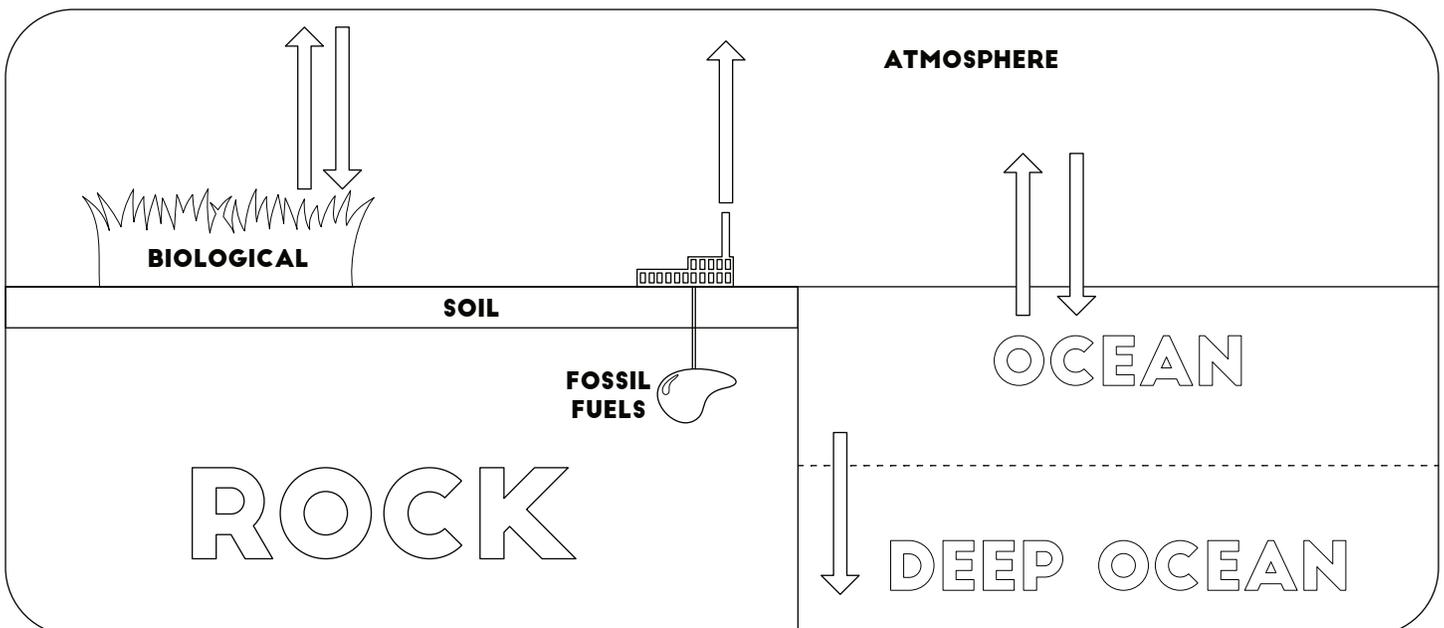
All life that we know of is carbon based.

Removing all CO₂ from the atmosphere would benefit life on Earth.

Carbon can form bonds with MANY other elements. It's found in every living thing and is often called "the building block of life." But carbon can also exist in the air as carbon dioxide (CO₂) or methane (CH₄), in rocks in many different minerals such as calcite (CaCO₃), siderite (FeCO₃) and magnesite (MgCO₃), and in fossil fuels as long chains of carbon and hydrogen (hydrocarbons).

Earth's carbon is primarily located in 5 reservoirs or pools. Carbon moves between some of the pools in years to decades (this is called the fast carbon cycle). But between other pools, meaningful movement takes hundreds of millions of years (this is called the deep carbon cycle or slow carbon cycle).

The diagram below shows the main carbon pools. The arrows represent some of the processes that moves carbon from one pool to another. **Label each arrow:**

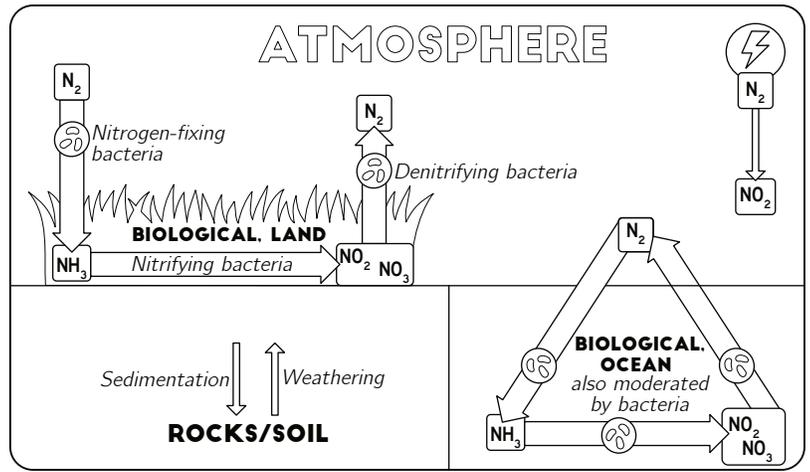


Nitrogen

Most of the atmosphere is nitrogen gas (N_2), also called **inorganic nitrogen**.

Animals, plants, and fungi cannot use this form. The forms that most living things need (such as NH_3 , NH_4^+ , NO_2 , N_2O) are called **organic nitrogen**.

Converting nitrogen gas (N_2) into organic nitrogen is called "fixing" nitrogen or "nitrogen fixation." In nature, nitrogen changes forms primarily through bacteria. Since 1910, humans have been using high pressure and heat to fix nitrogen industrially with the Haber-Bosch process.

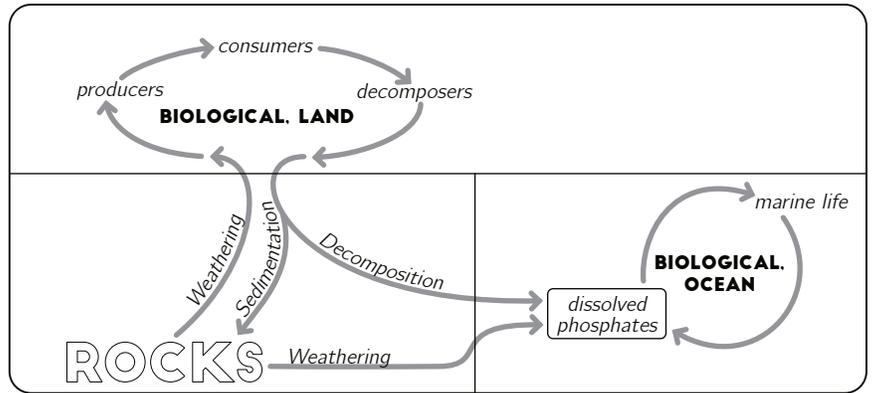


Phosphorus

Phosphorus exists in minerals, rivers, lakes, oceans, and in the cells of every living organism.

The largest reservoir of phosphorus, by far, is found in rocks. In water systems and biological reservoirs, phosphorus exists in relatively small quantities.

The atmosphere does NOT play a significant role in how phosphorus moves through ecosystems.



3-Ingredient Cookie Recipe:
1 cup nut butter
$\frac{3}{4}$ cup sugar
1 large egg
Mix well. Shape dough in 24 balls. Flatten each slightly with fork. Bake at 350 for 10 minutes. Let cool completely.

Bob has dozens of cups of peanut butter and sugar, but only 2 eggs. Explain why eggs are the **limiting ingredient** for how many batches of cookies Bob can make. How is this similar to a **limiting nutrient** in an ecosystem?

FACT or FICTION? Write your verdict below each statement:

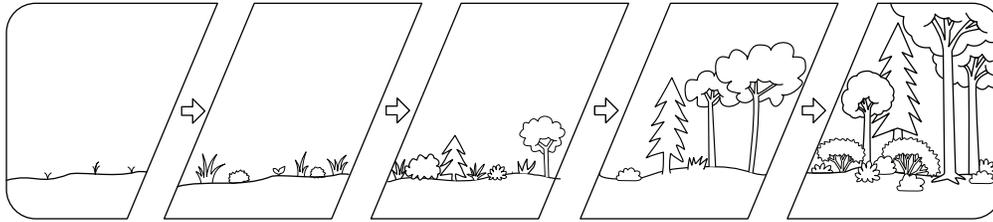
Every summer, too much phosphorus enters the Gulf of Mexico and creates an enormous "dead zone" where no fish can live.

DON'T SWIM OVER THERE! THE ALGAE ATE ALL THE OXYGEN!

You're part dinosaur breath! Carbon atoms in your body were exhaled by dinosaurs millions of years ago.

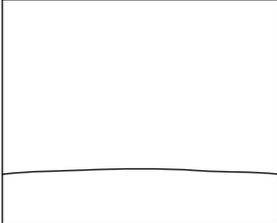
An acorn grows into a large oak. Most of the mass of the tree (carbon) came from the soil.

SUCCESSION

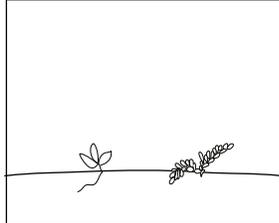


Ecological Succession:
A long-term change in the species which are present in an ecosystem.

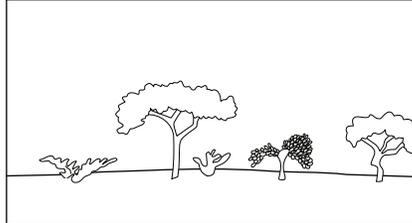
PRIMARY SUCCESSION: Example: A lava flow on Hawai'i



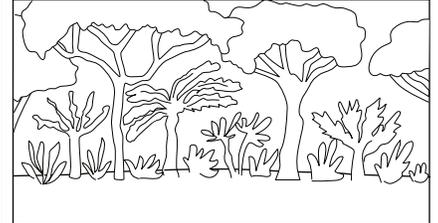
New lava flow: bare rock with no plants or soil



Pioneer species: lichens, 'ama'u fern, 'ōhi'a lehua

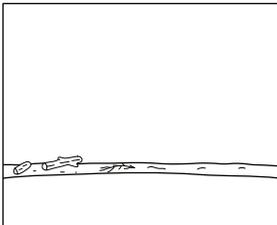


Intermediate: taller 'ōhi'a trees, hāpu'u 'i'i (tree ferns) begin growing

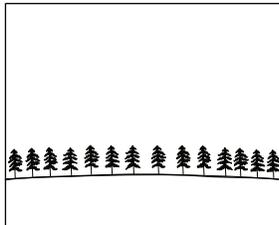


Mature forest: large ohī'a and koa trees, rich understory of tree ferns, diverse community of epiphytes and vines

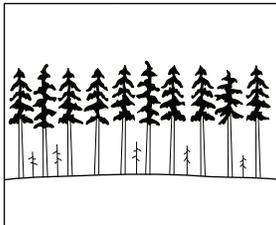
SECONDARY SUCCESSION Example: A forest after logging



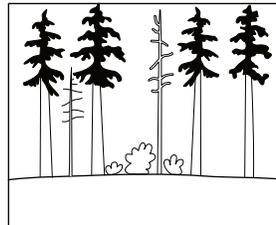
Soil with seed bank and coarse woody debris



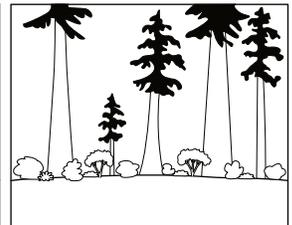
Stand initiation



Stem exclusion phase

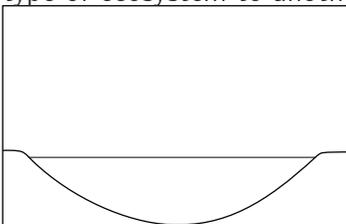


Understory reinitiation

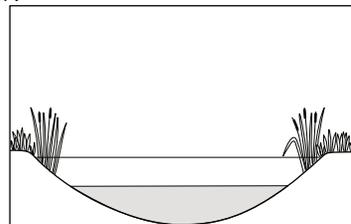


Old growth

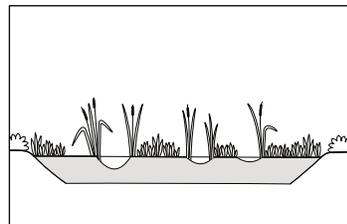
Succession isn't limited to the colonization of bare rock or a disturbed area! It can also mean a change from one type of ecosystem to another:



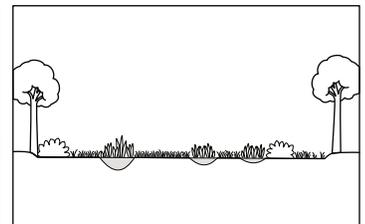
Pond with open water



Plant material deposited starts filling in the bottom



Emergent plants cover the pond, turning it into a marsh



The marsh becomes a field or meadow

Match each term with its definition

DISTURBANCE

PIONEER SPECIES

SEED BANK

MUSKEG

UNDERSTORY

The first species to grow in a bare area

The seeds contained in soil, many of which are dormant

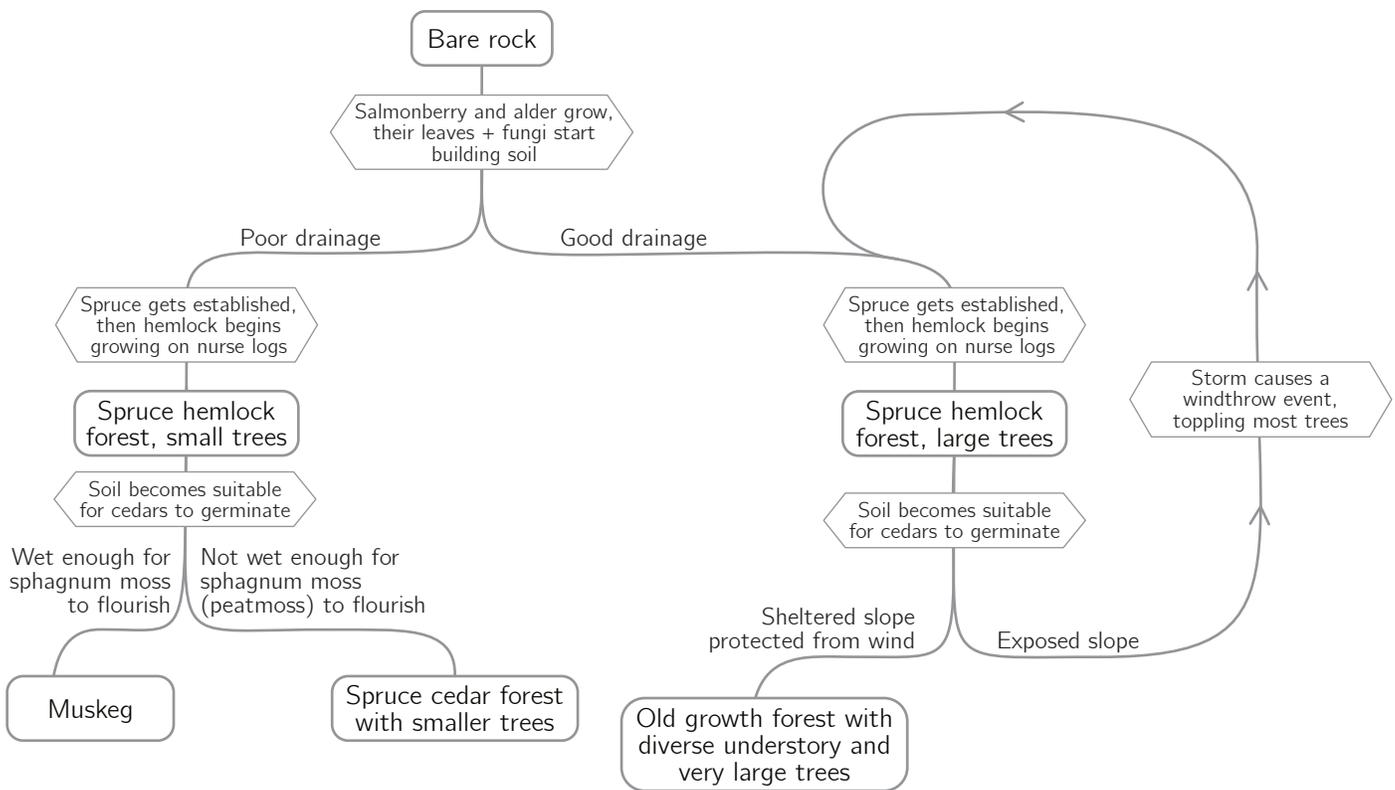
A change in environmental conditions that results in a significant change to the structure of the ecosystem

The layer of forest under the canopy, made of shade-tolerant species

A wet bog dominated by sphagnum moss (peat)

Succession paths in the Tongass

The Tongass is the largest intact temperate rainforest in the world. It covers more than 68,000 km² or 26,255 mi². The forest is dominated by conifers such as hemlock, spruce, and cedar, but also supports a diverse understory of shrubs such as Alaska blueberries and red huckleberries. Interspersed throughout the forest are numerous peatlands called muskegs.

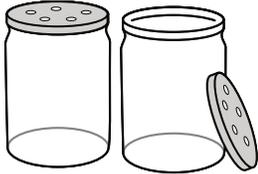


Describe an example where the environment determines the path of succession.

Describe an example where an organism influences the path of succession.

ACTIVITY: COMPOSTING

MATERIALS



At least 2 clear jars (lids with holes or cover jars with cloth secured with a rubber band)



Spray bottle filled with water



Soil gathered from an outdoor location



Compostable materials such as leaves, food scraps, newspaper

GOALS

- ★ Set up and carry out an experiment on composting
- ★ Learn more about variables and good experimental design
- ★ Create your own soil

Directions:

① Choose your question & experiment

Decide which experiment you will do. Fill in the first box of the data sheet with your experiment name and driving question(s). You could model it on one of the examples listed here you could design your own.

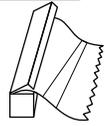
OPTIONAL ADDITIONAL SUPPLIES IF DOING SOIL STERILIZATION:



Baking dish



Oven



Aluminum foil

② Identify your variables & label your jars

Record your variables in the second box of the data sheet. Your **independent variable** is the thing you will change between the jars. For example, in the light vs dark experiment, the amount of light is the independent variable. Everything else should be as similar as possible, such as the size of the jars, the amount of soil, and the type of compostable material. Your **dependent variable** is the thing you will measure or observe. In most experiments, this will be how much decomposition happens.

Label your jars with the experiment name, treatment for the jar, and the date.

EXAMPLES:

Experiment Name: Light vs Dark Experiment

Driving Questions: Does lighting have an effect on composting? Will it work better in the dark?

Labels for jars →	Light vs Dark Experiment YYYY-MM-DD Dark jar	Light vs Dark Experiment YYYY-MM-DD Light jar
-------------------	--	---

Questions: Do invertebrates speed up composting? If yes, by how much?

Insect Compost Experiment YYYY-MM-DD Control: no bugs	Insect Compost Experiment YYYY-MM-DD Bug jar
---	--

Question: How biodegradable is compostable cutlery?

Compost Experiment YYYY-MM-DD Plastic spoons	Compost Experiment YYYY-MM-DD Biodegradable spoons
--	--

Question: What ratio of paper to kitchen scraps will compost the fastest?

Compost Ratio Ex. YYYY-MM-DD 2:1 paper to scraps	Compost Ratio Ex. YYYY-MM-DD 1:1 paper to scraps	Compost Ratio Ex. YYYY-MM-DD 1:2 paper to scraps
--	--	--

Did you know?

1 gram of soil can contain more than 1 billion bacteria and several miles of fungal filaments!

1 gram of soil is about 1/4 of a teaspoon!



Source: Dr Kate Scow, soil microbiologist, UC Davis

④ Prepare your materials

▷ Jars with lids that allow airflow

You can poke holes in a lid or use a piece of cloth secured with a rubber band.

▷ 1 cup of soil per jar

Be sure to get the soil from an outdoor location. Remove any large rocks and sticks so the soil is fairly uniform. The soil should contain living organisms such as worms, springtails, rotifers, and pill bugs. If you don't see any, that's okay—many detritivores are too small to see with the naked eye.

A dark loamy soil with visible invertebrates and worms will work much better than a sandy or clay-based soil that doesn't have visible life.

If your soil has earthworms, try to divide it so you have the same number of worms in each jar.

▷ Compostable materials to fill the rest of the jar

For best results, use a mix of "green" and "brown" materials with more "brown" than "green."

Green materials are nitrogen-rich. Examples: carrot peelings, grass clippings, apple cores, banana peels etc.

Brown materials are carbon-rich. Examples: shredded newspaper, brown kraft paper, dead leaves that have turned brown, straw, sawdust (from wood that is not treated or painted).

Materials to avoid:

Anything that has recently been sprayed with insecticide.

It is best not to use banana peels, citrus peels or pulp, pineapple, tea leaves, coffee grounds, or salty food scraps.

No meat or dairy products because they will release unpleasant odors as they decay.

No paper with gloss, heavy ink, or thermal receipts

▷ Spray bottle with water

⑤ Assemble the jars

Basic set up:

- ▷ Place 1 cup of soil in the bottom of each jar.
- ▷ Mist with water until the material is fully damp but not soggy.
- ▷ Add about 3 cups of compostable material on top of the soil, misting with water as the material is added.
- ▷ Cover the jar with cloth or a lid that has holes for ventilation. Place the jars in their locations.
- ▷ Check the jars every week and record your observations on the data sheet.
- ▷ Add water with the spray bottle if the material starts to look dry.

Note: If choosing the "Bug effect" experiment, be sure to have adult supervision for the sterilization step! Sterilize one set of soil by placing it in an oven-safe dish and covering it tightly with aluminum foil. Then bake it at 93°C or 200°F for 30 minutes. Let cool completely, and then place the sterilized soil in the control jar.

Some like it HOT!

A backyard compost pile can easily heat up to 50° C (122° F) in just a few days! The heat from bacteria digesting organic matter speeds up decomposition and kills harmful microbes and weed seeds.

In commercial "hot composting," large piles are kept at 54-71°C (130-160 °F) and turned regularly so they can finish in as little as 18 days!

If a big pile isn't managed appropriately, it can get hot enough to catch fire. 

Small piles don't retain heat. Their "cold composting" process is slower, often needing 3 to 6 months for items to fully decompose.



WHY SIT ON EGGS WHEN THE COMPOST CAN DO THE INCUBATING?

A Smart Turkey!

The male Australian Brush-turkey is a master composter! Instead of sitting on its eggs to incubate them, the male builds a huge mound of leaves and rotting plant material.

He uses his beak to check the temperature of the pile and carefully maintains it between 33-38°C (91-100°F) by digging holes and adding or removing material.

One mound can contain up to 50 eggs from several different females. Eggs are incubated for an average of 49 days before hatching.

When they hatch, the baby birds dig their way to the surface of the pile and emerge fully fledged; they can fly within hours and are completely independent from their parents.

DATA SHEET

Experiment Name: _____

Driving Question(s): _____

Independent variable: _____

Dependent variable: _____

Prediction: _____

Check on the jars every week if possible. If you miss a week, note it on the log. A sample scale from 0-5 is provided, though you could also make up your own.

Sample Status Scale:

0 = looks new, no change

1 = very slight change

2 = some softening or color change

3 = clearly breaking down

4 = mostly broken into
unrecognizable pieces

Report Your Findings

Were you able to answer your experimental question? If not, that's okay, and it's still worth reporting. Write your conclusions in a paper or a poster, or design a presentation.

Your report should include answer to all of the questions below.

1. What was your experimental question?
2. What variable(s) did you test? How did you set up the experiment, and did you use a control?
3. What did you expect to happen? Include your original prediction/hypothesis and explain why you thought that.
4. What actually happened? Summarize what you observed in each jar over time.
5. Did your results support your hypothesis? Explain using your scores, notes, and or photos.
6. What were some possible sources of error or limitations in your experiment?
7. If you could do this experiment again, what would you improve or change?

ECOSYSTEM RESILIENCE

FILL IN THE BLANKS (WORDS FROM THE BOX MAY BE USED MORE THAN ONCE OR NOT AT ALL)

adapt collapses disturbance
recover resilience tipping

_____ is the ability of an ecosystem to withstand, _____ from, and _____ to disturbances while maintaining its core structure. Every ecosystem can handle some change, but if a _____ is too big or happens too often, an ecosystem will cross a _____ point where it _____ or changes into a different type of ecosystem.

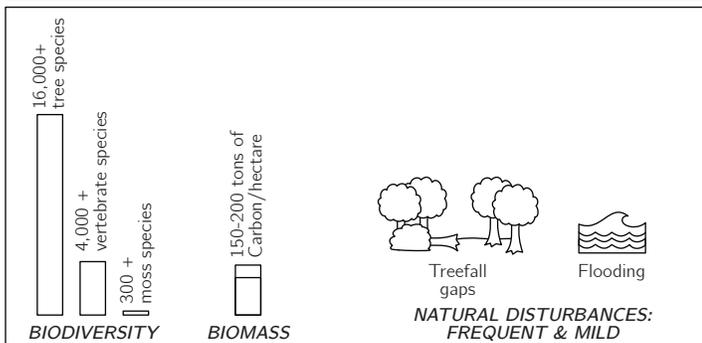
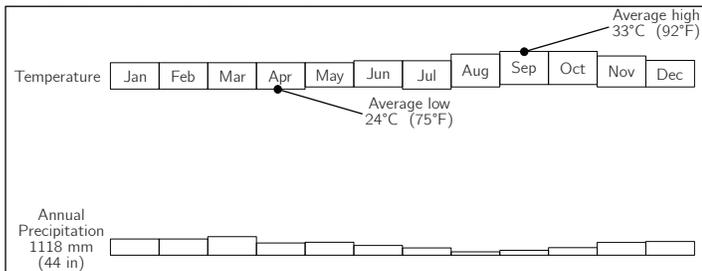
A Tale of Two Rainforests

The Amazon and Tongass rainforests have different levels of resilience to logging. The Tongass returns to forest after being logged. The process takes several hundred years, but the land becomes mature forest again.

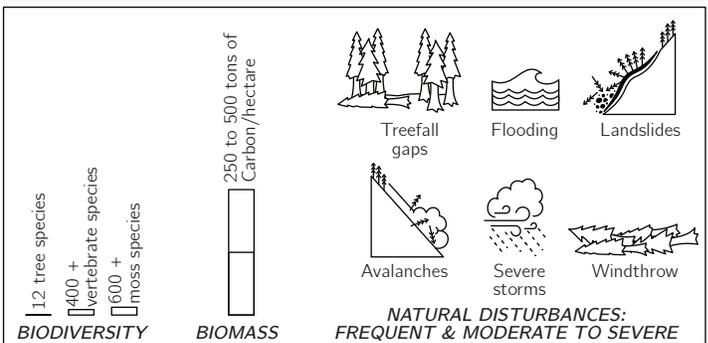
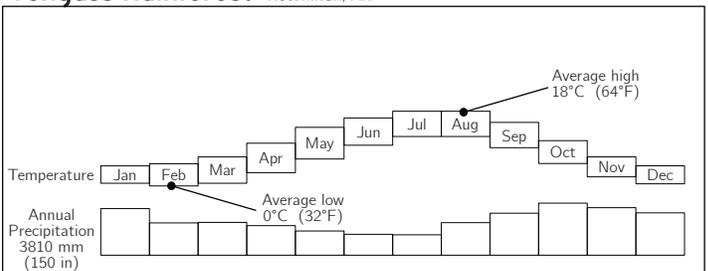
In certain parts of the Amazon, logging is followed by burning and grazing. Land in these areas does not return to forest. Instead, it becomes a low-productivity grassland where the original rainforest cannot get reestablished.

Compare the features of each forest and answer the questions below:

Amazon Rainforest Manaus, Brazil



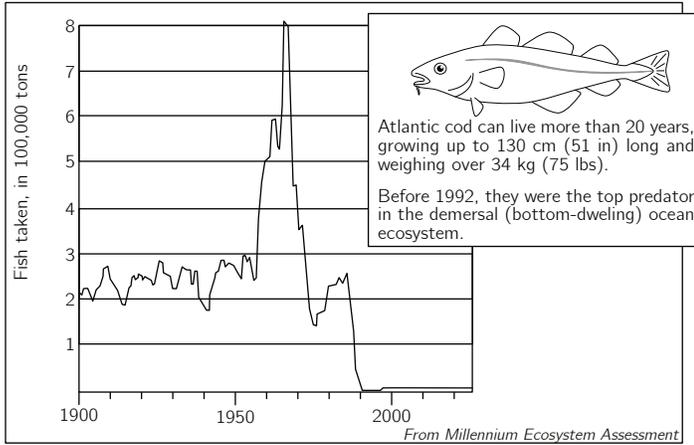
Tongass Rainforest Ketchikan, AK



Identify a difference between the two forests that is not represented above:

What features or factors contribute to the Tongass being more resilient to this type of disturbance?

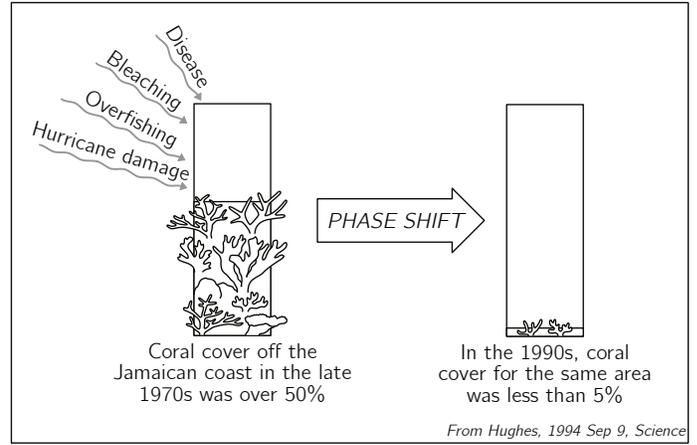
Tipping points:



For hundreds of years, northern cod were one of the most abundant fish in the North Atlantic. In the 1950s, new fishing technology let huge trawlers catch more cod than the population could replace.

In 1992, cod numbers had dropped to 1% of their historic biomass, and cod fishing was banned.

Some 40 years later, the cod populations still haven't recovered. The ecosystem has changed. Smaller forage fish such as capelin predate on cod eggs and young cod, preventing the fish from returning to their former population levels.



Coral reefs used to be common along the north coast of Jamaica, covering more than 50% of shallow ocean floor. Today, coral cover is only 5%.

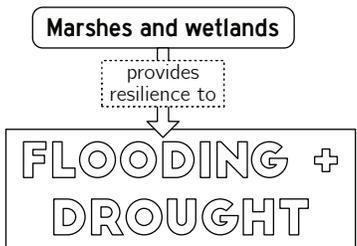
A combination of stresses led to the collapse of these Caribbean corals: overfishing removed herbivorous fish, powerful hurricanes broke up corals, a disease killed most of the grazing sea urchins that kept seaweed in check, and warm temperatures contributed to coral bleaching.

The ecosystem has changed from coral-dominated reefs to dense algae mats.

Explain how the following characteristics provide resilience to the disturbances in the examples below:





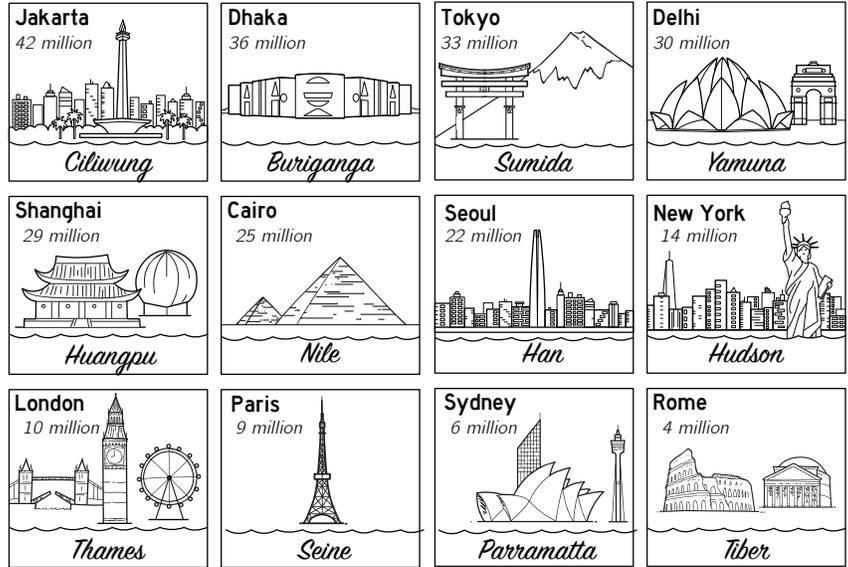


HUMAN GEOGRAPHY

Roughly $\frac{3}{4}$ of the world's cities are next to rivers and 40% of the world's population lives within 100 km of the sea.

What is the nearest water to where you live?

Why is it important for human settlements to be near water?

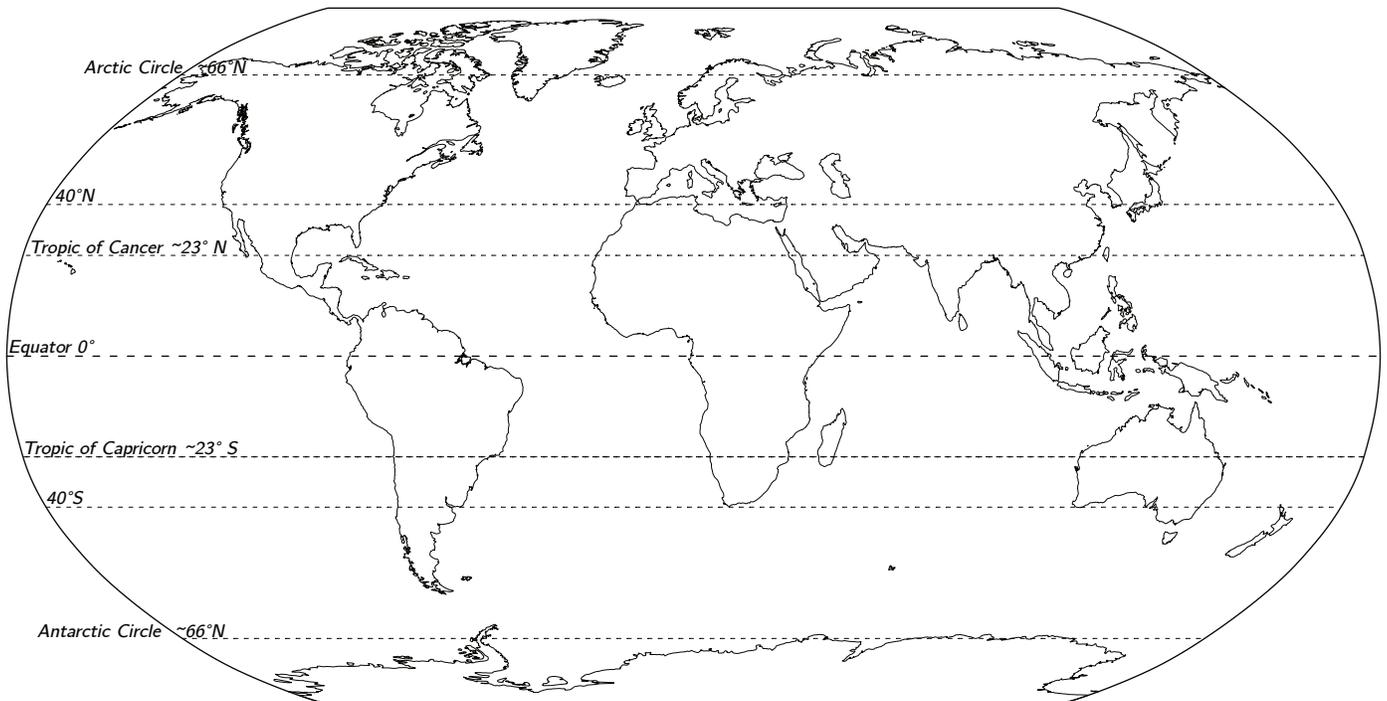


The world can be roughly divided into 3 categories based on latitude. Read about each and then outline and label the regions on the map. Then answer the questions on the opposite page.

Tropics and Subtropics: The tropics are the latitude from Earth's Equator to about 23° north or south. They experience hot weather year round and often have abundant rainfall. The latitudes between 23° to about 40° are called the subtropics. They have hot summers and mild winters with infrequent freezing temperatures.

Temperate: Latitudes from about 40° to 66° experience temperate climates with four seasons: a cold winter with frequent freezing temperatures, spring, a warm or hot summer, and a cool autumn period.

The Arctic and Antarctic (Polar): Latitudes above approximately 66° N or below 66° S are in the Arctic or Antarctic circles. During winter, these latitudes experience at least one polar night where the Sun does not rise above the horizon for 24 hrs. During summer, they experience at least 24 hours of "midnight sun" or polar day, where the Sun never dips below the horizon. The polar latitudes are defined by exceptionally cold winters and cool summers. Freezing temperatures can occur any time of the year.



Which classification best describes where you currently live in? Would you want to live in a different latitude? Why or why not?

50% of the human population lives between _____ latitude (check the correct box)

60°S - 40°S

40°S - 20°S

20°S - 0°

0° - 20°N

20°N - 40°N

40°N - 60°N

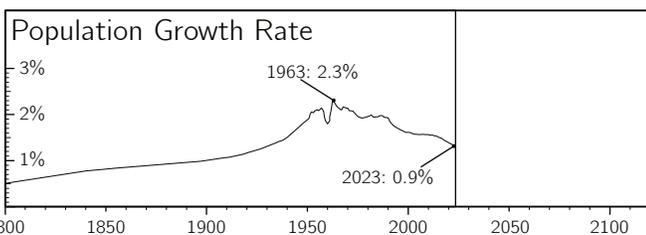
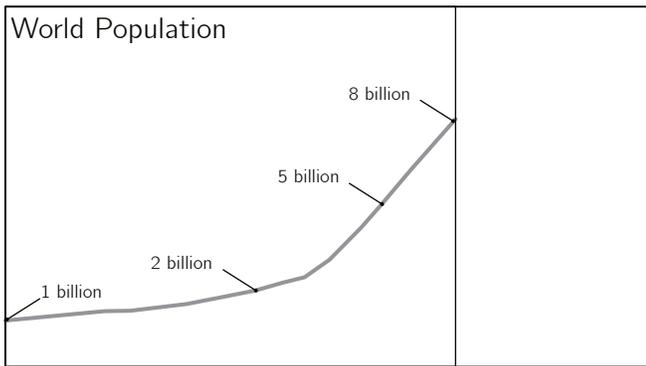
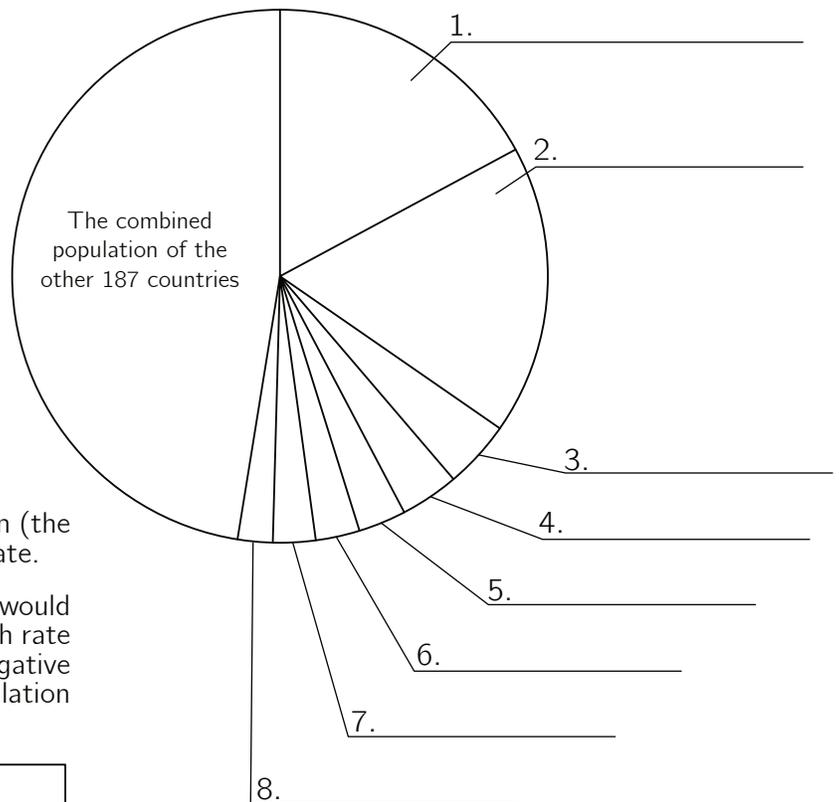
Demographers (scientists who study the way populations change) estimate the world had approximately 1 billion people in the year 1800. How many people are estimated to live on Earth today?

There are approximately 195 countries in the world, but more than half of the human populations lives in just 8 countries.

Label the 8 most populous countries in the chart on the right.

Study the graphs below showing world population (the number of people) and the population growth rate.

A population that isn't growing or shrinking would have a growth rate of 0. The value for the growth rate can be positive (growing population) or negative (shrinking population). The value for the population cannot be negative.

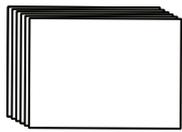


Someone born in the year 2000 would celebrate their 100th birthday in the year 2100. Make a prediction for the human population and growth rate in the year 2100. Will the population be higher, lower, or the same as today?

Adapted from OurWorldinData.org

ACTIVITY: INVASIVE SPECIES COMIC

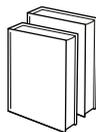
MATERIALS



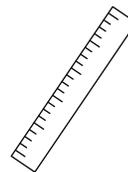
Blank paper



Internet connection or books about an invasive species



Drawing supplies



Ruler (optional)

GOALS



Research an invasive species and its history



Use vocabulary from this unit to tell a story.

DIRECTIONS

IN THE FORM OF A COMIC STRIP!

1. CHOOSE A SPECIES.

YOU CAN CHOOSE ONE FROM THIS LIST OR ANOTHER SOURCE.



- Burmese python
- Kudzu
- Zebra Mussels
- Spotted lantern fly
- Prickly pear
- Cane toad
- European Green Crab
- Sea Lamprey
- New Zealand Mudsnail
- Giant Hogweed
- Wild boar
- Japanese knotweed

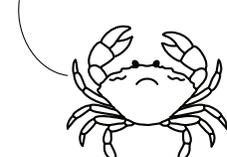
2. FACT CHECK: WHERE IS IT CAUSING TROUBLE?

TO QUALIFY, MAKE SURE YOUR ORGANISM HAS BEEN CLASSIFIED AS AN INVASIVE SPECIES BY A STATE, PROVINCE, OR COUNTRY.

INVASIVE

NOT INVASIVE

LIKE US - EUROPEAN GREEN CRAB!
IT'S ILLEGAL FOR PEOPLE TO TRANSPORT US IN SEVERAL STATES AND PROVINCES.



3. READ AND STUDY!

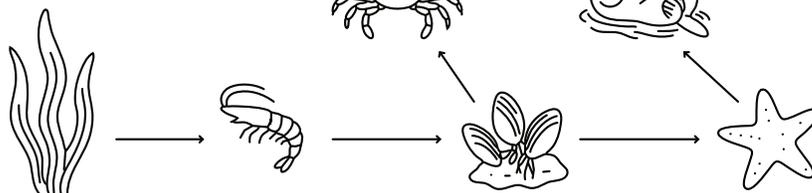
LOOK UP THE STORY. FOR EXAMPLE, I GOT TRANSPORTED LOTS OF PLACES BY RIDING IN THE BILGE WATER FROM BOATS!



4. FILL OUT THE QUESTIONNAIRE ON THE NEXT PAGE.

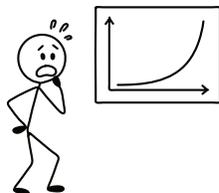
FIND OUT EXACTLY HOW AND WHY THIS SPECIES IS CAUSING PROBLEMS. WHAT MAKES IT "INVASIVE" INSTEAD OF JUST "INTRODUCED"?

THIS WILL GIVE YOU LOTS OF INFORMATION TO MAKE YOUR COMIC STRIP.



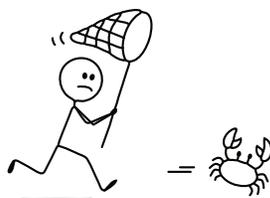
5. MAP THE STORY

MAKE AN OUTLINE OF THE WHOLE STORY: HOW IT ARRIVED. HOW IT BECAME A PROBLEM, AND WHAT PEOPLE ARE DOING TO TRY TO STOP IT.



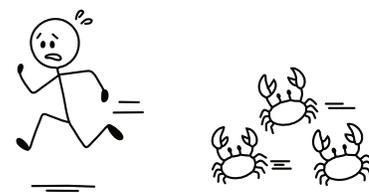
6. DRAW PANELS AND TEXT

A RULER AND A PENCIL AND ERASER ARE HELPFUL FOR THIS STEP! STRAIGHT LINES MAKE YOUR PANELS LOOK MUCH MORE PROFESSIONAL.



7. ADD ARTWORK

HAVE FUN! AND SHOW YOUR COMIC-PAGE STORY TO SOMEONE ELSE WHEN YOU'RE DONE.



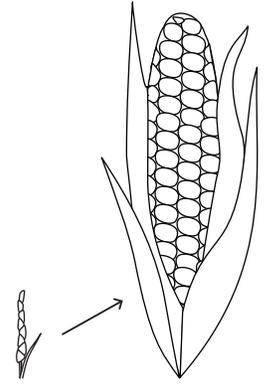
INVASIVE SPECIES QUESTIONNAIRE

1. Common name and scientific name:
2. Native range (where it originally lived)
3. Invaded range (where it is now causing problems)
4. How did it first arrive? (accidental, pets released, ships, farms, etc.)
5. When did it first show up in the area? (approximate decade or year)
6. What kind of ecosystem(s) does it invade? (forest, bog/wetland, lake, river, grassland, ocean, etc.)
7. What does it eat? What eats it (if anything) in the new ecosystem?
8. How has it changed the food web in the ecosystem?
9. Does it cause declines or extinctions of native species? If so, which species are most at risk?
10. Does it affect nutrient cycles or how the ecosystem can respond to a disturbance?
11. Does it cause problems for people?
12. How are people responding? (control efforts, laws, public education, biological control, etc.)

AGRICULTURE

Approximately 10,000 years ago, groups of people began to *cultivate* food instead of getting all of their calories from hunting, fishing, or gathering edible plants (foraging). This change allowed human populations to grow much larger than before and it transformed ecosystems too. Humans are the most impactful ecosystem engineers on the planet.

Plants were independently cultivated for agriculture in at least 11 different regions of the world. In some cases, the modern domesticated variety looks very similar to its wild relative. In other cases, they look very different! Altogether, humans domesticated hundreds of plants, but only a handful of them are staple foods.



Define staple food below and then make notes about how each of these crops is grown and used:

What is a STAPLE FOOD? _____

*Eating... is inescapably an agricultural act.
How we eat determines, to a considerable extent, how the world is used.*
- Wendell Berry

MAIZE

RICE

WHEAT

-----**THE BIG THREE**-----

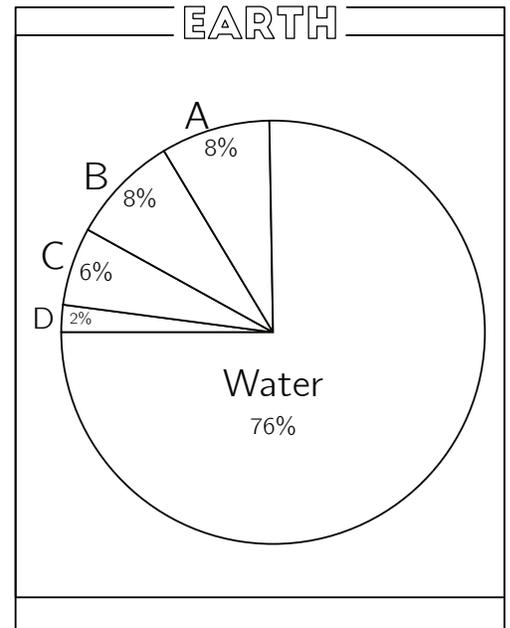
_____ % of the food energy for the entire human population comes from maize, rice, and wheat

POTATOES

SOYBEANS

CASSAVA

The pie chart here shows how much of Earth's surface is water, arable (crop land), pasture (range land), habitable land that isn't being used for agriculture (forest, urban, etc), and inhospitable land that is either ice-covered, barren desert, or too steep, etc.



A _____

B _____

C _____

D _____

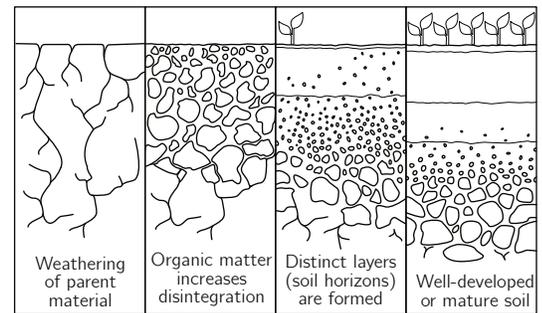
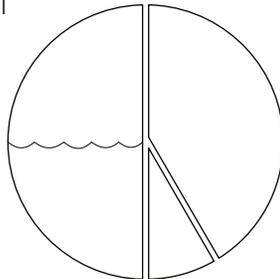
The foundation of terrestrial life

Soils are more than dirt! In addition to mineral-based particles like sand (aka dirt), soil has a whole ecosystem of bacteria, microscopic animals, and fungi.

By volume, most soils are close to 50% pore space. This empty space between particles can be filled with water or air. Most plants prefer conditions where pore space is half air and half water. The solid material in soil is organic matter (often 3-6%) and mineral matter.

Color the soil pie chart

- Pore space filled with air
- Pore space filled with water
- Mineral matter (sand silt clay rock)
- Organic matter



SOIL FORMATION
200 to thousands of years

FACT or FICTION? Write your verdict below each statement:

Almost 20% of the food grown in the US goes to landfills instead of feeding people

WHAT A WASTE!

Every year, millions of beehives are delivered to California's almond orchards

HERE WE COME FOR OUR 6-WEEK VISIT!

A flowering stalk of a single banana plant can produce more than 200 bananas

FLOWER →

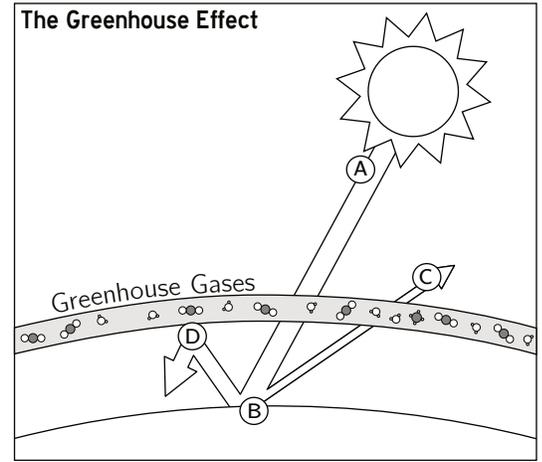
GREENHOUSE EFFECT AND ENERGY CHOICES

Without greenhouse gasses, Earth would not retain enough heat from the Sun to support life.

The most influential greenhouse gasses are water vapor (H_2O), carbon dioxide (CO_2), and methane (CH_4). They each have a powerful effect on warming even though they make up a very small amount of the overall atmosphere (less than 1%).

Describe each step labeled in the diagram:

- A) _____
- B) _____
- C) _____
- D) _____



CARBON
DIOXIDE

% AMOUNT: _____

WARMING IMPACT: _____

WARMING LIFESPAN: _____

NOTES: _____

METHANE

% AMOUNT: _____

WARMING IMPACT: _____

WARMING LIFESPAN: _____

NOTES: _____

WATER

% AMOUNT: _____

WARMING IMPACT: _____

WARMING LIFESPAN: _____

NOTES: _____

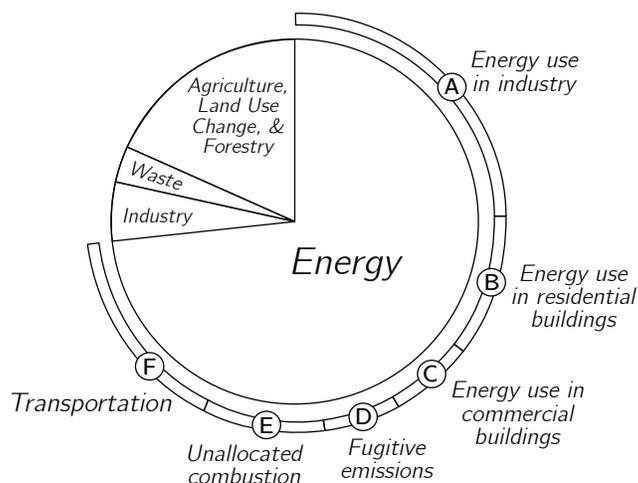
Fossil Fuels

Coal ~ 3,048 Gt	Oil ~ 1,029 Gt	Natural Gas ~ 700 Gt
A combustable sedimentary rock formed during the Carboniferous and Permian periods, some 300 million years ago.	Includes petroleum, bitumens, oil shales, tar sands, & heavy oils	95% methane with traces of propane, helium, and CO ₂

Estimated reserves in Gigatonnes of carbon(Gt), from Parker, Royal Society of Chemistry, 2024

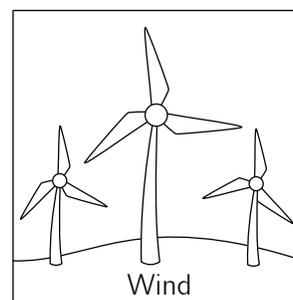
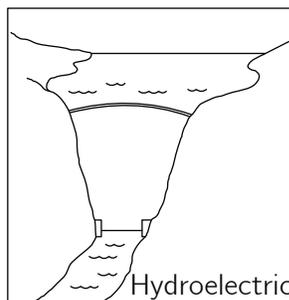
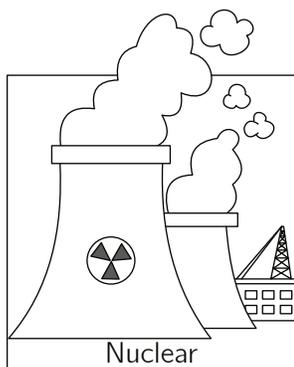
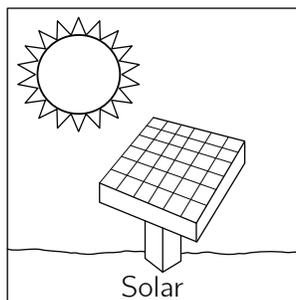
The energy sector produces nearly 75% of greenhouse gas emissions. Match each example below with the subset (labeled A-F) of energy use in the chart:

- ___ Electricity use in a data center
- ___ A leaky valve at an oil refinery releases methane
- ___ Someone cooking on a gas stove in their home
- ___ A semi truck driving along a freeway
- ___ A pulp and paper mill burning coal for power
- ___ Cement production
- ___ Flying in an airplane
- ___ An office building heated with natural gas furnace



DRAW A LINE TO MATCH THE ENERGY SOURCE WITH THE CORRECT ADVANTAGES AND DISADVANTAGES

Pros: Uses land efficiently and has a low water footprint	Pros: Can store huge amounts of energy and quickly change output levels	Pros: Has no moving parts and can be put to use quietly making electricity where people live	Pros: Produces a huge, steady amount of electricity from a very small amount of fuel, day and night
--	--	---	--



Cons: Creates waste and battles inaccurate political messaging

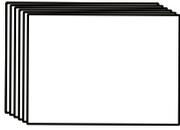
Cons: Makes little or no electricity at night or on very cloudy days

Cons: Dams flood valleys and block rivers, harming fish migration and river ecosystems

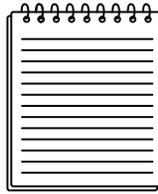
Cons: Spinning blades can be noisy and can injure birds and bats if turbines are placed in poor locations

ACTIVITY: NATURAL RESOURCE SCAVENGER HUNT

MATERIALS



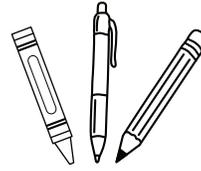
Blank paper



Notebook



Computer for research



Drawing supplies

GOALS



Learn more about where common materials come from



Better understand how natural resources

Directions:

1 Complete the Matching

Everything around you started as materials from nature. Match each item from the list to the category that best describes its source.

2 Conduct a Scavenger Hunt

Use the Bingo-style boxes on the opposite page to conduct your own scavenger hunt to see what items you can identify in your own home.

3 Research One Item and Write a Summary

Consumable goods are used up and replaced quickly. Food, medical supplies, cleaning products, and personal hygiene items are consumable. *Durable* goods such as cars or a house are meant to last for a long time.

Choose one item from the scavenger hunt to research. Describe whether it's meant to be consumable or durable and then explain where it comes from and what natural resources were involved.

Supply chains are complicated and you may not be able to trace things back to their origin. But do your best! Learn as much as you can about how this item is made.



Cardboard



Electrical Wires



Table Salt



Paper



Metal Fork



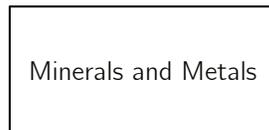
Eggs



Bread



Polyester Shirt



Minerals and Metals



Plants



Fossil Fuels



Animals



Gasoline



Coins



Plastic bottle



Glass Cup



Cheese



Leather Shoes



Wool Sweater



Cotton T-shirt

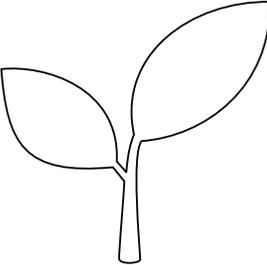


Natural Resource Scavenger Hunt

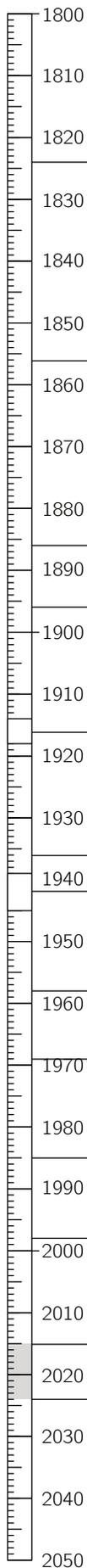


Locate items in your home that match each description in the bingo grid below. Write each item you find in the corresponding box. Fill in as many squares as you can! Try to use a different item for each box. For an added challenge, set a 15-minute timer and see how many “bingos” of 5 in a row you can get before the timer ends.

Once you’ve finished, look at each item and ask yourself if it’s from a **renewable** resource (one that could be harvested again in a reasonable amount of time) or a **nonrenewable** resource. Color the boxes containing renewable items one color and the boxes containing non-renewable items another color.

Something that keeps you healthy	Something made from more than 1 natural resource	Something that uses electricity	Something that could harm wildlife if it ended up in the ocean	Something that could be repaired instead of thrown away
Something designed to be thrown away within a week	Something that came from underground	Something made from plastic	Something made from glass	Something that uses batteries
Something designed to create trash every time its used	Something that helps save energy		Something made from metal	Something designed to last at least 5 years
Something that keeps you warm without using electricity	Something that needs water to be useful	Something made from a tree	Something that was made or grown close to home	Something that was made in another country
Something recycled or reused	Something designed to save water	Something made by an animal	Something you could easily live without	Something you use every single day

A Climate Change Timeline



1824: Joseph Fourier describes how the atmosphere retains warmth and compares it to the glass walls of a greenhouse.

1856: Eunice Foote publishes first paper to show CO₂ increases atmospheric temperature. In **1859**, John Tyndall publishes paper demonstrating how CO₂ blocks IR radiation and warms Earth's atmosphere.

1886: Karl Benz puts first gasoline-powered car into production. The motorized tricycle had a top speed of 16 kph (10 mph)

1896: Svante Arrhenius writes landmark paper on the greenhouse effect, explaining how burning coal and increased CO₂ levels would warm Earth's climate

1914-1918: World War I

1936: First commercial flights across the Pacific ocean (Pan Am)

1939-1945: World War II

1958: Charles Keeling starts daily measurements of CO₂ at Mauna Loa

1969: First spaceflight to land humans on the Moon (Apollo 11)

1986: Meltdown of reactor at Chernobyl halts plans to replace fossil fuels with nuclear power

1998: Michael E. Mann publishes reconstruction of temperatures from the past 1,000 years

2015: 195 nations signed the Paris Agreement

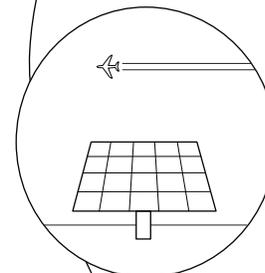
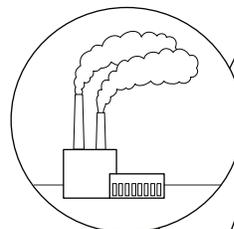
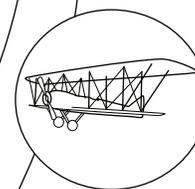
2015-2024: More than 100 lawsuits are filed against fossil fuel companies in more than 10 different countries. Several lawsuits demonstrate that giant corporations like Chevron and Exxon Mobile waged decades-long deliberate misinformation campaigns about the impact of burning fossil fuels.

Internal documents show these companies understood the climate risks associated with their carbon emissions. But instead of being honest about those risks, they funded biased research, attacked climate scientists, created doubt about consensus, lobbied heavily, misled investors, and formed front groups to delay climate action.

How it started: 1850

Atmospheric CO₂ = 290 ppm

Mean Global Temperature = 13.6 °C



How it's going: 2024

Atmospheric CO₂ = 423 ppm

Highest level in millions of years

Mean Global Temperature = 14.9 °C

Warmest in over 100,000 years

Review: 3 key facts

1. Climate is different than weather!

Weather is what atmospheric conditions we have on a given day. It changes all the time!

Climate is the long-term average of the weather, usually taken over a 30 year period.

Plants and animals have adaptations to certain climates and might not be able to survive outside them, so a changing climate is a big deal!

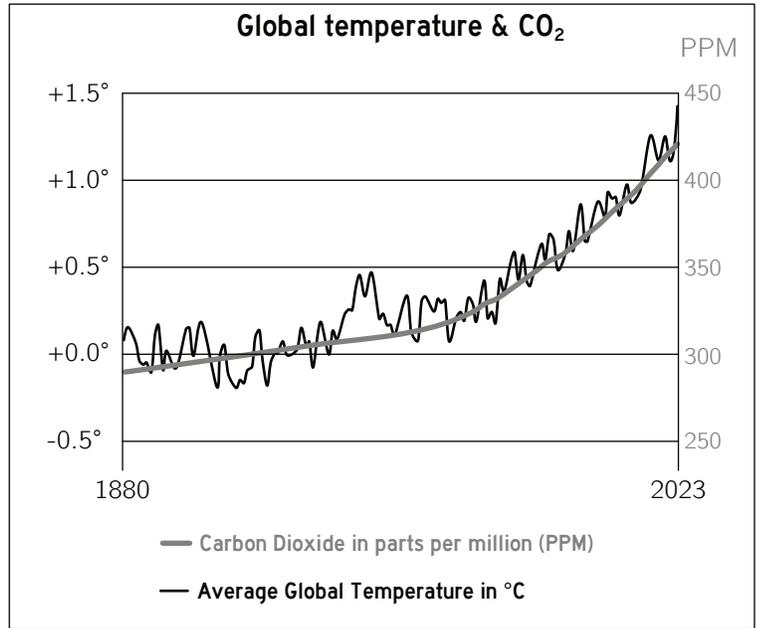
Climates have changed throughout geologic history. If this change happens slowly, then plants and animals can migrate and adapt. If climate change happens quickly, it causes mass extinctions.

2. Earth is getting warmer

The **average global temperature** is calculated by looking at temperatures and anomalies over the entire surface of the Earth. Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the past 2,000 years.

3. CO₂ is a greenhouse gas

Since the mid 1800's, people have known that carbon dioxide is a greenhouse gas with a strong warming effect. Venus is the hottest planet in the solar system because its atmosphere is mostly CO₂.



Global temperature anomalies averaged and adjusted to early industrial baseline (1881-1910)
Source: Climate Central, a policy-neutral nonprofit

5 MYTHS ABOUT CLIMATE CHANGE

Correct the myths!
Identify any problems
& provide a rebuttal!

**MYTH #1:
IT'S NOT US**

"IT'S BEEN HOT BEFORE,
SO THIS ISN'T FROM US.
IT'S JUST PART OF A
NATURAL CYCLE."

The facts:

"IT WAS COLD THIS WINTER, SO
GLOBAL WARMING IS A HOAX"

The facts:

"CO₂ IS A TINY PORTION OF THE
ATMOSPHERE SO IT COULDN'T CHANGE
THE ENTIRE CLIMATE, PLUS VOLCANOES
MAKE MORE CO₂ THAN WE DO"

The facts:

**MYTH #2:
SCIENTISTS
DISAGREE**

"THERE ARE VALID ARGUMENTS ON BOTH SIDES. SOME SCIENTISTS SAY OUR ACTIONS CAUSE WARMING, OTHERS DISAGREE."

The facts: _____

VARIATION ON MYTH #2:

"CLIMATE SCIENTISTS ARE JUST IN IT FOR THE MONEY AND ATTENTION, SO YOU CAN'T TRUST THEM."

The facts: _____

**MYTH #3:
IT'S NOT BAD**

"CO₂ IS FOOD FOR PLANTS, SO MORE CO₂ IS A GOOD THING!"

The facts: _____

**MYTH #4:
WE CAN'T
FIX IT**

"THE SOLUTIONS TO CLIMATE CHANGE ARE WORSE THAN A LITTLE WARMING"

The facts: _____

**MYTH #5:
IT'S TOO
LATE**

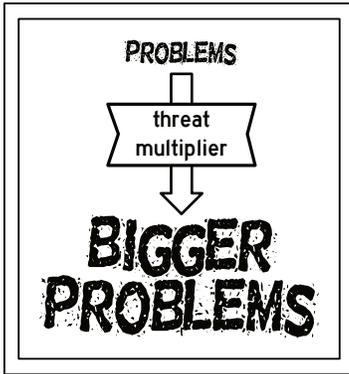
"WE'VE ALREADY PASSED THE POINT OF NO RETURN"

The facts: _____

Every action matters, every bit of warming avoided matters, and every year matters; deep emissions reductions now can still secure a liveable and sustainable future for all." - United Nations

CLIMATE SOLUTIONS

*Climate Change is a **THREAT** multiplier*

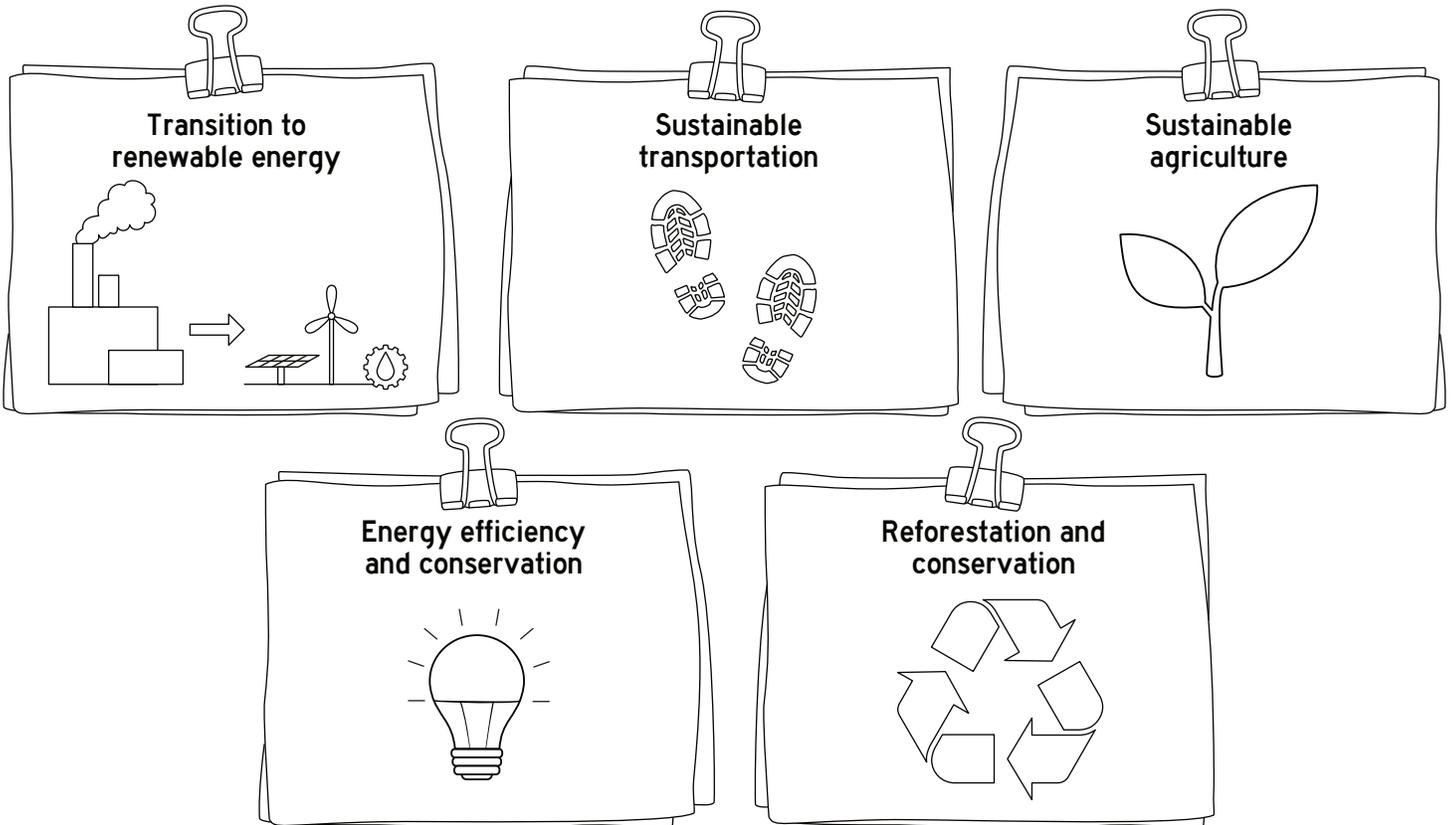


A **threat multiplier** amplifies existing problems by creating new or intensified risks.

Example 1: Consider a family living paycheck to paycheck. They already have several forms of stress. If their car breaks down, that's a threat multiplier because it makes all of the existing stresses much worse.

How is climate change a threat multiplier?

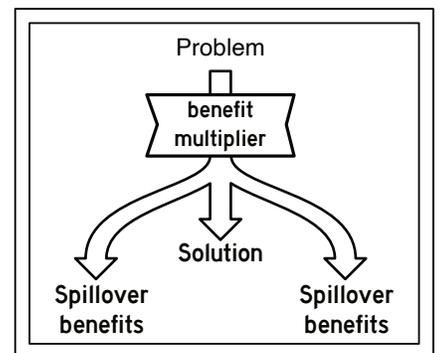
MOST SOLUTIONS TO CLIMATE CHANGE FALL INTO ONE OF 5 CATEGORIES:



*Climate Solutions are **BENEFIT** multipliers*

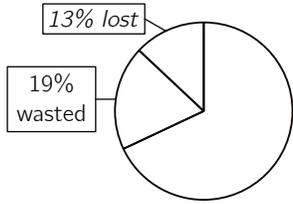
A **benefit multiplier** is something that produces multiple additional benefits or spillovers besides its main goal. The total "upside" of a benefit multiplier is bigger than whatever the primary goal was.

Example 1: A vacant lot is planted with wildflowers because the owner wants it to look nicer. In addition to being aesthetically appealing, the meadow also cools the surrounding area during the summer, reduces erosion during rainstorms, and boosts pollinators and insect biodiversity.



1. Reduce food waste

Total Food Produced in 2023



2.3 billion tonnes lost/wasted*

Every year, between 30-40% of the global food supply is lost (discarded after harvest but before market) or wasted (tossed out after going to market).

*FAO (Food and Agriculture Organization of the UN)

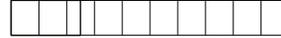
Food waste reduction ideas:

Speed of Action



Emergency Brake

Potential CO₂ saved



1.2-2.5 GtCO₂/yr

Success Story



Seoul, South Korea

How did Seoul go from recycling only 2% of food waste to recycling 95%?

What are some of the main spillover benefits? Check all that apply:



Protects water quality



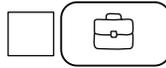
Improves air quality



Increases biodiversity



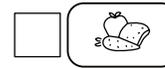
Saves money



Creates new jobs



Improves human health



Better food security



Fewer injuries



Better energy security



Reduces pollution stress on ecosystems

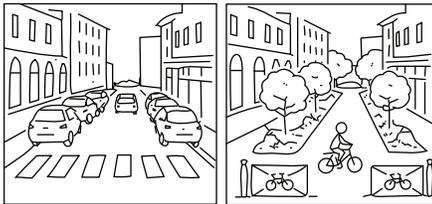


Reduces drought and fire risk



Reduces flood risk

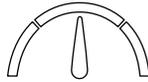
2. More non-motorized transportation



2004

2024

Speed of Action



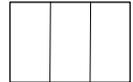
Gradual

Potential CO₂ saved



1.4-1.9 GtCO₂/yr

Success Story



Paris, France

Over 20 years, Paris decreased air-pollution by more than 50%. Premature deaths related to air pollution dropped by 1/3. How did this happen?

Worldwide, cars are a leading cause of death. More than 1 million people die each year in traffic accidents and over 300,000 of those deaths are vehicle-pedestrian collisions.

Ideas to boost non-motorized travel:

What are some of the main spillover benefits? Check all that apply:



Protects water quality



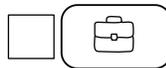
Improves air quality



Increases biodiversity



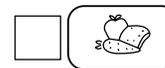
Saves money



Creates new jobs



Improves human health



Better food security



Fewer injuries



Better energy security



Reduces pollution stress on ecosystems



Reduces drought and fire risk

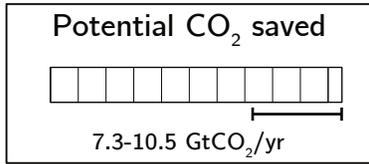
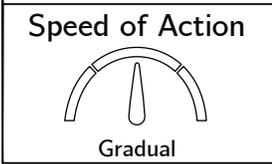


Reduces flood risk

3. Deploy Wind Turbines

On shore Off shore

China is currently the global leader in wind energy development. In 2021, they added 16.9 GW of offshore wind capacity, enough to power several mid-size cities.



How did Kodiak transition to producing 99.7% of it's own power?

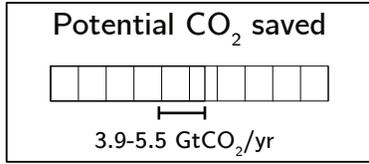
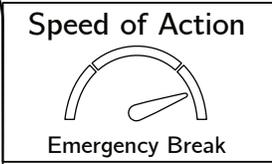
Renewable energy ideas:

What are some of the main spillover benefits? Check all that apply:

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Protects water quality	Improves air quality	Increases biodiversity	Saves money
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creates new jobs	Improves human health	Better food security	Fewer injuries
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Better energy security	Reduces pollution stress on ecosystems	Reduces drought and fire risk	Reduces flood risk

4. Protect Wetlands, Peatlands, and Forests

Terrestrial Carbon Stores



How did Costa Rica transform from one of the most deforested countries to a world leader in ecotourism?

Ideas to help with conservation:

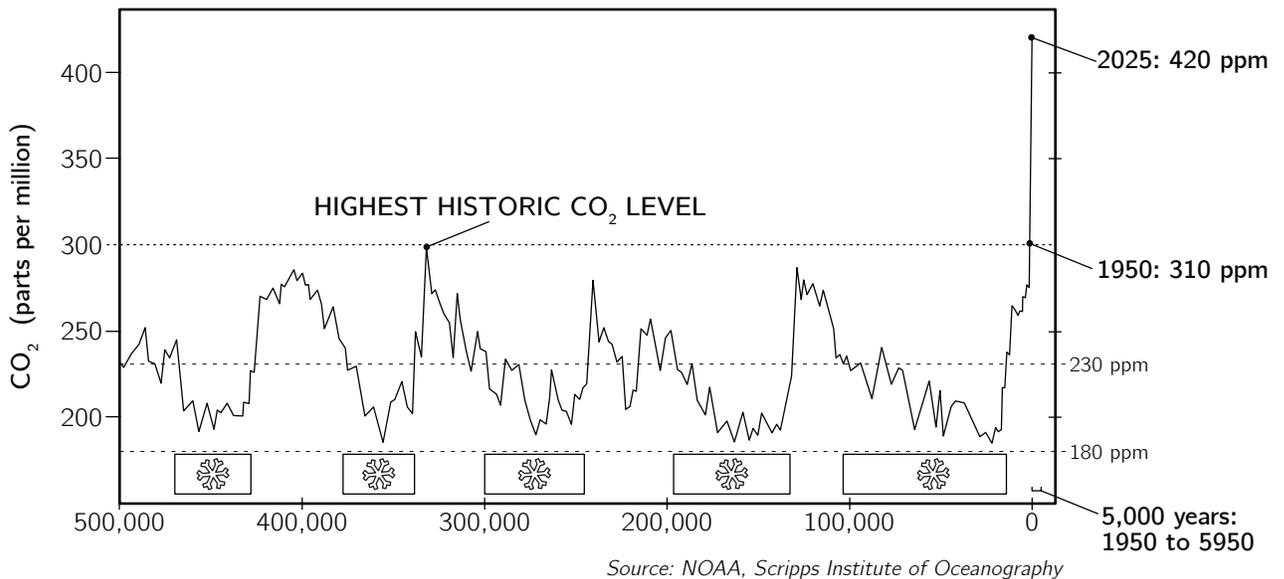
What are some of the main spillover benefits? Check all that apply:

<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Protects water quality	Improves air quality	Increases biodiversity	Saves money
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Creates new jobs	Improves human health	Better food security	Fewer injuries
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Better energy security	Reduces pollution stress on ecosystems	Reduces drought and fire risk	Reduces flood risk

ECOLOGY AND HUMAN SYSTEMS UNIT ASSESSMENT

- 1 Which of the following best describes the difference between energy flow and matter cycling in ecosystems?
- Energy is recycled while matter flows one-way through the ecosystem
 - Energy flows one-way through the ecosystem while matter is recycled
 - Both energy and matter are recycled in ecosystems
 - Both energy and matter flow one-way through ecosystems
- 2 What is Net Primary Productivity (NPP)?
- The total amount of energy or carbon biomass captured by producers through photosynthesis
 - The energy or carbon biomass captured by producers minus the energy or carbon they used for respiration
- 3 Why does biomass typically decrease at each trophic level?
- Organisms at higher levels are usually smaller.
 - There is less sunlight available to higher trophic levels
 - Energy is lost at each level
 - Decomposers consume most of the biomass
- 4 A keystone species is different from other species in the ecosystem because:
- It is the largest organism in the ecosystem
 - It produces the most energy in the ecosystem
 - It has a disproportionately large impact on the ecosystem
 - It is always at the top of the food web
- 5 Nitrogen fixation is important because:
- It converts nitrogen gas into forms plants and animals can use
 - It releases nitrogen gas into the atmosphere
 - It removes excess nitrogen from the soil
 - It converts ammonia into nitrates
- 6 What portion of the human population lives in the Northern Hemisphere?
- Less than 50%
 - 50%
 - 75%
 - 90%
- 7 Which of the following removes carbon from the atmosphere?
- Phytoplankton and other organic material falling to the ocean floor as "marine snow"
 - Volcanic eruptions
 - The growth of large fungi networks in Earth's forests
 - Primary consumers moving material up a food web into higher trophic levels
- 8 Which human action frequently disrupts the phosphorus cycle and causes toxic algae blooms in aquatic ecosystems?
- Increasing carbon emissions
 - Excessive use of fertilizers
 - Paving surfaces such as roads and side walks
 - Using antibiotics
- 9 Which three crops provide 60% of total human calorie intake worldwide?
- Soybeans, potatoes, and wheat
 - Rice, beans, and corn
 - Maize (corn), rice, and wheat
 - Barley, rye, and millet
- 10 What is the main difference between primary and secondary succession?
- Primary succession occurs in water; secondary succession occurs on land
 - Primary succession starts with no soil; secondary succession starts with existing soil
 - Primary succession is faster than secondary succession
 - Primary succession only occurs after fires
- 11 Pioneer species are important because they:
- Are the final species in a climax community
 - Grow very large and store vast amounts of carbon
 - Prevent invasive species from moving into an area
 - Are the first to colonize barren areas and help create conditions for other species
- 12 Ecosystem resilience refers to:
- The ability of an ecosystem to resist change
 - The number of species present in an ecosystem; its diversity
 - The ability of an ecosystem to recover after a disturbance

- 13) What is the transition or point of change called where an ecosystem shifts into a new stable state that is difficult to reverse?
- A. Tipping point
 - B. Collapse
 - C. Succession
 - D. Evolution
- 14) Where do most people in the world get their drinking water from?
- A. Rivers and lakes
 - B. The ocean (after desalinization treatment)
 - C. Collecting rainwater
 - D. Groundwater (wells that tap into aquifers)
- 15) Most land on Earth is not suitable for growing crops. Why?
- A. Large portions of land are covered in ice, too dry, or too steep for agriculture
 - B. Most land doesn't get enough sunlight for growing crops
 - C. Most land is covered by cities and roads
 - D. Large amounts of Earth's land are too hot for food crops to grow
- 16) Which greenhouse gas from fossil fuel use is the largest driver of recent long-term warming?
- A. Water vapor
 - B. Methane (CH_4)
 - C. Carbon dioxide (CO_2)
 - D. Oxygen (O_2)
- 17) What happens in Earth's energy budget when greenhouse gases increase?
- A. More heat is trapped in the atmosphere instead of escaping to space
 - B. More sunlight enters the atmosphere
 - C. Less sunlight reaches Earth's surface
 - D. The atmosphere becomes cooler
- 18) What is the difference between renewable and nonrenewable energy sources?
- A. Renewable sources are more expensive; nonrenewable sources are cheaper
 - B. Renewable sources can be replenished naturally; nonrenewable sources are finite
 - C. Renewable sources produce more energy; nonrenewable produce less
 - D. The distinction is artificial. A nonrenewable source can be turned into a renewable one with the correct technology
- 19) What is the difference between weather and climate?
- A. Weather and climate are the same thing
 - B. Weather is long-term patterns; climate is day-to-day conditions
 - C. Weather is day-to-day conditions; climate is long-term patterns over decades
 - D. Weather occurs on land; climate occurs over oceans
- 20) Of the following activities, which contributes the most to increasing atmospheric CO_2 ?
- A. Transportation
 - B. Energy use in residential buildings
 - C. Energy use in industry
 - D. Agriculture
- 21) Which climate solution directly removes carbon dioxide from the atmosphere?
- A. Renewable energy transition
 - B. Energy efficiency and conservation
 - C. Reforestation and forest protection
 - D. Sustainable transportation
- 22) If primary consumers in a grassland receive $5,000 \text{ kcal/m}^2/\text{year}$ from producers, approximately how much energy would be available to secondary consumers, and why?
- A. $5,000 \text{ kcal/m}^2/\text{year}$; energy is fully transferred between levels
 - B. $2,500 \text{ kcal/m}^2/\text{year}$; exactly half the energy moves up each level
 - C. $500 \text{ kcal/m}^2/\text{year}$; only about 10% of energy transfers to the next trophic level
 - D. $50 \text{ kcal/m}^2/\text{year}$; most energy is used by decomposers before reaching consumers
- 23) Which statement about wind turbines is correct?
- A. Wind turbines use more energy to build than they ever produce
 - B. Modern turbines typically "pay back" the energy used to make them relatively quickly, then produce far more energy over their lifetime
 - C. Wind power is more consistent and predictable than hydroelectric power
 - D. Wind turbines have a strong effect on the temperature of the air surrounding them



Scientists have analyzed air bubbles trapped in ice layers from Greenland and Antarctica to study past climates. For the last 800,000 years, CO₂ levels have varied between 180 ppm and about 280 ppm. The graphic above displays atmospheric CO₂ levels over the past 500,000 years, with year 0 set to be 1950.

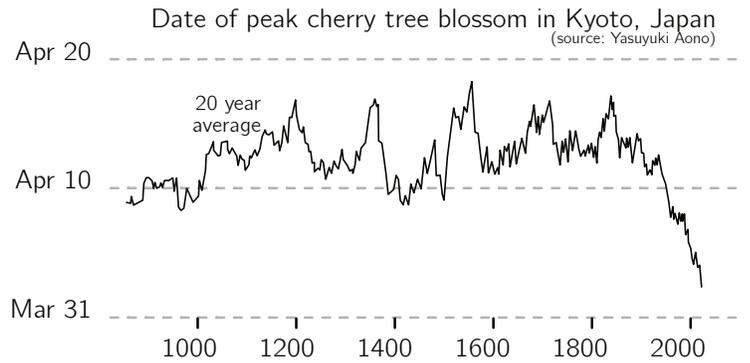
The Quaternary Period (2.6 million years ago till present) has been defined by a cyclical series of glaciations. Throughout this period, Earth has alternated between colder periods with extensive ice sheets and lower sea levels (glacial periods) and warmer periods with less ice and higher sea levels (interglacial periods).

- 24) What statement is true about the relationship of CO₂ levels and ice ages? Mark all that apply:
- A. Previous glacial periods had CO₂ levels which varied from about 180-230 ppm
 - B. There isn't a direct correlation between CO₂ and glacial periods
 - C. Interglacials had lower CO₂ levels than glacial periods
 - D. The highest pre-industrial atmospheric CO₂ level occurred during an interglacial period
- 25) What does this graph indicate we should expect as atmospheric CO₂ rises far above its historical range?
- A. A return to an ice age
 - B. No change, because CO₂ levels aren't correlated with temperature
 - C. A tendency toward a warmer global climate
 - D. There is not enough information to say
- 26) What is the approximate threshold of CO₂ below which a glacial period tends to occur?
- A. 180 ppm
 - B. 230 ppm
 - C. 300 ppm
 - D. There is not enough information to say
- 27) What impact on climate do CO₂ levels have during a glacial period?
- A. Lower CO₂ levels → less heat trapped → cooler climate and expanding ice sheets
 - B. Lower CO₂ levels → more heat trapped → melting ice sheets
 - C. Higher CO₂ levels → less heat trapped → cooler climate and expanding ice sheets
 - D. Higher CO₂ levels → more heat trapped → melting ice sheets
- 28) The woolly mammoth and saber-toothed cat went extinct at the end of the last glacial period. Which explanation below best explains why extinctions have been shown to occur during the transition between glacial and interglacial periods?
- A. There are no glaciers during interglacial periods, so cold-adapted animals can't survive the change
 - B. Climate shifts occur over thousands of years, so they can't contribute to extinction
 - C. Climate shifts can rearrange habitats faster than some species can migrate or adapt, causing population collapse

29 The graph below shows the 20-year average of the peak cherry blossom bloom in Japan over 1,000 years.

Which claim does this data best support?

- A. In the last 50 years, spring has shifted to occur later
- B. In the last 50 years, spring has shifted to occur earlier
- C. Blooming time is random and not associated with spring
- D. Cherry trees are evolving to behave differently



SHORT ANSWER QUESTIONS:

30 Why doesn't a cold winter disprove global warming?

31 In your own words, describe ecological succession:

32 How does biodiversity contribute to ecosystem resilience?

33 What impact do rising CO₂ levels have on the pH of the ocean?

34 List 5 or more other climate change solutions that weren't discussed in the notes on pages 94-95. *If you aren't sure of ideas, go to Project Drawdown and browse their list of solutions.*
