Climate Change Lesson

Grade Level: High School Earth/Environmental Science
Standards: EEn.1.1.1, EEn.2.6.2, EEn.2.6.3, EEn.2.6.4
Description: Students read graphs, maps, diagrams and text; watch videos; and write answers to questions while exploring causes of climate change, evidence for it, impacts, and what we can do about it.

WARM-UP ACTIVITY

You have probably heard people make a number of statements about climate change and perhaps you wondered if some of them were true. In this activity, you will use evidence to evaluate a number of statements.

Directions: Use the graphs provided to determine which of the following statements are true and which are false. Write down your answers on the worksheet at the end of this lesson. If it is false, write a true statement about what the graph is actually showing.

TRUE or FALSE (if false, write a true statement about the graphs):

1. The oceans are getting warmer and sea level may rise in the future, but it hasn't started rising yet.

   Fig. 1 Graph of change in global average upper ocean heat content

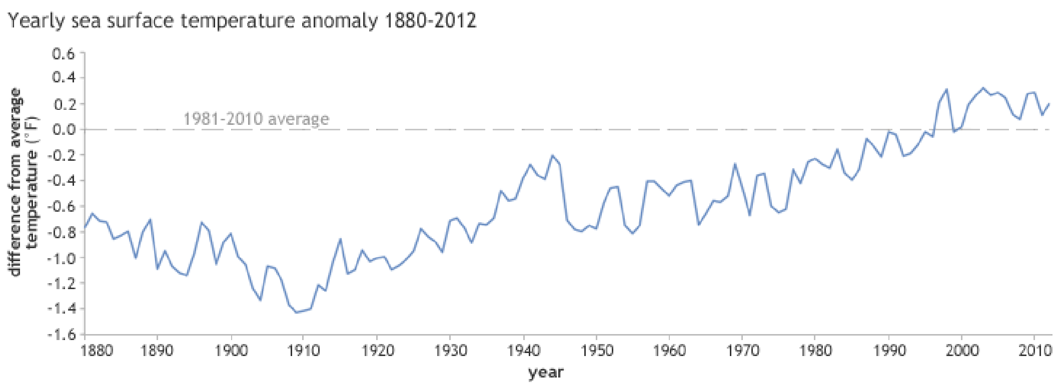
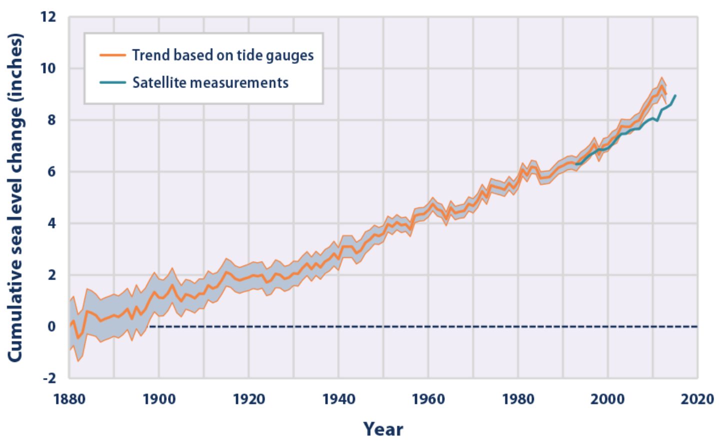
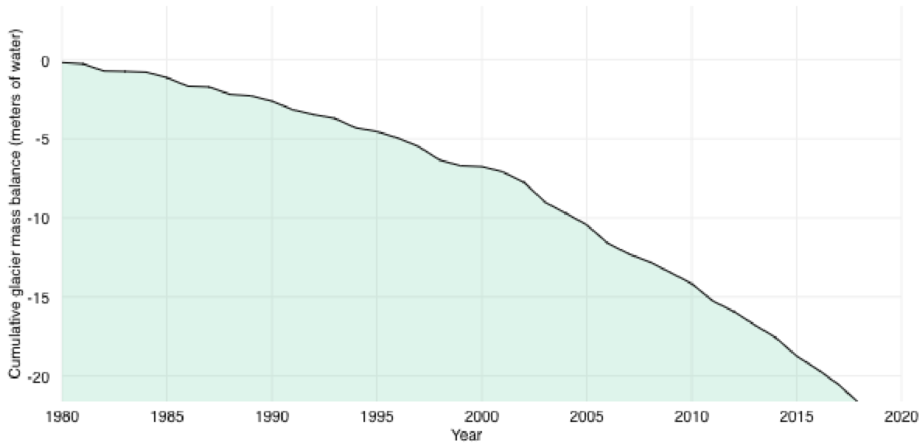


Fig. 2 Graph of sea level change



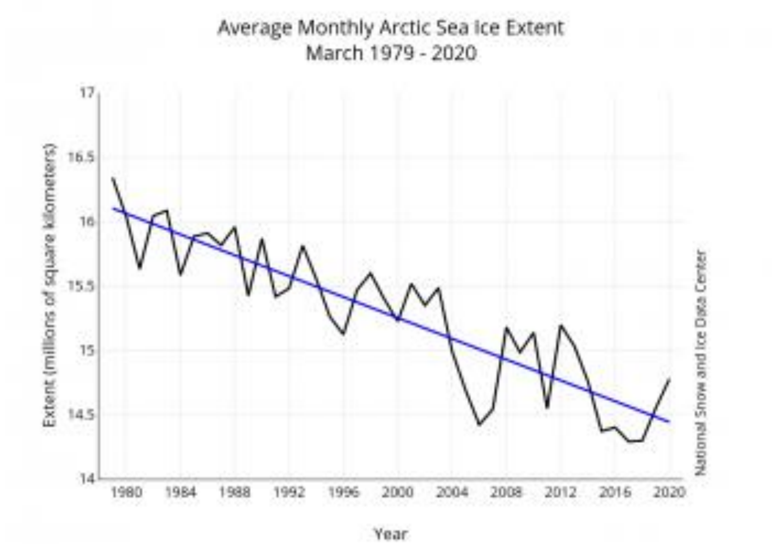
2. Glaciers are shrinking, and there is about half as much ice near the North Pole as there used to be.

Fig. 3 Graph of change in glacier mass



Note: "glacier mass balance" measures the change in the amount of ice based on how much the glacier gains by snowfall and how much it loses through melting or sublimation (changing from a solid into water vapor). A negative mass balance indicates more ice melted than was added to the glacier in a year.

Fig. 4 Graph of Arctic sea ice extent



3. Winters are less snowy now than in the 1950s; but hurricanes, storms, and floods are more frequent now than in the past.

Fig. 5 Graph of northern hemisphere spring snow cover

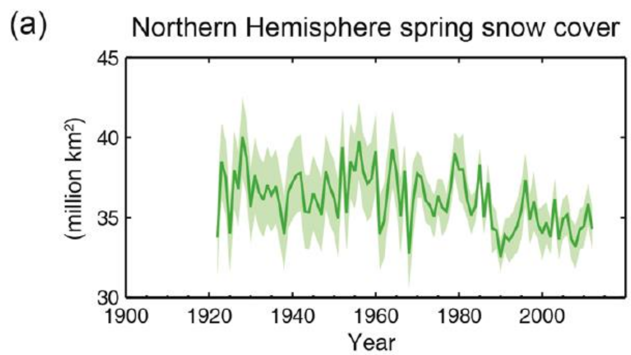
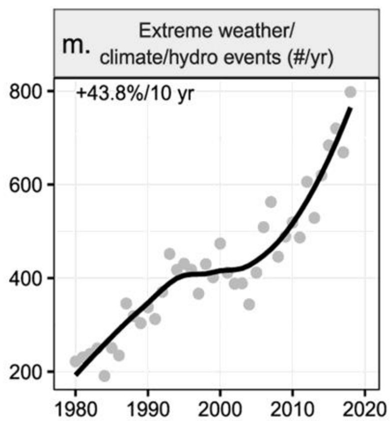
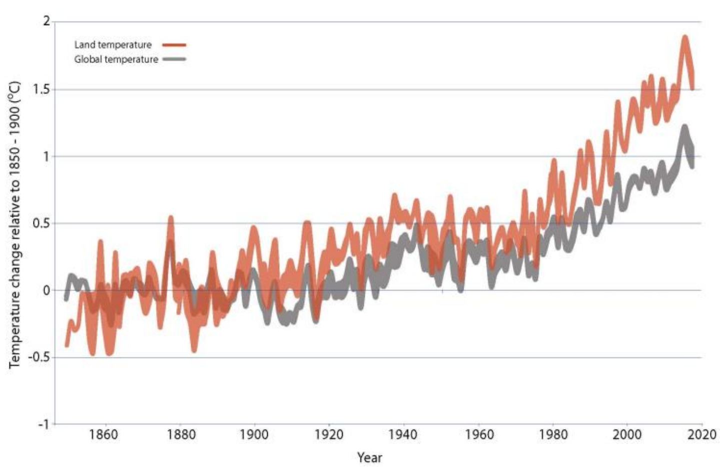


Fig. 6 Graph of extreme weather/climate/hydro events (#/yr.)



4. Although there is some variation, overall, the earth's climate is getting warmer.

Fig. 7 Graph of temperature change relative to 1850-1900 (°C)



5. The rise in earth's temperature shows the same increasing trend as the amount of carbon dioxide (CO_2) in the atmosphere. But the temperature trend is the inverse (opposite) of the trend for the amount of methane and nitrous oxide in the atmosphere.

Fig. 8 Graph of globally averaged combined land and ocean surface temperature anomaly 1880-2019

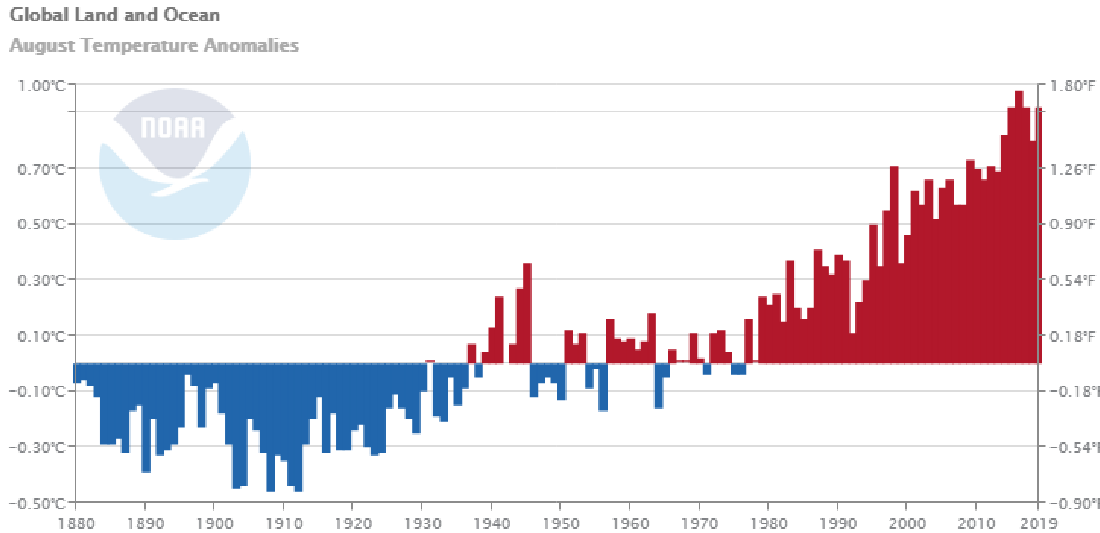


Fig. 9 Graph of atmospheric CO_2 (or Carbon dioxide)

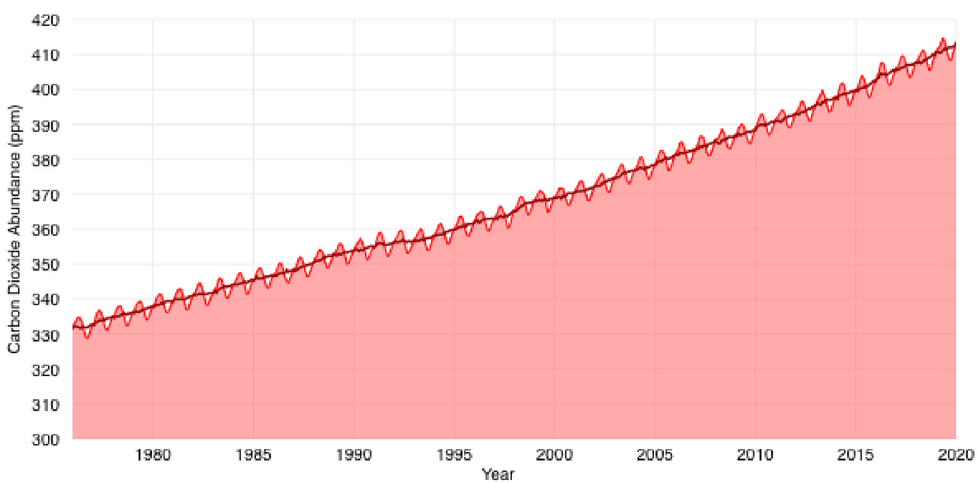


Fig. 10 Graph of methane ($CH_{4,}$ in parts per billion)

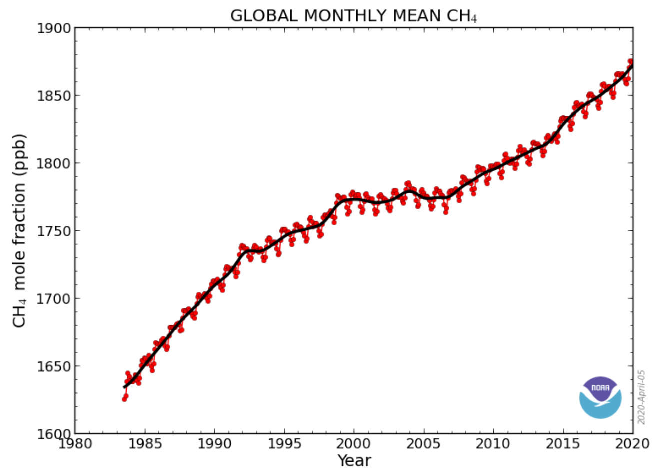
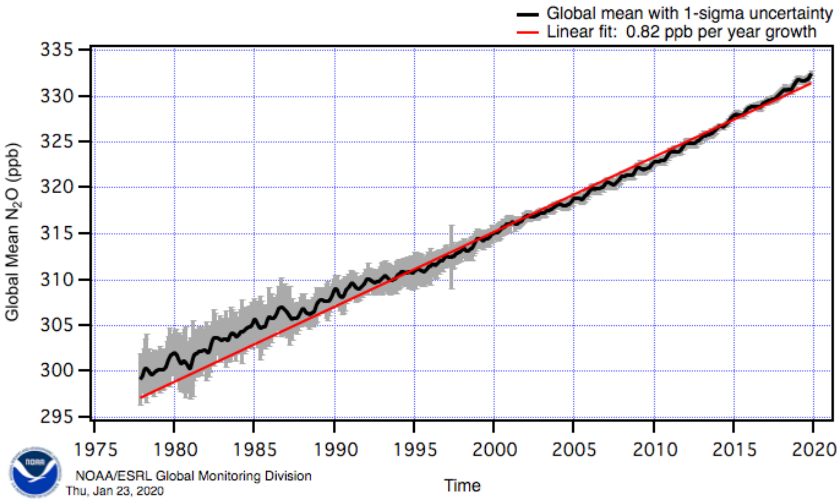


Fig. 11 Graph of nitrous oxide (N_2O, in parts per billion)



6. As pH drops, oceans become more acidic. Over time, oceans are becoming increasingly acidic, which threatens coral reefs.
   Fig. 12 Graph of ocean acidity (pH)

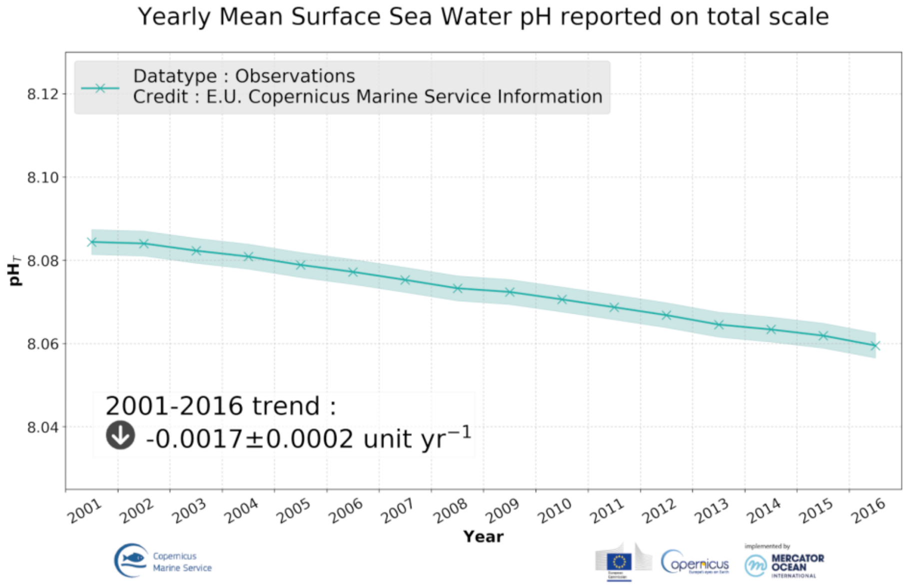
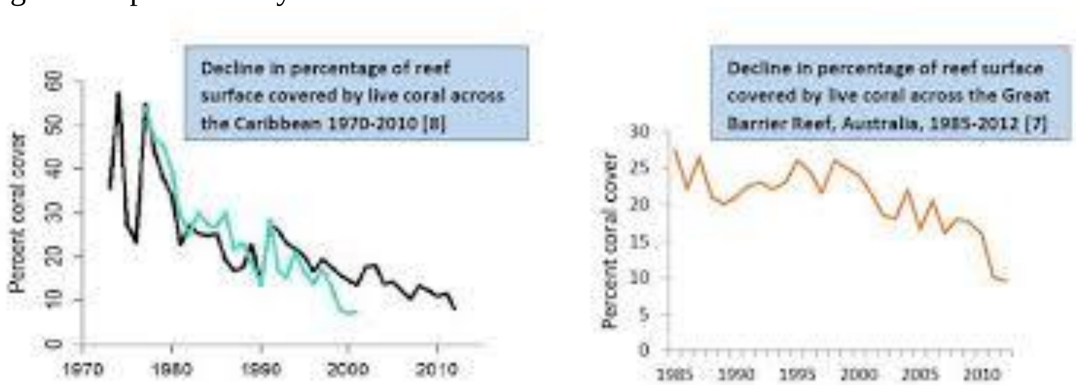


Fig. 13 Graphs of decay of coral reefs

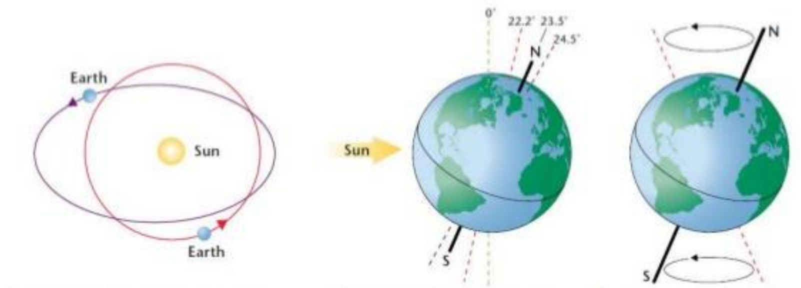


CAUSES OF CLIMATE CHANGE

There are both natural and human causes of climate change. As you read about them, pay attention to the time frames over which the changes take place. Consider which causes best explain the changes we have seen recently.

- Natural Causes of Climate Change
    - Milankovitch Cycles
        - These cycles are related to glacial periods and warming periods.
        - Fig. 14 Milankovitch cycles

Milankovitch Cycle



Eccentricity Earth encounters more variation in the energy that it receives from the sun when Earth's orbit is elongated than it does when Earth's orbit is more circular.

Tilt The tilt of Earth's axis varies between 22.2° and 24.5°. The greater the tilt angle is, the more solar energy the poles receive.

Precession A gradual change, or "wobble," in the orientation of Earth's axis affects the relationship between Earth's tilt and eccentricity.

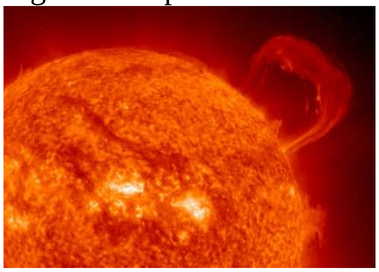
Note: "Eccentricity" means how circular or oval the earth's orbit is. "Tilt" refers to the angle of the earth's axis. "Precession" means earth's wobble on its axis.

- Milankovitch Cycles depend on:
  - Shape of the earth's orbit (Eccentricity) – how oval or circular earth's orbit around the sun is.
    - A more circular orbit causes a colder climate.
    - A more elliptical (oval) orbit causes a warmer climate because the earth gets closer to the sun.
    - The shape of the earth's orbit changes over a cycle of about 100,000 years.
  - Tilt of the earth's axis (Obliquity = Axial Tilt)
    - It may increase or decrease.
    - This changes over a period of 41,000 years from 21.5º to 24.5º.
    - The smaller the angle of tilt, the warmer the winter. So the warmer air could hold more moisture, and you'd get more snowfall. Summers would be cooler, and there would be less melting of ice. So ice sheets would expand.
  - Wobble (Precession) – earth's wobble on its axis
    - This changes over a period of 23,000 - 26,000 years.
    - Right now, winter occurs when the earth is <u>closest</u> to the sun.
    - In 10,500 years, winter will occur when earth is <u>farthest</u> from the sun and summer when earth is closest to the sun. This will result in larger seasonal contrasts. The earth will have warmer summers and colder winters.
  - When all these cycles coincide in a certain way, it can cause an ice age or warming period.

- Milankovitch Cycles cause climate fluctuations that occur over tens of thousands to hundreds of thousands of years.
- Video of simulations of precession, axial tilt, and shape of orbit (more circular or more oval).
- Write your answer (see worksheet at end of lesson): Could the sort of climate change we see now be due solely to Milankovitch Cycles? Why or why not?
- Write your answer before proceeding: What are other "natural" causes of climate change?

- Volcanic eruptions
  - Fig. 15 Volcano erupting

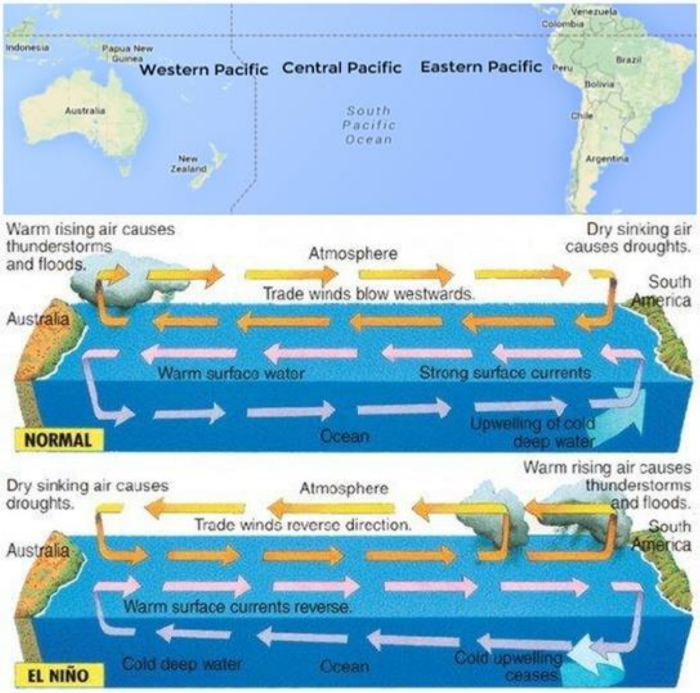
  - Volcanic ash can stay suspended in the air for several months to several years, block solar radiation, and cause cooler temperatures.
  - But the effect is short-term.
  - Sulfur dioxide (SO_2) ejected into the atmosphere converts to sulfuric acid. This condenses in the stratosphere to form sulfate aerosols that reflect the sun's rays back into space and can cause cooling of earth's surface for several years.
  - Volcanoes emit carbon dioxide (CO_2), but they release less than 1% of the CO_2 currently released by human activities. CO_2 released by recent volcanic eruptions has never caused detectable global warming. (volcanoes.usgs.gov/vhp/gas_climate.html)
- Sunspots/solar activity
  - Fig. 16 Sunspots and solar flare



  - Sunspots are darker, cooler areas on the sun's active surface.
  - They form where magnetic fields are particularly strong.
  - They are associated with solar flares (sudden explosions of energy) and coronal mass ejections [CMEs] (huge bubbles of radiation and particles from the sun that explode into space).
  - Sunspots increase to a maximum and decrease to a minimum over cycles of 11 years.

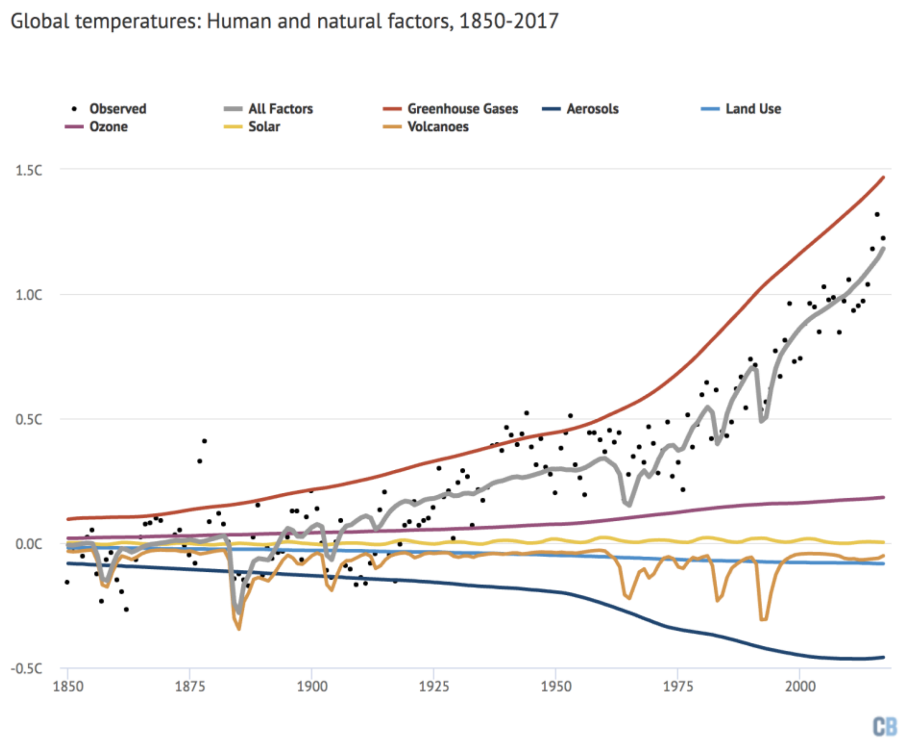
- Periods of low solar activity (less sunspots, solar flares, CMEs) coincide with colder climatic conditions. High solar activity coincides with warmer than normal climates.
- But scientists don't think changes in solar activity can explain the climatic change we see now.
- And solar activity is included in most up-to-date climate models like those used by the United Nation's Intergovernmental Panel on Climate Change (IGPCC).

- El Nino/La Nina
  - Fig. 17 Normal wind and water currents compared to those of El Nino



  - El Nino and La Nina involve changes in ocean temperature and air temperature in the central Pacific Ocean due to periodic changes in wind patterns and ocean circulation that impact climate around the world.
  - El Nino increases the temperature in the southern and central Pacific and a number of other areas (but not the southeastern U.S.).
  - La Nina decreases the temperature in the southern and central Pacific and a number of other areas (but not the southeastern U.S.).
  - This occurs over a cycle of about 5 years (3-10 years); so changes are short-term.
- Consider whether the time frame for any of the natural causes matches the climatic changes we've seen recently.
  - Examine the graph below.

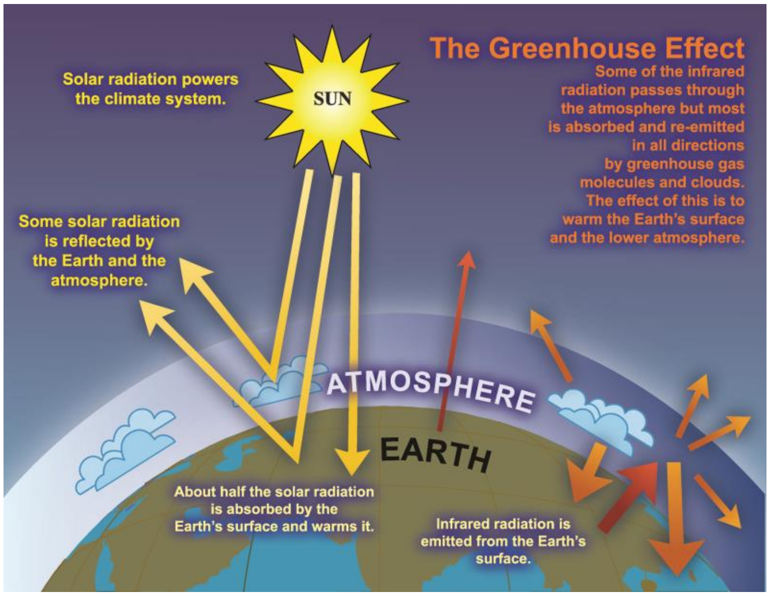
- Fig. 18 Graph of global temperatures: human and natural factors, 1850-2017



- Write your answer: Is current warming natural?

- NASA says natural causes have too small of an influence or occur too slowly to explain the rapid warming seen in recent decades. (earthobservatory.nasa.gov/features/GlobalWarming/page4.php)

- Human Causes of Climate Change
  - Write your answer: What are some causes of climate change that are linked to human activity?
  - Greenhouse Effect
    - What is it?
      - It causes warming of the earth's surface.
      - It can be compared to the way a greenhouse heats up more than the air outside because the sun's radiation passes through the windows, but heat is held in by the windows.
      - It's similar to a car sitting in the sunlight in winter and being warmer inside than the air is outside the car.
      - In the greenhouse effect, gases in the atmosphere absorb heat and reradiate it back toward the earth.
    - How does the greenhouse effect work?
      - See the diagram of the greenhouse effect below.
        Fig. 19 The greenhouse effect



      - Most of the solar radiation coming from the sun to the earth is in the form of ultraviolet (UV) rays and visible light. Some of these rays are reflected back into space by the atmosphere and clouds, but most pass through to the surface of the earth. Some rays of UV and visible light are reflected into space by the surface of the earth. But most are absorbed by the surface of the earth and reradiated into the lower atmosphere as infrared rays which we can't see. But we feel their warmth. Some of the infrared rays escape into space. But most are absorbed by greenhouse gases in the lower atmosphere. These greenhouse gases in the lower atmosphere heat up and radiate infrared radiation toward the earth. So the greenhouse gases trap the heat close to the earth's surface.
    - Part of this is natural and part is a result of human activity.
      - Some of the greenhouse effect is natural and keeps the surface of the earth warm enough to sustain life, but it is relatively constant and doesn't cause long-term global climate change.
      - Some is caused by humans and contributes to global warming.
  - Greenhouse Gases
    - Write your answer: What are some of the greenhouse gases?
      - Greenhouse gases:
        - Water vapor (H_2O)
        - Carbon dioxide (CO_2)
        - Methane (CH_4)
        - Nitrous oxide (N_2O, NO_x)
        - Chlorofluorocarbons (CFCs)
          - Hydrochlorofluorocarbons (HCFCs)
        - Ground level ozone (O_3)
    - Compare them.

Fig. 20 Comparison of greenhouse gases

Comparison of Major Greenhouse Gases

Greenhouse Gas	Concentration In 2017	Duration In Atmosphere	Global Warming Potential (over 100 years)
Water vapor (H_2O)	Varies with temperature	9 days	<1
Carbon dioxide (CO_2)	407 ppm	Varies from years to hundreds of years	1
Methane (CH_4)	1.85 ppm	12 years	25
Nitrous oxide (N_2O)	0.33 ppm	114 years	300
Chlorofluorocarbons (CFCs)	0.0007 ppm	55 to over 500 years	1,600 to 13,000

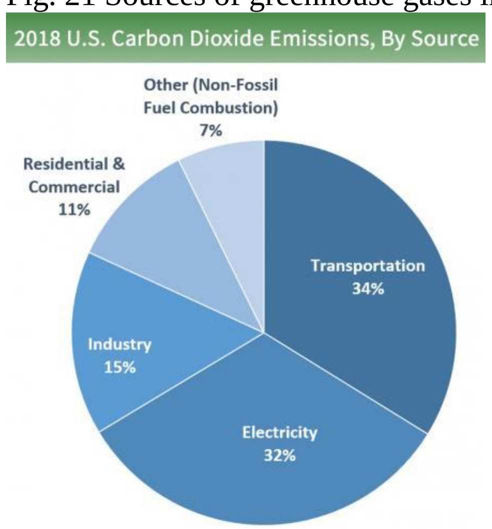
- Write your answer: Compare the greenhouse gases in the table above by concentration, global warming potential, and how long they last in the atmosphere: (a) Water vapor is the most abundant greenhouse gas. Which greenhouse gas has the second highest concentration in our atmosphere? (b) Which has the greatest potential to warm the atmosphere? (c)Which one has the shortest duration in the atmosphere? (d) Are we more concerned about CO_2 emissions than CFCs because of its concentration in the atmosphere or its global warming potential?

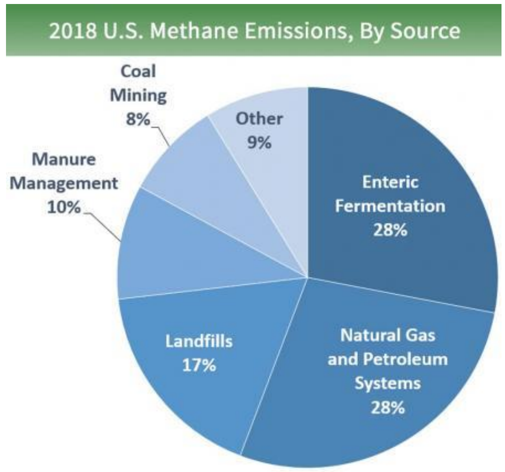
- Water vapor is the most common greenhouse gas. But the amount in the atmosphere is controlled by nature through the water cycle. So over time, there's not a big increase or decrease. And it's not causing significant global climate change. Water vapor gets into the atmosphere through evaporation and transpiration.
- Ozone in the stratosphere protects us from UV rays. But in the lower atmosphere it's a greenhouse gas and harms plants and peoples' respiratory systems.
- Methane is produced by decomposition in places without much oxygen like wetlands, animal digestion (termites, cows), coal mining, burning fossil fuels including oil and gas, landfills, and some agricultural practices (rice paddies, synthetic fertilizers, manure, nitrogen fixing crops like soybeans, manure lagoons that are not aerated).
- Sources of NO_x include denitrification in wet soils and bottoms of wetlands, lakes, and oceans; burning oil and gas; and fertilizers.
- CFCs don't occur in nature. They are man-made. They destroy stratospheric ozone and caused a "hole" in the ozone layer. So they've

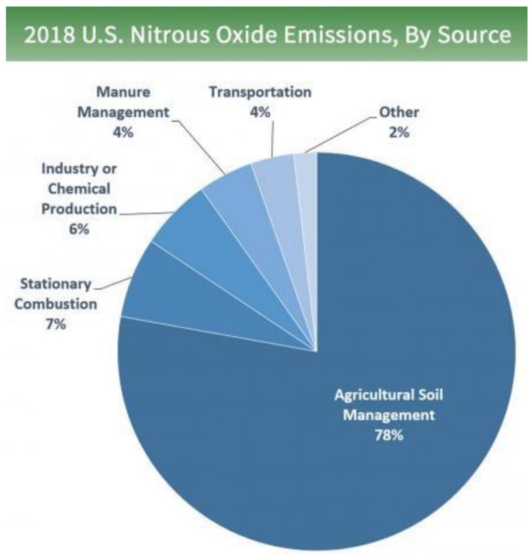
been banned, and the ozone layer has stopped thinning. But their replacement, HCFCs, have high global warming potential.

  - CO_2 is more abundant than any other greenhouse gas except water vapor. Scientists are most concerned about CO_2 because it has the biggest impact on global warming of any of the greenhouse gases.

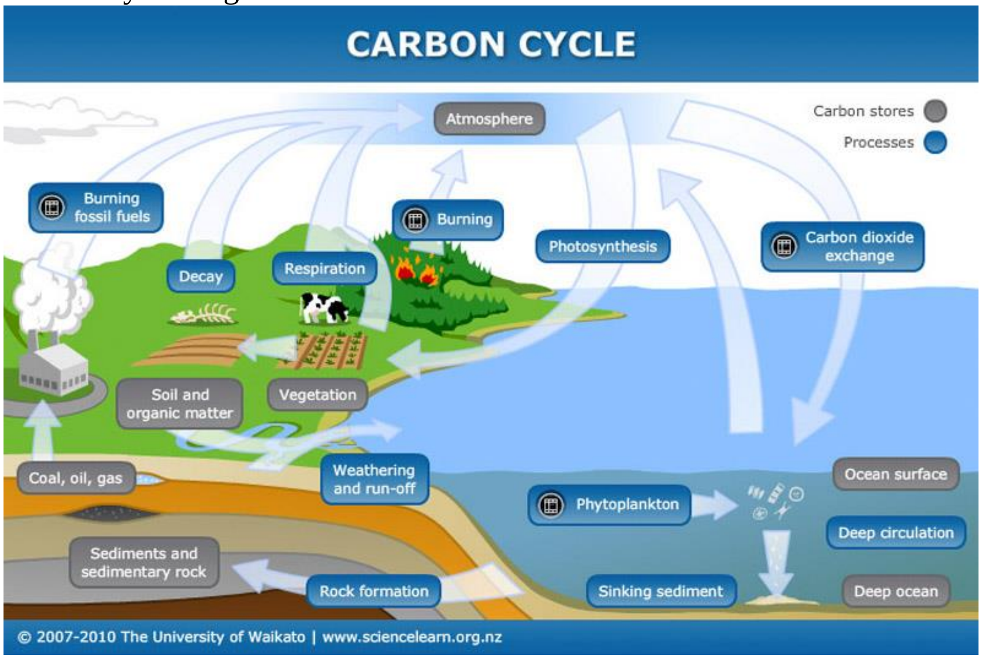
- Write your answer: What are some sources of CO_2 in the atmosphere?
  - Sources of CO_2:
    - Burning fossil fuels
      - What are the fossil fuels? (a: coal, oil, natural gas)
      - Burning coal produces the most CO_2.
      - Burning oil produces 85% as much CO_2 as coal.
      - Burning natural gas produces 56% as much CO_2 as coal.
      - Fossil fuels are burned for producing electricity, transportation (cars, airplanes, etc.), industry, and residential and commercial uses.
    - Deforestation and burning vegetation
      - When trees and other plants are cut and burned or left to decompose, they give off CO_2. They are also no longer able to remove CO_2 from the atmosphere through photosynthesis.
    - Manure
      - Manure from livestock that decomposes under high-oxygen conditions produces CO_2.
    - Fig. 21 Sources of greenhouse gases in the United States




2018 U.S. Methane Emissions, By Source
Coal Mining 8%
Other 9%
Manure Management 10%
Enteric Fermentation 28%
Landfills 17%
Natural Gas and Petroleum Systems 28%


2018 U.S. Nitrous Oxide Emissions, By Source
Manure Management 4%
Transportation 4%
Other 2%
Industry or Chemical Production 6%
Stationary Combustion 7%
Agricultural Soil Management 78%

- Fig. 22 Carbon cycle diagram

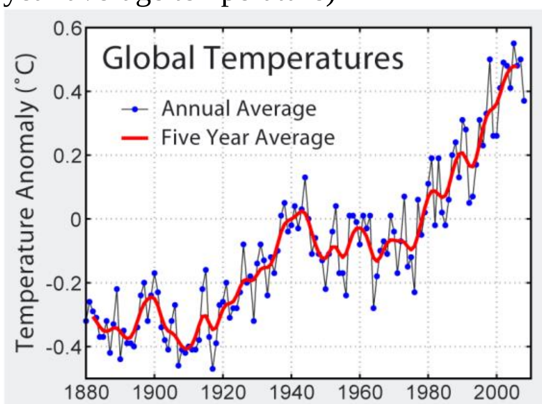


Click here for an interactive version of this diagram:
https://www.sciencelearn.org.nz/image_maps/3-carbon-cycle

- Carbon emissions are where carbon is being released into the atmosphere. Carbon sinks are where carbon dioxide is absorbed out of the atmosphere and stored.
- (a) Where are the carbon sinks in the diagram above? (b) Where are carbon emissions being discharged into the atmosphere?

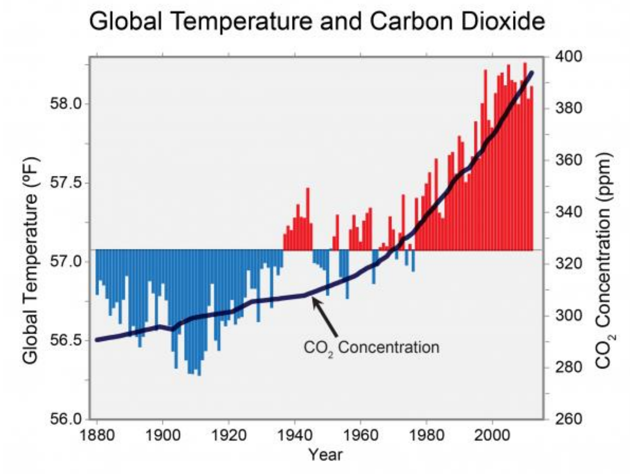
EVIDENCE FOR CLIMATE CHANGE

- Although the average annual temperature varies from year to year, global temperatures have slowly been rising since 1880
    - Fig. 23 Global temperature anomalies (differences from the average yearly or 5-year average temperature)

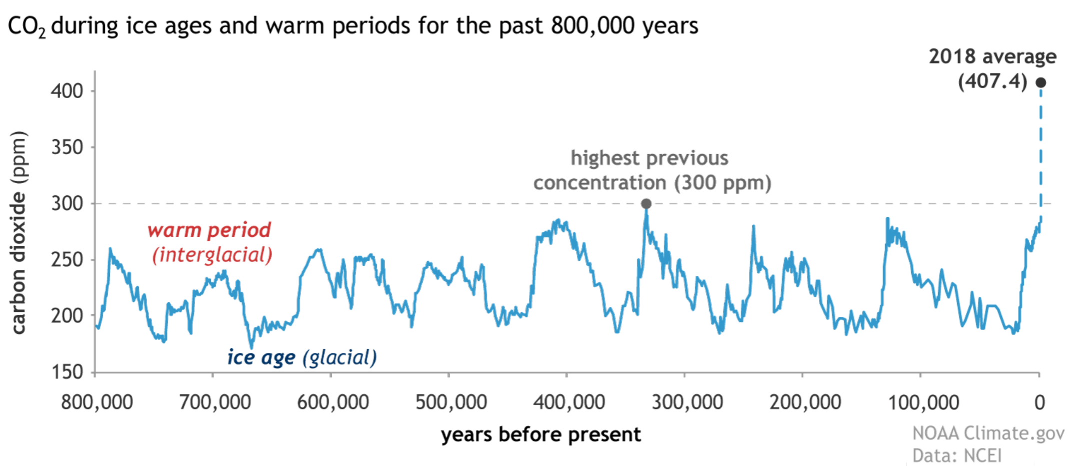


"The record of global average temperatures compiled by NASA's Goddard Institute for Space Studies. The "zero" on this graph corresponds to the mean temperature from 1961-1990, as directed by the Intergovernmental Panel on Climate Change (IPCC)."

- The increase in amount of CO_2 in the atmosphere over time correlates with the rise in global temperature over time.
  - Fig. 24 Global temperature and CO_2 concentration

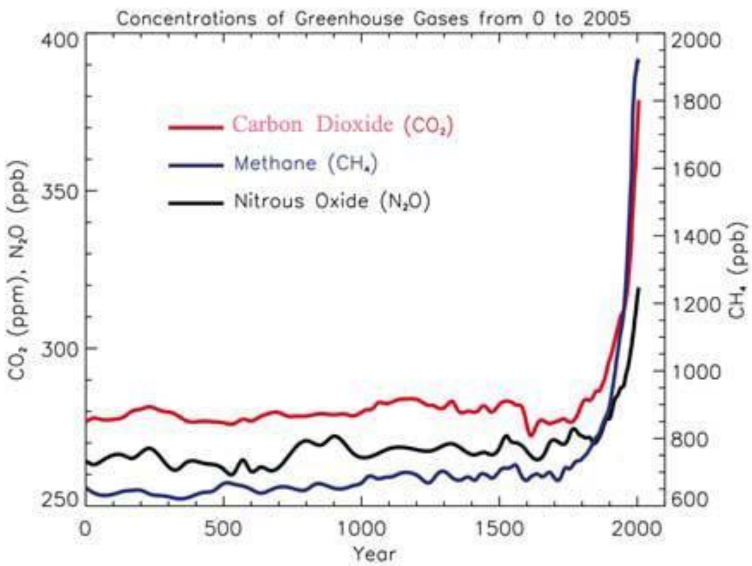


- Concentrations of CO_2 determined by indirect measurements such as air bubbles trapped in ancient ice cores dating back over 400,000 years show CO_2 levels were never higher than 300 ppm until 1950 and they have now risen to over 400 ppm.
  - Fig. 25 CO_2 concentrations over the past 800,000 years

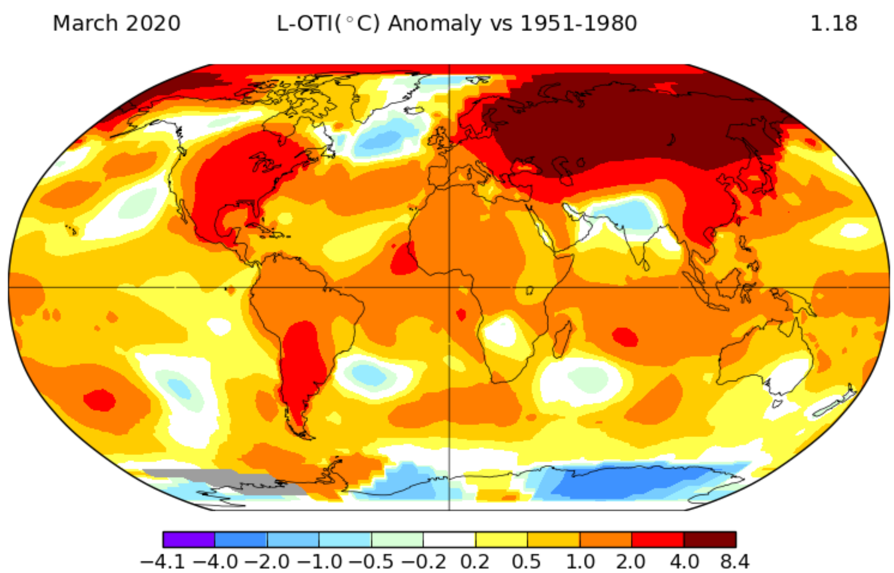


- Concentrations of methane, carbon dioxide, and nitrous oxide varied a little bit over the past 2,000 years, but they have risen dramatically in recent years.

- ○ Fig. 26 Graph of historic concentrations of methane, CO_2, and nitrous oxide



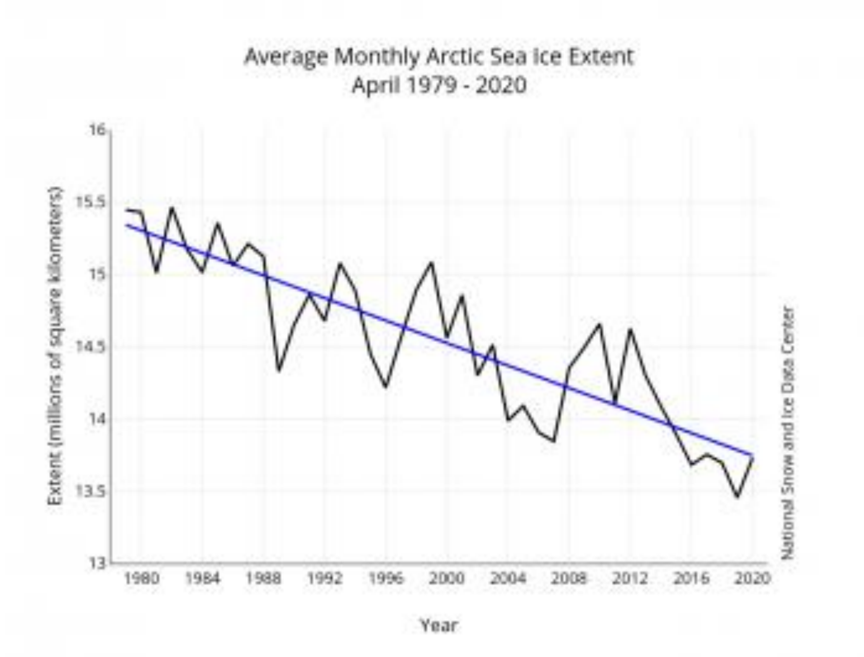
- More regions of the world are warming than are cooling or staying the same.
  - ○ Fig. 27 Map of changes in average temperature in different regions of the world



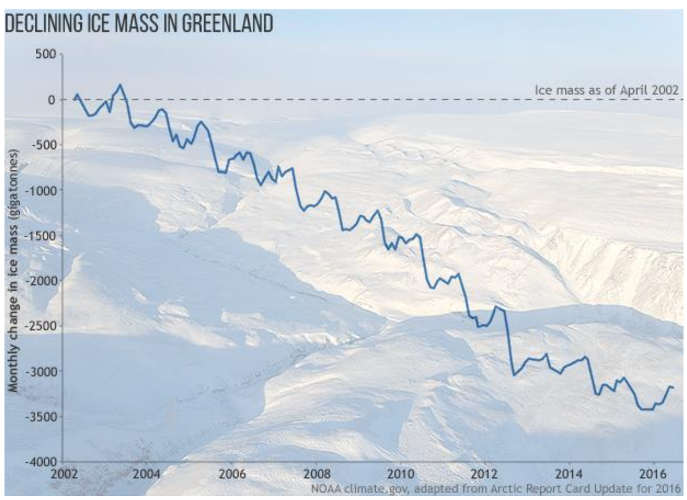
The surface temperatures on the map show differences between the average temperature from 1951-1980 and the temperature in March 2020. Temperature anomalies (differences) greater than zero indicate warming. Those less than zero indicate cooling.

- The ice cap near the North Pole has been melting over the last 3 decades.

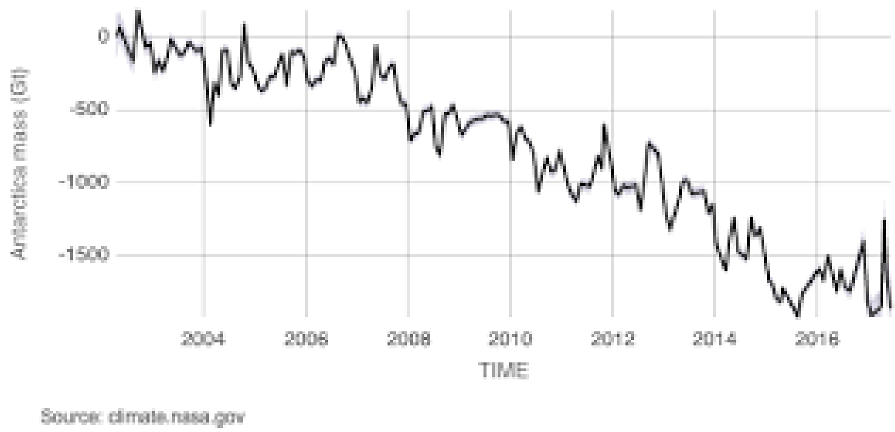
- Fig. 28 Graph of the decreasing ice cap near the North Pole



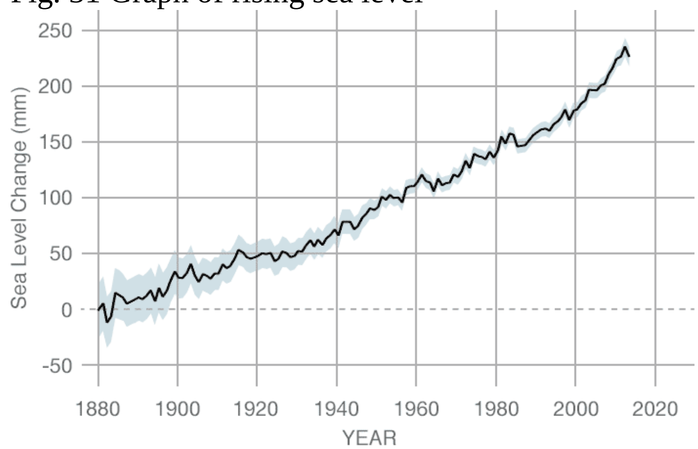
- The ice in Antarctica and Greenland has been melting since 2002.
  - Fig. 29 Graph of the decreasing ice mass in Greenland



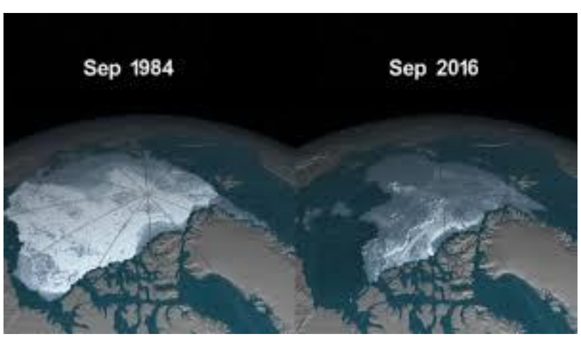
- Fig. 30 Graph of the decreasing ice mass in Antarctica



- Sea level has risen by 220 mm (9 inches) since 1880.
  - Fig. 31 Graph of rising sea level



- More evidence for climate change:
  - CO_2 concentrations have been increasing for the past 7 decades.
  - Global temperatures have been increasing since record-keeping started in 1880.
  - 17 of the 18 warmest years since 1880 (and before 2018?) occurred between 2000 and 2017.
  - Nearly 45% of the northern ice cap has melted.
  - Fig. 32 Extent of melting of Arctic ice cap from 1984 to 2016



- The concentrations of 3 greenhouse gases: CO_2, methane, and nitrous oxide all rose dramatically from 1800 to the present.
    - This coincides with the start of the industrial revolution when people started burning lots of fossil fuel.
- We are already seeing a lot of the impacts that climate scientists had predicted.

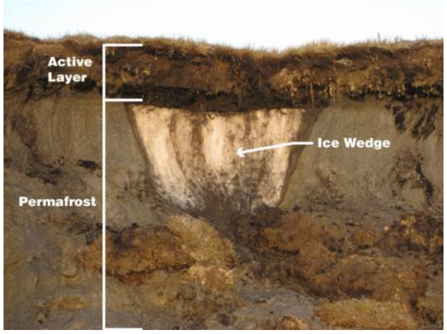
IMPACTS OF CLIMATE CHANGE

- Write your answer: List as many impacts of climate change as you can think of.

    - Examples of some impacts:
        - Warming temperatures
        - Melting of glaciers, polar ice caps, and permafrost
        - Rising sea level
        - Increase in heat waves
        - Fewer and less intense cold spells
        - Changes in precipitation patterns and more heavy precipitation and flooding
        - Shifting ocean currents
        - Increase in droughts
        - Increase in insect pests and vector-borne diseases
    - Write your answer: Which of these impacts have we seen already?
- More info on impacts:
    - Melting of glaciers, polar ice caps, and permafrost
        - Glacial meltwater is a water source for some communities. If glaciers melt faster in summer than they are replenished in the winter, they may not be a reliable source of water.
        - Fig. 33 Glacial meltwater

        - Melting ice caps have caused sea level to rise.
        - Melting of the Arctic ice cap could open new shipping lanes but also make a lot of oil and natural gas easier to extract. Burning of those fossil fuels could contribute to further global warming.
        - Permafrost is permanently frozen ground. If it melts, the ground can become unstable and sink or slide causing damage to homes, buildings, and pipelines.

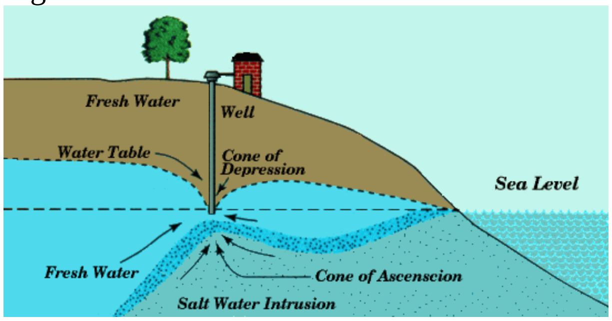
- Fig. 34 Permafrost



- Also as permafrost melts, large amounts of organic matter in the soil start decomposing, releasing methane into the atmosphere, and contributing to global warming.

- Rising sea level
  - Fig. 35 Many cities along coasts are at or near sea level

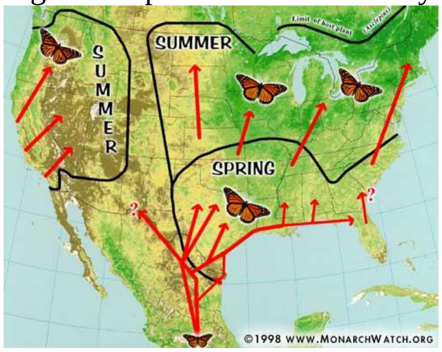
  - Rising sea levels could flood coastal cities and low-lying island nations, especially during storms.
  - People may have to evacuate or move. Most of the world's cities are along coasts. Right now, 100 million people live within 3 feet of sea level. There could be mass migrations.
  - Rising sea level could increase salt-water intrusion into aquifers.
    - Fig. 36 Salt-water intrusion could make well water unusable



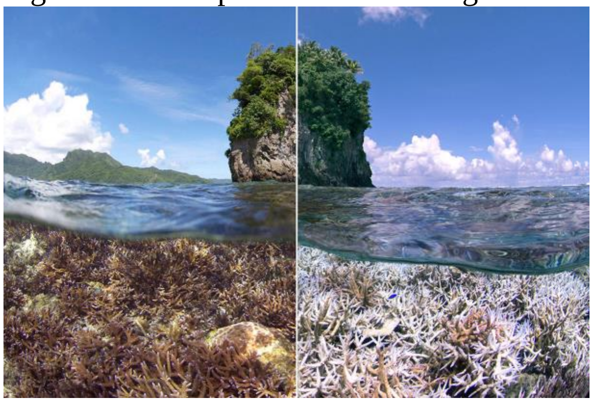
  - It could also increase soil erosion.
- Impacts on living things
  - Warming temperatures could cause plants to bloom earlier and then be damaged by later freezes.
  - Growing seasons for plants have lengthened by 4-16 days in the last 40 years in the Northern Hemisphere.

- There can be mismatches between when plants bloom and when pollinators are available.
    - Fig. 37 Hummingbird and monarch butterfly pollinating milkweed

- There can be mismatches between when birds come north and when the insects are out for them to eat.
- Some plants and animals have shifted the ranges they occupy toward both poles.
    - In the past, organisms have migrated in response to climate changes or they have evolved adaptations.
    - But if climate change is too rapid for them to evolve adaptations or if migration is blocked by development and habitat fragmentation, species may become extinct.
- There already are disruptions in the migration to Mexico of monarch butterflies and the Mexican free-tailed bat.
    - Fig. 38 Map of monarch butterfly migration



- Coral bleaching
    - Fig. 39 Pre- and post-coral bleaching

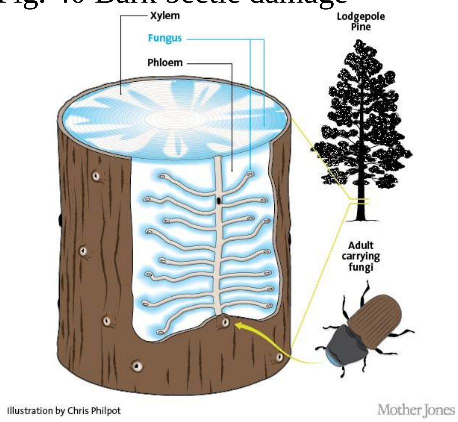


"A before and after image of the bleaching in American Samoa. The first image was taken in December 2014. The second image was taken in February 2015."

- If the ocean temperature is 1^{o}C warmer than usual in summer, corals may undergo "bleaching". They eject the algae living in them and providing them with energy. The coral turns white and if the bleaching lasts long enough, they die.

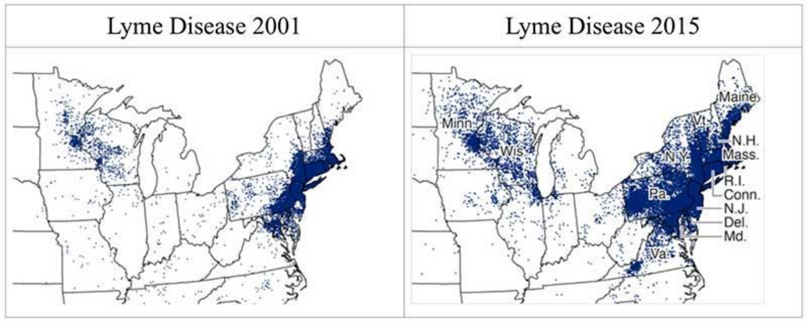
▪ Millions of trees of the Mountain West have died from pine, spruce, and pinyon ips bark beetles over the last 3 decades. The beetles usually die off in freezing temperatures. Warmer winters and record low precipitation can make trees more susceptible to infestation. In Colorado, warmer winter temperatures resulted in slightly larger spruce beetles emerging and flying around longer.

- Fig. 40 Bark beetle damage



- Increase in insect pests and vector-borne diseases
  - ▪ Warming temperatures can cause insects like mosquitos and other disease-causing organisms to migrate (toward the north in the northern hemisphere).
  - ▪ Infectious diseases and illnesses caused by bacteria and fungi may extend over a wider range.
  - ▪ Cold winter temperatures kill mosquitos. Warmer temperatures will enable larger populations to survive through the winter. It's already warm enough in the South for the mosquito species that can carry dengue, chikungunya, and Zika. West Nile is expected to increase.
  - ▪ Deer ticks are increasing. They can carry Lyme disease and anaplasmosis.

- Fig. 41 The spread of Lyme disease between 2001 and 2015



- Negative affect on health
  - Global warming can cause heat stress and impact the health of humans, livestock, and other animals and plants.
- Increase in heat waves
  - Heat waves are expected to be more frequent.
    - So people will use more energy for air conditioning – leading to more emissions of greenhouse gases.
  - People without air conditioning during a heat wave are more likely to die, especially if they are elderly or very young.
  - Heat waves can contribute to droughts and crop damage and increase the need for irrigation.
    - Fig. 42 Drought

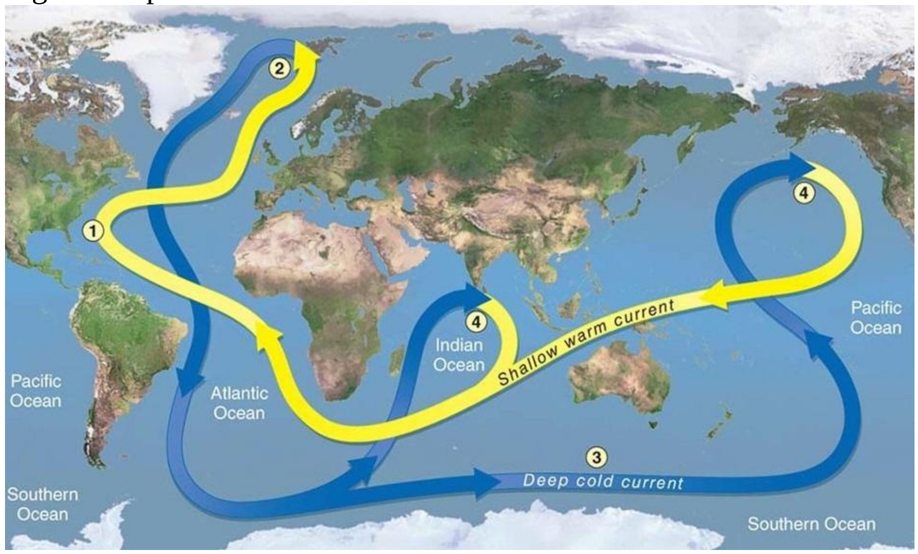
    - This could cause the cost of producing food to rise and affect farmers and consumers.
- Fewer and less intense cold spells
  - Global warming is expected to decrease the number of very cold days and the number of days it's below freezing.
  - This would have some benefits, but without the freezing temperatures, some insect pests, like the Balsam Woolly Adelgid, may expand their range.
    - Fig. 43 Balsam Woolly Adelgid

- Changes in precipitation patterns causing more floods and droughts
  - Increased precipitation could result in flooding, landslides, and/or soil erosion.
    - Fig. 44 Flooding from Hurricane Florence in North Carolina

  - Less precipitation could cause droughts, a scarcity of fresh water, and difficulty growing crops.
- Increase in storm intensity
  - Climate change is expected to cause more intense and more frequent hurricanes.
  - Hurricanes are expected to extend farther north along the Atlantic Coast.
  - Hurricanes get their energy from warm ocean waters.
    - Fig. 45 Hurricane near Florida and Cuba

  - A lot of cities are built along coastlines and would be at risk.
- Shifting ocean currents
  - Climate change could cause ocean currents to shift or stop and that could disrupt the way ocean currents distribute heat around the planet and have major effects on the climate of nearby continents.
  - The Great Ocean Conveyor (thermohaline circulation)
    - One type of ocean current that distributes heat throughout oceans around the world works almost like a giant conveyor belt. It is known as The Great Ocean Conveyor. How deep or shallow the water in this current is depends on how salty and how warm the water is. So it is called a thermohaline current (thermo = heat, haline = salt).

- Fig. 46 Map of thermohaline circulation in the ocean



- This density current involves circulation of water in the deep ocean. Warmer water moves from the Gulf of Mexico past Europe toward Greenland where it becomes colder and saltier (as some of the water freezes or evaporates). The more dense, cold, salty water sinks to the ocean floor. It mixes with deep waters of the ocean, circulates, and resurfaces near the equator and eventually returns to the Gulf of Mexico after flowing through the Atlantic, Indian, and Pacific Oceans.
- This current warms the climate of western Europe.
- But global warming that causes more melting of ice from Greenland and the northern polar ice cap could dilute the salty ocean water enough to prevent it from sinking near Greenland and stop the thermohaline circulation.
- This would cause significantly colder temperatures in Europe.
  - Right now, England's winter temperature is 36ºF (20ºC) warmer than that of Newfoundland, Canada, which is at a similar latitude.

- Economic impact
  - Crop losses
    - Climate change could decrease the yield of some crops in California by up to 40% by 2050, and California provides about 2/3 of the nation's produce.
    - Crops that are likely to be affected by warming temperatures and a shrinking snowpack include: walnuts, peaches, apricots, almonds, avocados, cherries, grapes, corn, tomatoes, rice, strawberries, blueberries, etc.
    - Some plants need a certain number of chill hours or "sleep" each year.

    - Peaches need cold temperatures for their plants to set fruit. The winter of 2016-2017 was too warm for Georgia peaches and 80% of the crop failed.
  - Plants will be affected by drought, heat waves, pests, and diseases.
  - Pollinators may not be able to pollinate plants.
    - Fig. 47 Honeybee pollinating flower

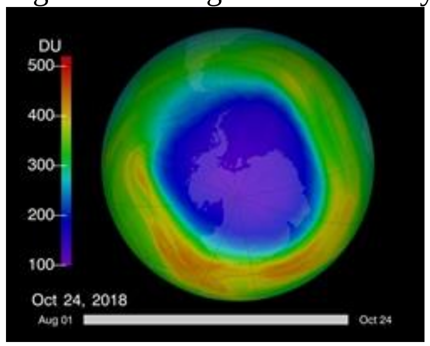
    - If it's not cold enough, honeybees fly out of their hives and queens might start laying eggs. They expend energy and eat more of the honey stored for winter. They may starve if their calendar doesn't coincide with that of the blooms they need for nectar.
  - Food security issues could result.
- Buildings, homes, and infrastructure may be damaged or destroyed by rising sea level, floods, severe storms, and increased fires brought on by climate change. These could result in property losses as well.
  - Fig. 48 Massive fire in California

- Businesses schools, and government offices may not be able to operate as a result of severe storms, floods, fires, or disease pandemics.
- Tourism may be hurt in ski resorts with less snow and in warmer areas with damaged/bleached coral reefs.

WHAT TO DO ABOUT CLIMATE CHANGE

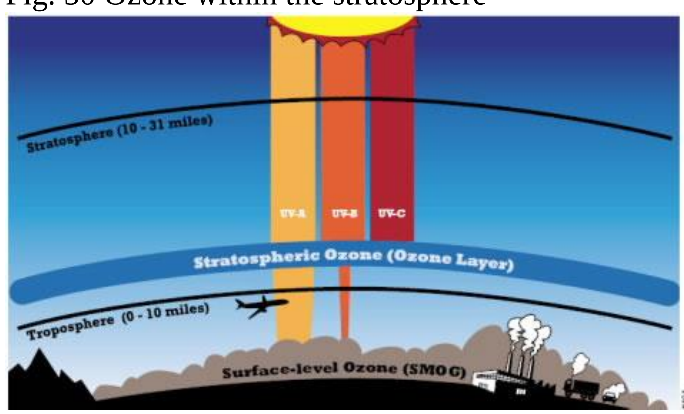
- Should we give up, say we're doomed, and do nothing?
  - Have we ever solved very big environmental problems that threatened our health, well-being, and existence before?
  - Examples of big environmental problems we faced in the past and what we did about them:
    - CFCs and the "hole in the ozone"

- Fig. 49 Thinning of the ozone layer above Antarctica



“The view of total ozone over the Antarctic pole from October 24, 2018. The purple and blue colors are where there is the least ozone, and the yellows and reds are where there is more ozone. Credit: NASA Ozone Watch”

- Although ground-level or tropospheric ozone can damage plants and cause respiratory problems in people, ozone higher up in the stratosphere is beneficial to living things. Stratospheric ozone protects us from UV rays which cause skin cancer and cataracts in humans and harms plants. So without the ozone layer, life as we know it would not be possible on earth.
  - Fig. 50 Ozone within the stratosphere



- In the mid-1980s, scientists noticed that stratospheric ozone in Antarctica had been decreasing each year since the 1970s. There was more ozone depletion at the poles, but it was occurring worldwide. The area of very thin stratospheric ozone over Antarctica became known as the “ozone hole”.
- Scientists from around the world worked together to understand the causes and find a solution. They found the ozone depletion was caused by man-made chemicals that don’t occur in nature called chlorofluorocarbons (CFCs). CFCs were being used as refrigerants in air conditioners and refrigerators, propellants in spray cans, and products like Styrofoam.

- Fig. 51 CFCs used to be used as propellants in spray cans

- To solve the problem, representatives from 24 nations came together in 1987 to sign the Montreal Protocol to limit the sales and use of CFCs. Later more than 180 countries signed a series of increasingly strict amendments that eliminated the production and use of CFCs in the developed world by 1996. One of the types of chemicals substituted for CFCs was HCFCs: hydrochlorofluorocarbons, which are potent greenhouse gases. In 2016, an amendment was adopted to limit production and consumption of HCFCs. Since the Montreal Protocol, stratospheric ozone levels have fluctuated, and some scientists think the overall trend is improving. We may need more data before we can be sure. Older reports predicted the ozone layer would recover by 2030. Newer reports are saying the ozone layer may recover by about 2070. But here is a case where people around the world worked together to stop putting ozone-destroying chemicals in the atmosphere. And since CFCs are greenhouse gases, that also slowed down the rate at which we are causing global warming.
    - Fig. 52 Insignia of the Montreal Protocol

- Pollution of the 1960s and 1970s and resulting environmental laws
    - Air, water, and soil pollution and dumping of toxic wastes got pretty bad in the U.S. by the 1960s and 1970s.
        - In Jan. 1969, an offshore oil platform near Santa Barbara, California exploded and leaked 3 million gallons of oil over 11 days. It kept leaking throughout the year. The oil coated seabirds, marine mammals, fish and 35 miles of the shoreline.

    - Fig. 53 Santa Barbara oil spill

      https://www.latimes.com/local/lanow/la-me-ln-santa-barbara-oil-spill-1969-20150520-htmlstory.html

- The Cuyahoga River caught fire on June 22, 1969 near the Republic Steel Mill in Cleveland, Ohio. This was a result of industrial water pollution. The river caught fire 13 times.
    - Fig. 54 The Cuyahoga River on fire

- Rachel Carson published the book <u>Silent Spring</u> in 1962. It told about the harmful impact of the pesticide DDT on bird eggs.
    - Fig. 55 Rachel Carson wrote Silent Spring

- Very bad smog was a big problem in cities like New York and Los Angeles. Smog forms when compounds emitted by vehicles, power plants, and industry react in the presence of sunlight to create ground-level ozone.

- In the 1960s, the US. Didn't have strong air quality standards.
- In Nov. 1953 and Nov. 1966, a heat inversion in New York City trapped chemicals and particulates in the air that created deadly smog that killed about 200 people each time.
    - Fig. 56 Smog in New York City

- In 1962, smog in London killed about 750 people.

- One river in Washington, DC was so polluted that my brother and I called it the "chocolate milk river" when we were little because that's what it looked like.
    - Fig. 57 Polluted water in the Potomac River in 1973

- What people did to help solve these problems
    - In 1963, Congress passed the Clean Air Act and set aside $95 million for study and clean up.
    - The National Environmental Policy Act (NEPA) was passed in 1969 to give the President and advice on environmental issues and review Environmental Impact Statements. It requires federal agencies to assess environmental impacts of their proposed actions before making decisions.

- President Nixon started the Environmental Protection Agency (EPA) in 1970. The Occupational Safety and Health Administration (OSHA) was also started in 1970.
  - Fig. 58 Nixon signs the Clean Air Act in front of the head of the EPA

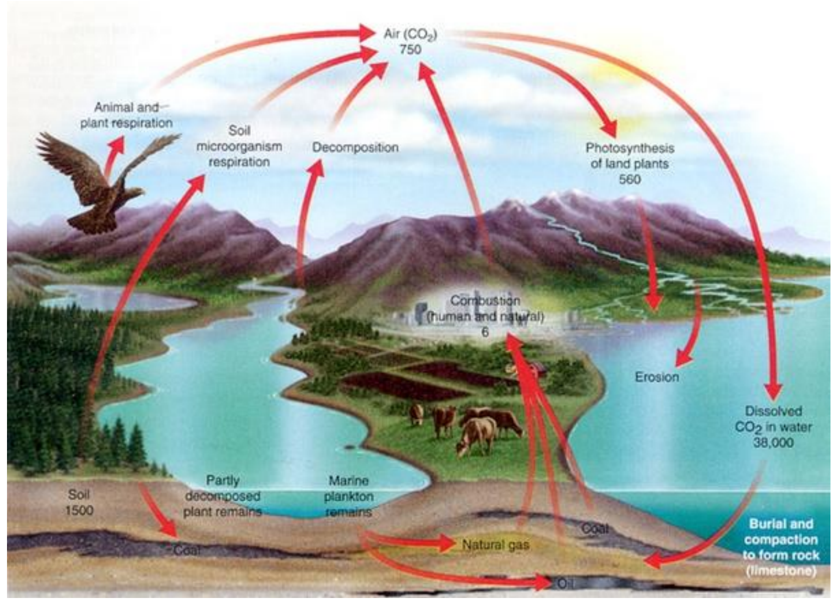
"Nixon signs the Clean Air Act of 1970 as William Ruckelshaus (*left*), head of the newly formed Environmental Protection Agency, and Russell Train (*right*), chairman of the Council on Environmental Quality, look on."

- The first nationwide Earth Day was celebrated April22, 1970.
- The Clean Water Act was passed in 1972.
  - Cleveland Mayor Carl Stokes (1st black mayor of a major city) and his brother, U.S. Representative Louis Stokes, helped get it passed.
    - Fig. 59 Mayor Carl Stokes

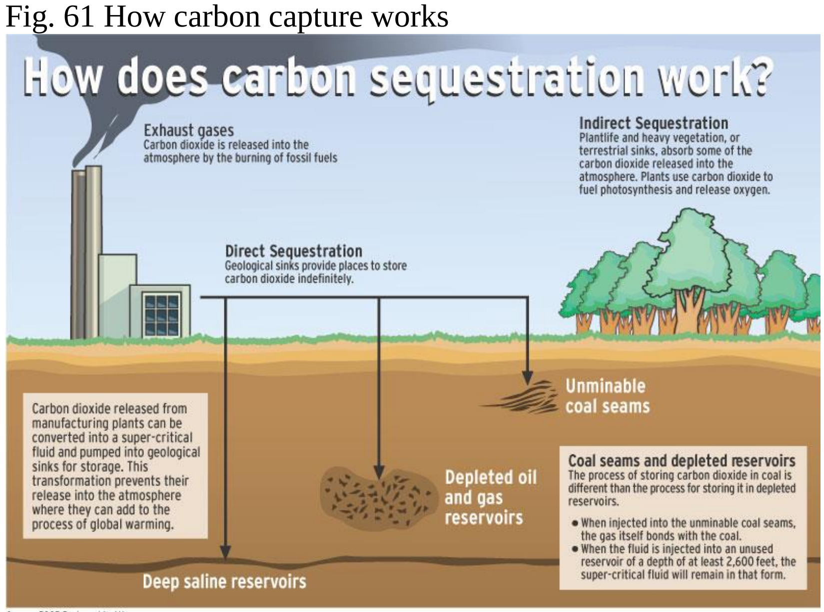
- The Resource Conservation and Recovery Act (RCRA) was passed in 1976 to regulate hazardous waste and garbage.
- The Soil and Water Conservation Act passed in 1977.
- The Surface Mining Control and Reclamation Act passed in 1977. And many other laws and regulations went into effect in the late 1960s and 1970s in reaction to the pollution and environmental problems of that time period.

- Write your answer: What are some things we can do about climate change?

- A little background information:
  - Individual efforts versus system-wide efforts
    - Individual efforts such as things you can do at home won't have as big an impact as system-wide efforts such as getting elected officials to set policies that impact climate change. But that doesn't mean you shouldn't make the individual efforts.
  - Carbon sinks are reservoirs or places that absorb carbon out of the atmosphere and store it. So they lower the concentration of CO_2 in the atmosphere.
      - Natural carbon sinks: the ocean, forests, soil
        - Fig. 60 The carbon cycle



    - Carbon capture (carbon sequestration)
      - Fig. 61 How carbon capture works



Source: PCOR Partnership Atlas

- CO_2 can be taken out of the atmosphere and stored in places like agricultural soil, abandoned oil wells, or the deep ocean.
  - There's more carbon in the soil than in the atmosphere: 2,500 billion tons of carbon in soil; 800 billion tons in the atmosphere.
  - Research is being done into technologies that could capture CO_2 from the air, from coal-burning power plants and from other sources, in a cost-efficient way.
- Potential new technology
  - Storing carbon in the ocean
    - There is interest in storing more carbon in the ocean through large-scale addition of nutrients. However there is concern about potential consequences to global nutrient cycles and marine ecosystems.
- Look at the following list of things people can do and set one short-term and one long-term goal for your own actions.

What Are Some Things We Can Do About Climate Change?

- Decrease the use of fossil fuels (coal, oil, natural gas).
  - Switch from coal and oil to energy sources that emit less or no CO_2.
    - Switch to renewables like solar, wind, hydropower, geothermal, wave, and tidal power.
      - Fig. 62 Solar panels and wind turbines

    - Switch to nuclear energy (which has its own hazards).
    - Switch to natural gas (which still emits CO_2, but less of it).
  - Use biomass energy as a bridge (while transitioning) to wind, solar, and water power.
    - Examples of biomass for energy: woody biofuel crops like Miscanthus, switchgrass, and Arundo donax (which grow in Eastern NC); waste wood, waste agricultural byproducts like discarded stalks, husks, leaves, and cobs.

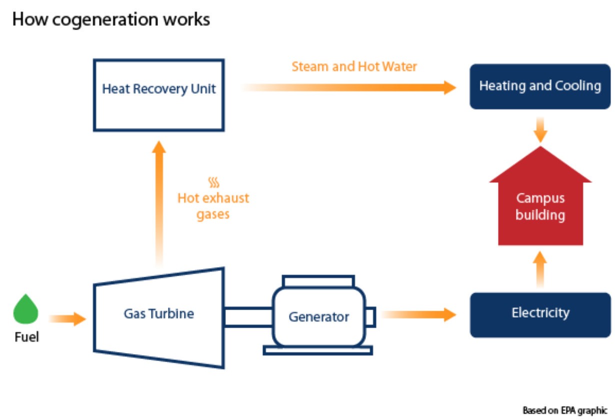
- Fig. 63 The biofuel crop, Miscanthus

- Increase the fuel efficiency of vehicles.
  - Fig. 64 Fuel efficient cars

- Drive less.
  - Use mass transportation (buses, railways, subways, light rail systems).
  - Carpool.
  - Combine trips.
  - Walk or ride a bicycle.
    - Fig. 65 Bicyclist

- Cogeneration
  - It captures excess heat generated while electricity is produced and uses the thermal energy at or near the site for heating and other purposes.

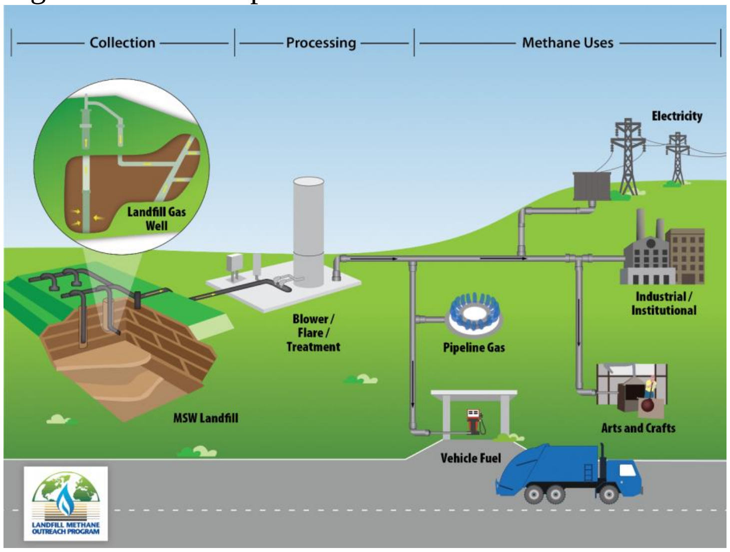
- Fig. 66 Cogeneration



- Methane digesters
  - Fig. 67 Methane digester near hog barns in North Carolina

  - They use waste from crops, animals, or food stuffs.
  - They have the waste undergo decomposition with the help of microbes in a sealed tank (anaerobic digester).
  - They produce methane (biogas) and solids that can be used as a nutrient-rich fertilizer
  - The methane (biogas) that is produced can be used for heating, electricity generation, and if cleaned, it can be used in vehicles that burn natural gas.
- Landfill methane
  - Landfills are a top source of methane emissions. And methane has 34 times the greenhouse effects of CO_2.
  - That methane can be trapped and used instead of coal, oil, or natural gas to generate electricity or heat.

- Fig. 68 Methane capture from a landfill



- Reforestation
  - Plant trees.
- Forest protection
  - Use sustainable forest management practices.
  - Preserve or restore tropical forests.
    - Fig. 69 Clearing of an Amazon rainforest

    - "Rainforests are being cut down at a rate that will eliminate them in 40 years." (Hawken, 2017, p. 111)
    - They sequester carbon. They can sequester 1.4 tons of CO_2/acre annually.
    - In recent decades, there has been extensive clearing, fragmentation, degradation, and depletion of flora and fauna.
    - They used to cover 12% of the world's land mass. Now they cover 5%.
    - Tropical forest loss accounts for 16 – 19% of greenhouse gas emissions from human activity.
  - In rainforest areas, ecotourism could be promoted rather than logging.
- Grow bamboo

- Fig. 70 Bamboo

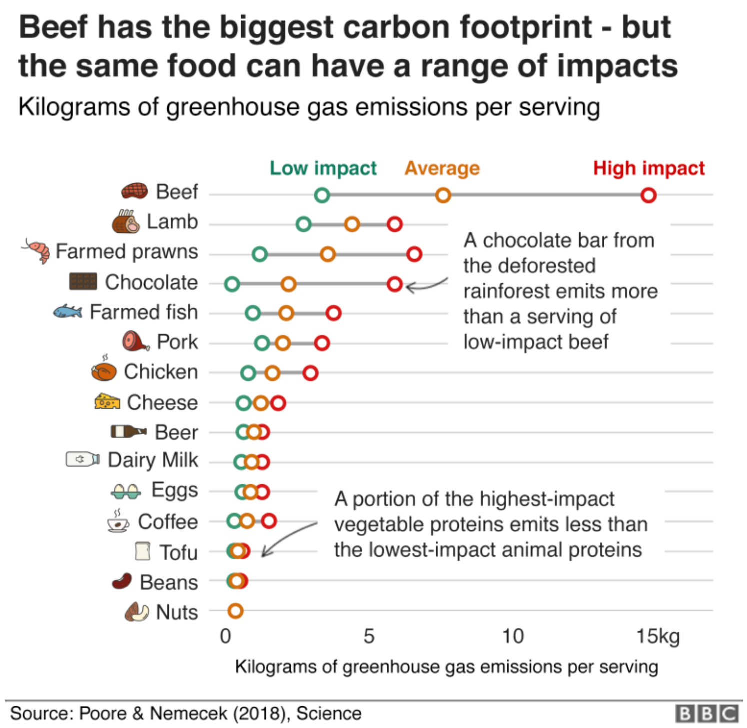
- It quickly sequesters carbon in biomass and soil. It takes carbon out of the air faster than about any other plant. Some species can sequester 75 to 300 tons of carbon/acre over a lifetime. It grows more than an inch/hour in the spring.
- It can live on inhospitable, degraded land.
- It may serve as a replacement for higher emission-producing materials (like cotton, plastics, steel, aluminum, and concrete).

- Coastal wetland protection
  - Coastal wetlands like marshes, mangroves, and meadows provide large carbon sinks. They can store 5 times as much carbon as tropical forests over the long term. Most of the carbon is stored in deep wetland soils. Much of this carbon would escape if these ecosystems were lost.
  - Coastal wetlands are often diked, dredged, and drained for farmland for building homes, etc. Over the past few decades, over 1/3 of the world's mangroves have been lost.
    - Fig. 71 Mangroves

- Clean cookstoves
  - Fig. 72 Preparing a meal with a cookstove

- 40% of the world's people cook with wood, charcoal, animal dung, crop residues, and coal. This contributes to 2-5% of global greenhouse gas emissions through deforestation, forest degradation, and cooking.
- The Global Alliance for Clean Cookstoves (GACC), which was started by the United Nations Foundation, and its partner organizations work to make clean cookstoves more widely available.

- Reduce food waste
  - It can be reduced at every stage: on the farm, during transportation, at storage facilities, in production facilities, during distribution, in stores, at restaurants, and at the consumer level.
  - The food we waste contributes 4.4 gigatons of CO_2 equivalent into the atmosphere per year. That's about 8% of total anthropogenic (human-caused) greenhouse gas emissions. Meanwhile nearly 800 million people worldwide go hungry.
- Eat less meat
  - It is estimated that raising livestock accounts for 15% to 50% of global greenhouse gas emitted directly and indirectly.
  - Cows generate methane while digesting their food. They release it into the atmosphere when they pass gas.
  - Manure and fertilizer emit nitrous oxide.
    - Fig. 73 Graph of greenhouse emissions from various foods



- Agricultural carbon capture (carbon sequestration)
  - Carbon is stored in agricultural soils in a number of ways. These methods also increase soil fertility, reduce erosion, and increase resilience to droughts and floods.

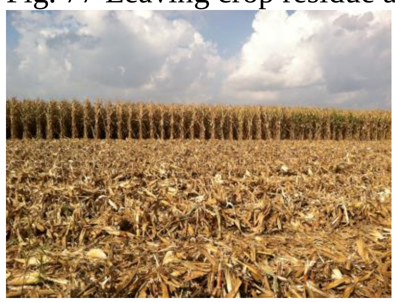
- No-till agriculture – plants seeds without plowing the land first.
    - Fig. 74 No-till farming

    - Conservation agriculture
        - Uses no-till farming and cover crops. But also uses synthetic fertilizers and pesticides.
    - Regenerative Agriculture
        - Restores degraded land through no-till farming, divers cover crops, using on-the-farm fertilization sources, little or no pesticides or synthetic fertilizers, multiple crop rotations, and managed grazing. It improves soil health by restoring its carbon content.
- Nutrient management
    - Fig. 75 Farmer applying fertilizer

    - Managing fertilizer application efficiently can prevent excess unused nitrogen from being converted into nitrous oxide. Avoiding overuse of fertilizer can also save farmers money.
- Agroforestry – cultivated crops are intermixed with growing trees.
    - Fig. 76 Agroforestry

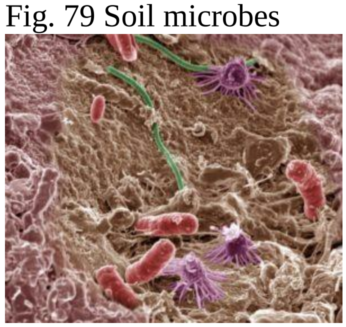
    - Also known as food tree intercropping

- Smaller crops are intermixed between trees (in rows, clusters, or randomly scattered)
  - It increases the carbon content of the soil and the productivity of the land. It can sequester carbon at a rate of 2.8 tons of carbon per acre per year.
- Applying animal manure, compost, or crop residues to fields.
  - Composting
    - Organic waste that decomposes in a landfill gives off methane, but the aeration involved in composting prevents the production of methane. So the organic material in compost is converted to stable soil carbon and it's made available to plants.
  - An example of crop residue would be stalks left behind after harvest.
    - Fig. 77 Leaving crop residue after harvest



- Biochar
  - Fig. 78 Turning biomass into biochar

  - Biochar is produced by the slow burning of biomass in the near or total absence of oxygen (a process called pyrolysis).
  - It produces very fertile carbon-rich soil and reduces CO_2 emissions.
- Increasing the diversity and number of soil microbes.
  - Fig. 79 Soil microbes



    - Soil carbon storage depends on microbes eating and processing nutrients.
    - Soil microbe diversity and numbers can be increased by increasing plant diversity. This will increase microbial activity and build more diverse microbe communities.
    - Applying manure can also support more diverse soil communities and increase microbial biomass.
- Controlling erosion by contour plowing or terracing.
    - Fig. 80 Contour plowing

- Providing a living cover for soils.
    - Fig. 81 Cover crop between rows in a vineyard

    - Planting cover crops that are not intended for harvest rather than letting fields lie bare after harvest.
    - Creating borders of permanent vegetation along the edges of fields.
- Soil management assistance could help farmers increase carbon capture.
    - Subsidies could give farmers incentives to invest in cultivating healthier soils.
    - The Natural Resources Conservation Service (NRCS) provides technical assistance and planning tools to help farmers make informed decisions about soil management.
    - More research is needed into how to estimate total benefits and which soil management practices offer the most potential for a given soil type, climate, and crop.
- Land use can be changed from a former crop field to forest, pasture, grassland or wetland by:
    - Reforestation
    - Grassland restoration

        - Only 3% of North America's tallgrass prairies remain.
    - Creation of wetlands and ponds
        - Fig. 82 Creating a wetland pond

        - This captures carbon because decomposition is greatly reduced in waterlogged soils from lack of oxygen.
    - Irrigation of pasture or rangelands
- Replanting degraded areas
    - Fig. 83 Replanting trees in a rainforest

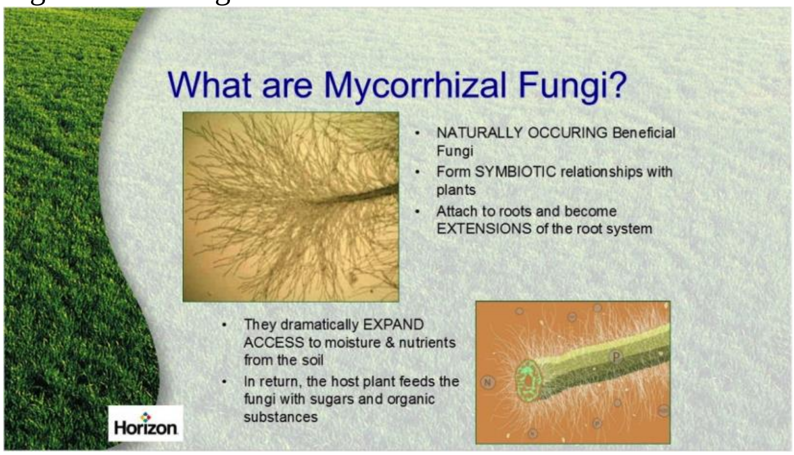
- Increased use of biomass for mulch rather than burning the biomass
    - Fig. 84 Using biomass for mulch

- Improved pasture management

- Fig. 85 Pasture for cows

- Managed grazing is rapid and intense with long rest periods as cattle are moved to other pastures. It sequesters carbon, unlike conventional grazing.
- Silvopasture integrates trees and pasture or forage.
- Holistic Planned Grazing (HPG) uses livestock as a tool for large-scale land restoration. It's based on the herding and grazing patterns of wild ruminants (the group that includes cows, sheep, goats, deer, elk, bison, and buffalo) that coevolved with grassland ecosystems. Animals are moved so that no plants are overgrazed, and grazing stimulates biological activity in the soil. The manure adds fertility, and as they move in a herd, their trampling aerates soil, presses in seeds, and pushes down dead plant matter so that it can be acted on by soil microorganisms. This generates soil carbon, plant carbon, and water retention.

- Effective erosion control
- Restoration of mangroves, salt marshes, and sea grasses
- Protecting root fungi (mycorrhizal fungi)
  - Fig. 86 Root fungi



  - Root fungi or mycorrhizal fungi (fungus that grows in a symbiotic relationship with plant roots) can be protected by minimizing tillage (plowing) and chemical inputs (applying pesticides, herbicides, and fertilizer), and using cover crops.

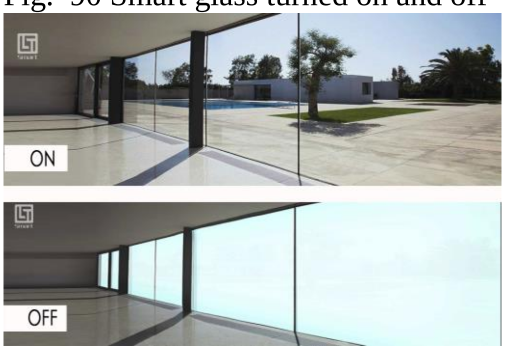
            - The fungi's hyphae (branching filaments or thread-like structures) are coated with glomalin (a sticky protein) which is very important in soil formation and in storing carbon.
        - Drip and sprinkler irrigation of crops
            - Fig. 87 Drip irrigation

            - It decreases carbon emissions from the energy required to do pump irrigation.
        - Improved methods of rice cultivation
            - This can sequester carbon and avoid methane emissions.
- Green roofs
    - Fig. 88 Green roof design

    - Traditional roofs in an urban area can contribute to creation of a heat island. Green roofs have soil and plants and a way to filter rainwater.
    - The soil and vegetation insulate and moderate building temperatures year-round, plus the plants and soil sequester carbon.
- Cool roofs
    - They reflect up to 80% of solar energy back into space. They may use light-colored metal, shingles, tiles, coating, membranes, etc.
- LED lighting
    - Fig. 89 LED lightbulbs compared to other types of light

- An LED light uses 90% less energy for the same amount of light than an incandescent bulb and ½ as much a compact fluorescent bulb without toxic mercury.

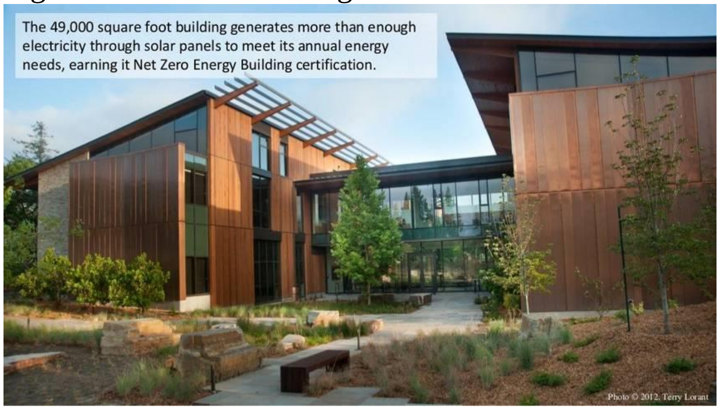
- Heat pumps
  - High efficiency heat pumps reduce fuel consumption to zero and use less electricity to generate heating and cooling. They can provide indoor heating, cooling, and hot water.
- Smart Glass
  - Fig. 90 Smart glass turned on and off



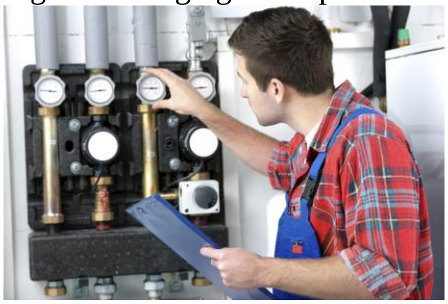
  - Smart windows reduce the energy load for lighting and improve heating and cooling efficiency. Electrochromic windows can be activated by electricity on a cold winter day to admit both visible light from the sun and thermal radiation. On a summer day, they can admit visible light but block heat. Or they can block and reflect both heat and light without blinds and curtains.
- Smart Thermostats
  - You can still turn the temperature up and down, but the devices remember your choices and routines, and as a result, save energy.
- Insulation
  - It's one of the most practical and cost-effective ways to make buildings more energy efficient in both new construction and retrofitting.
    - Insulation materials include fiberglass, plastic fibers, mineral wool, (made from basalt or blast furnace slag), cellulose (recycled

newsprint), polystyrene, hemp, sheep's wool, straw, and waste poultry feathers.

- Retrofitting buildings
  - Retrofits can make existing buildings much more energy efficient.
- Net Zero Buildings
  - Fig. 91 A net-zero building



  - A net zero building has zero net energy consumption. It produces as much energy as it uses in a year.
  - They use smart windows; green roofs; efficient heating, cooling, and water systems; better insulation; distributed energy storage; and advanced automation.
- Walkable cities
  - In a walkable city, sidewalks are wide and protected from traffic, tree-lined (creating shade), connected, safe, and have secure parking and good lighting.
- Bike infrastructure
  - There is a network of interconnected bike lanes or paths.
- Water distribution
  - Fig. 92 Managing water pressure



  - Pressure management and active leakage control could reduce water losses and result in a reduction of emissions from pumped water distribution.

WRAP UP

- Write your answer: List the following things:
  - One thing you learned about climate change

- One thing you could do now about climate change
- One thing you could do some day about climate change

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