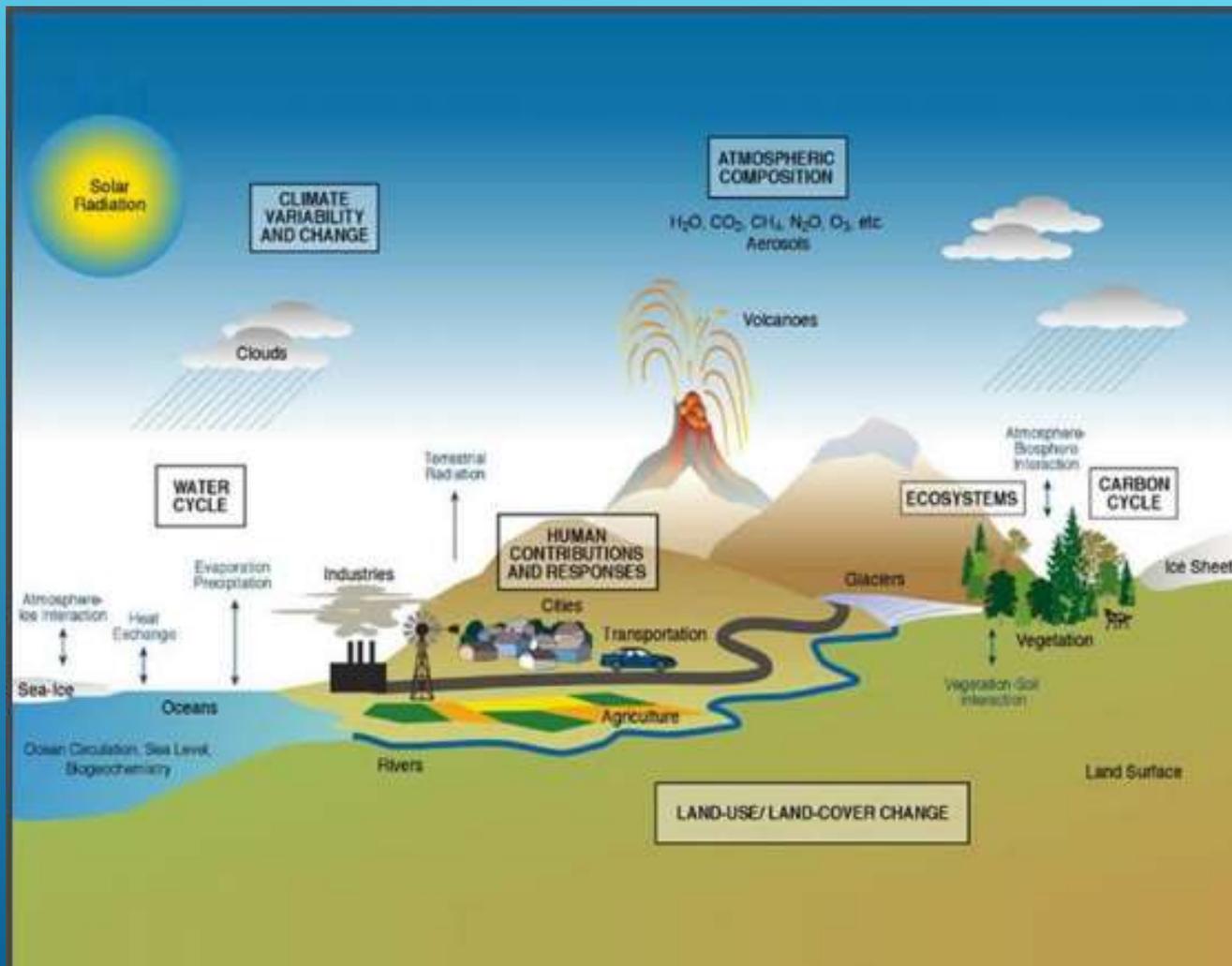


CLIMATE CHANGE

Scientific evidence for warming of the climate system is unequivocal.

- Intergovernmental Panel on Climate Change



The Global Climate System:

- The climate system is driven by a close interaction between the Atmosphere, the Geosphere (Lithosphere, Hydrosphere, Cryosphere) and space
- Human activities can affect/modify these interactions



www.photolibrary.com

Atmospheric circulation transfers a small proportion of the heat around the planet



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Oceanic circulation (currents) is by far the main medium for heat transfer around the planet. The general oceanic circulation is known as the oceanic conveyor belt or the thermohaline system

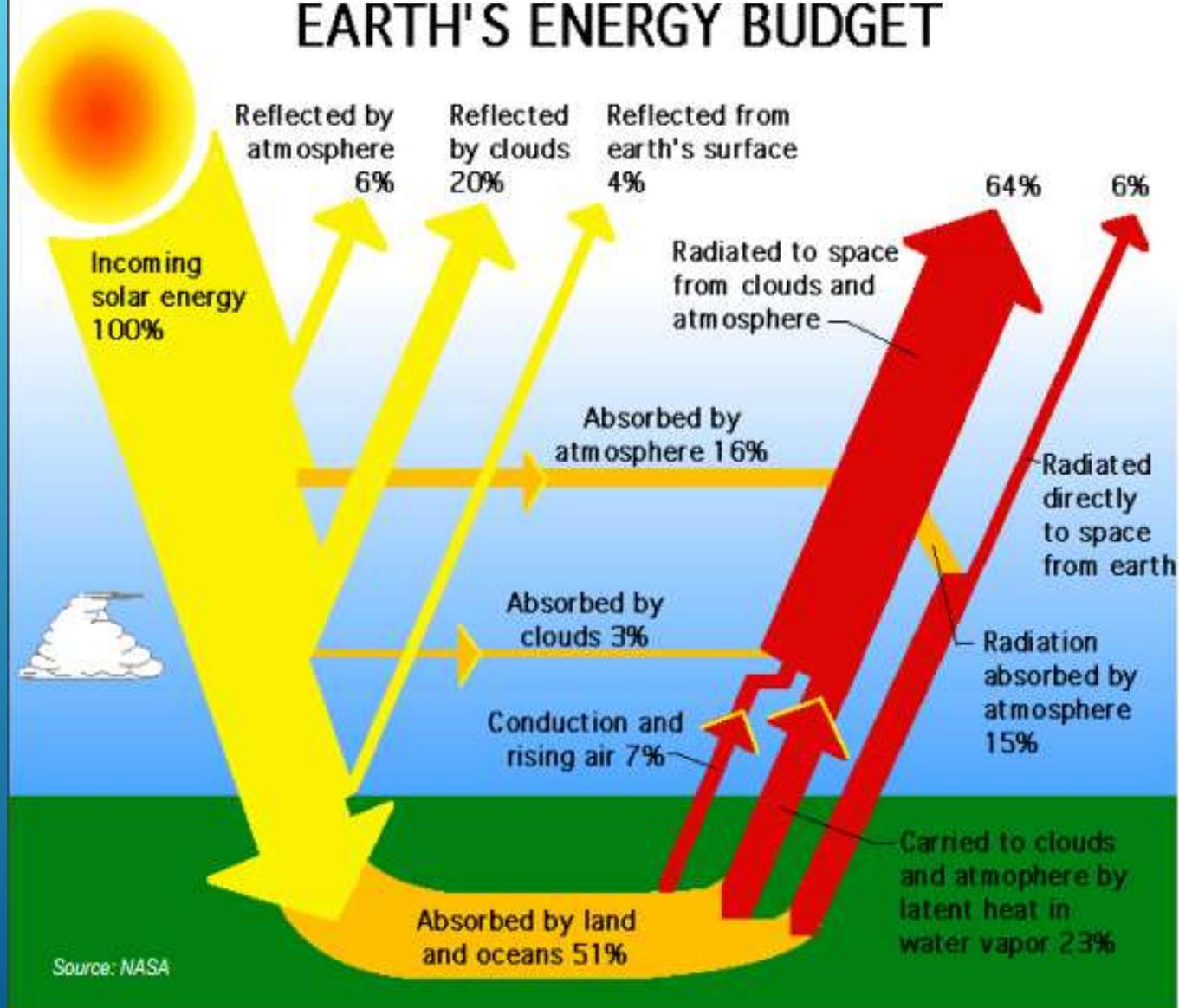
The Climate System: Heat Transfer

- There are constant heat exchanges occurring on the planet between the cold poles and the warm equatorial latitudes
- The earth receives energy from the sun equal to approximately 1360 W m^{-2} (as an annual average) and has an approximate albedo (reflectivity) of 0.3 . As such, without any atmosphere the average temperature of the earth would be approximately $-18 \text{ deg C}^{\circ}$
- There are two main systems by which temperatures are distributed around the planet which affect the weather:
 - The atmospheric air circulations
 - The oceanic currents
- The transfer of heat is derived from solar energy and from the motion of the earth around its axis
- The global temperature of the planet and how it is distributed has an important impact on the behaviour of the climate system
- Climate change is changing this temperature distribution which is expected to have major repercussions on our climate and weather system

The global energy balance is the balance between incoming energy from the sun and outgoing heat from the earth. The global energy balance regulates the state of the earth's climate and modifications to it, as a result of natural and manmade climate-forcing, is causing the global climate to change



EARTH'S ENERGY BUDGET



Water (H₂O) is stored in different phases on the planet and passes from one phase to another through a cycle referred to as the global water cycle:

There are 16 main elements of the water cycle:

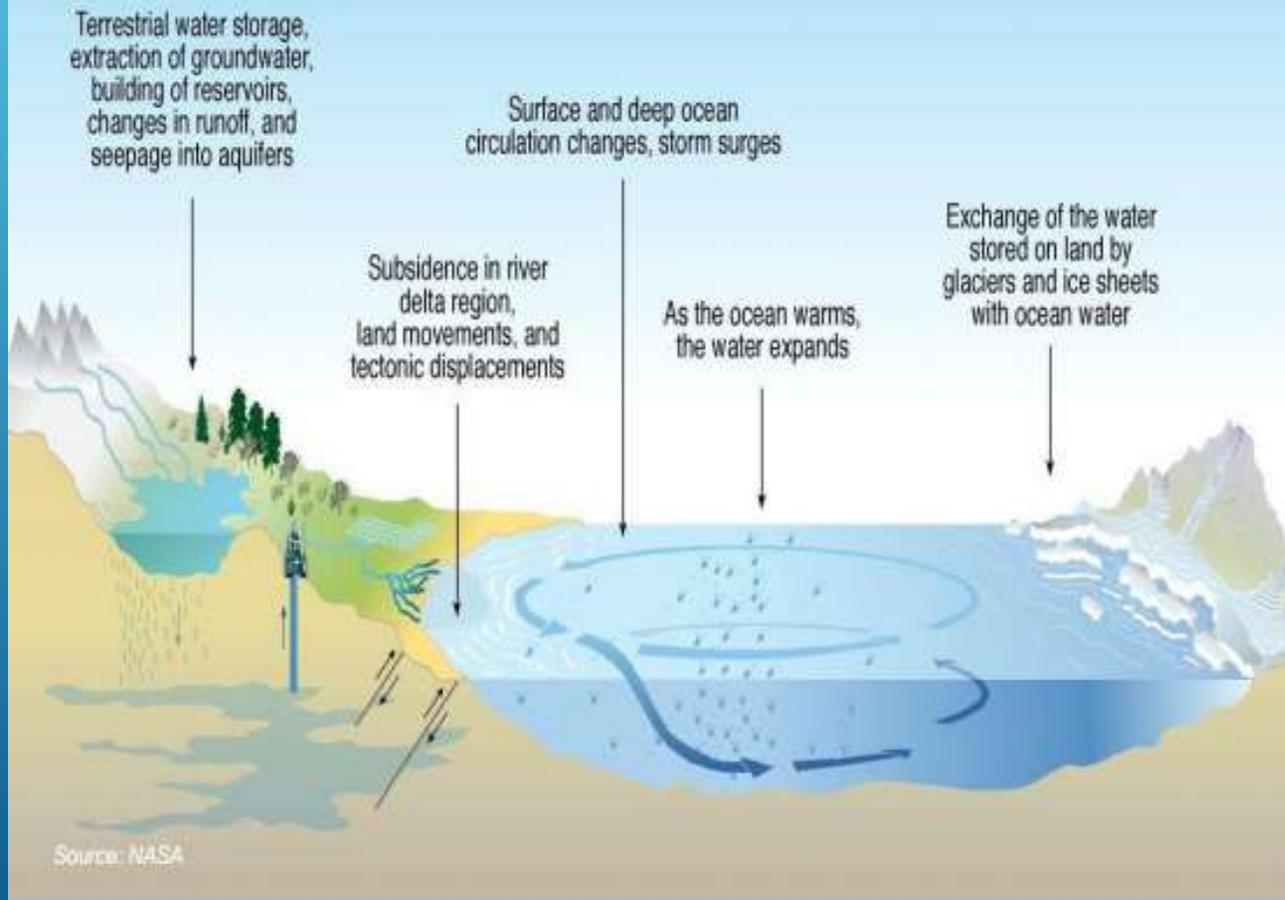
- ▶ • Water storage in oceans
- ▶ • Evaporation
- ▶ • Sublimation
- ▶ • Evapotranspiration
- ▶ • Water in the atmosphere
- ▶ • Condensation
- ▶ • Precipitation
- ▶ • Water storage in ice and snow
- ▶ • Snowmelt runoff to streams
- ▶ • Surface runoff
- ▶ • Streamflow
- ▶ • Freshwater storage
- ▶ • Infiltration
- ▶ • Ground-water storage
- ▶ • Ground-water discharge
- ▶ • Springs
- ▶ • Global water distribution

THE GLOBAL WATER CYCLE

- ▶ By modifying the water cycle, we are also impacting global levels.
- ▶ The main cause of level rise is due to thermal expansion of the water body as temperature rises.
- ▶ The second main cause of global sea level rise is ice melt from land ice
- ▶ There are also seasonal variations in sea level and during storm events as a result of change in atmospheric pressure

WHAT IS HAPPENING?

What causes the sea level to change?

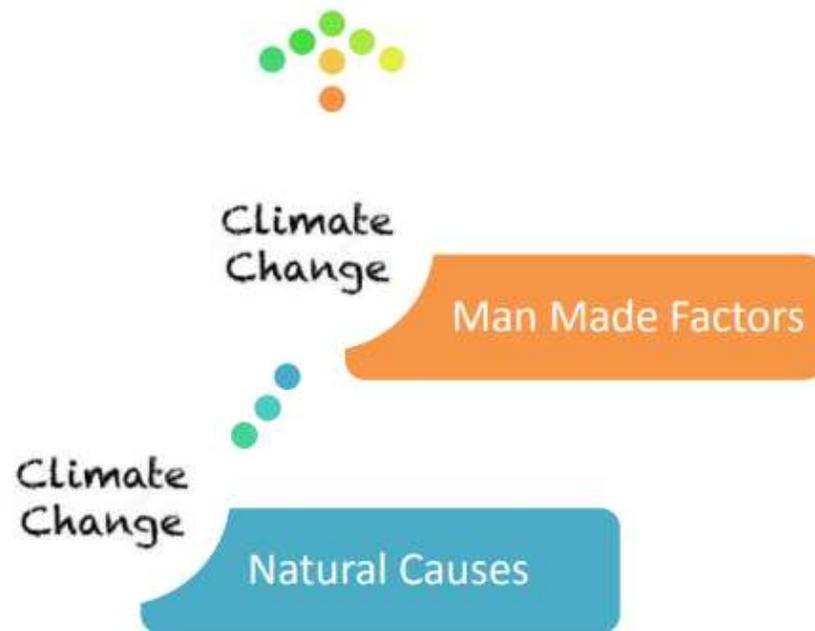


- ▶ Global sea level rose about 8 inches in the last century. The rate in the last two decades, however, is nearly double that of the last century.
- ▶ *Image: Republic of Maldives: Vulnerable to sea level rise*

REAL WORLD EXAMPLE...

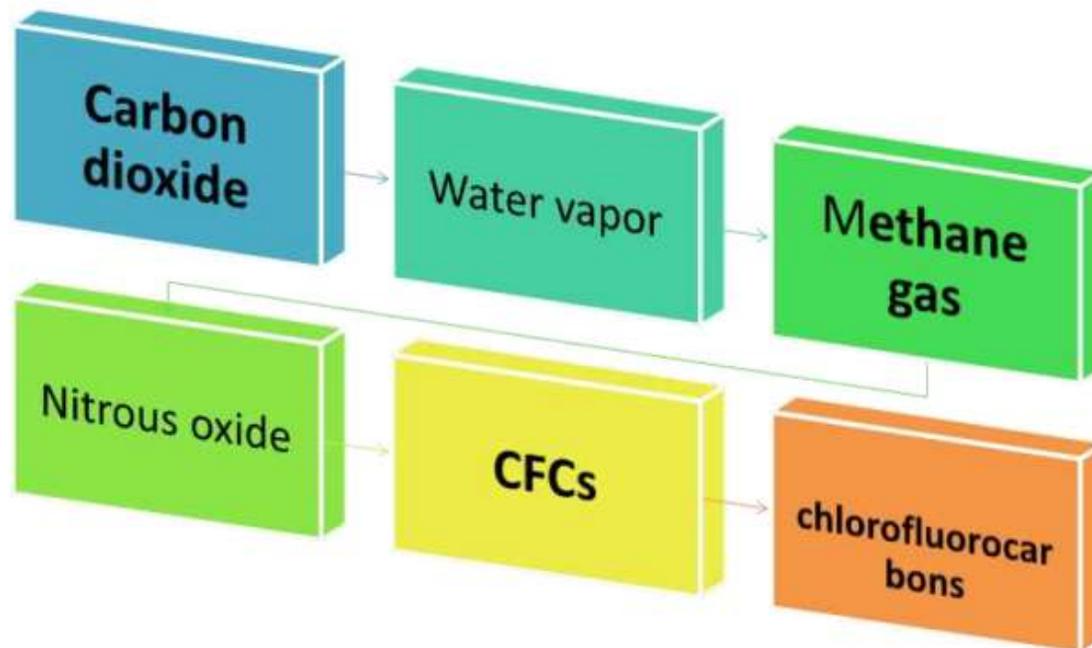


Causes of Climate Change

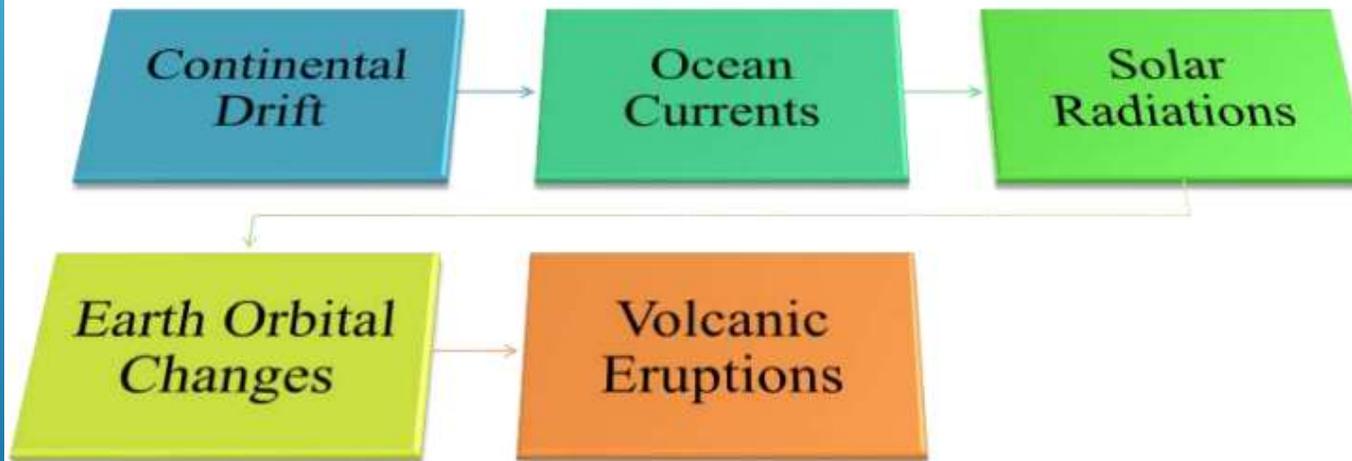


Man Made Factors of Climate Change

Greenhouse gases and their sources



Natural Causes of Climate Change

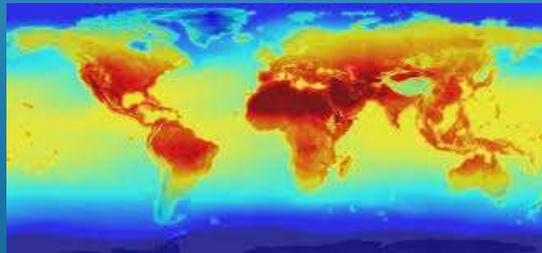


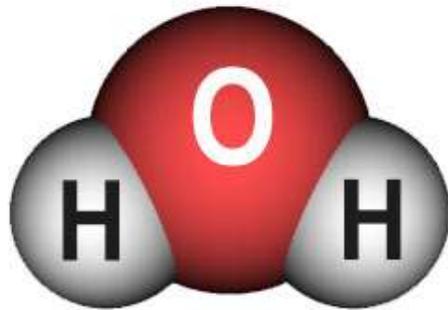
- ▶ Life on Earth depends on energy coming from the sun. About half the light reaching Earth's atmosphere passes through the air and clouds to the surface, where it is absorbed and then radiated upward in the form of infrared heat. About 90 percent of this heat is then absorbed by the greenhouse gases and radiated back toward the surface, which is warmed to a life-supporting average of 15 degrees Celsius (59 degrees Fahrenheit).

BASICALLY? WE LIVE IN A GREENHOUSE...



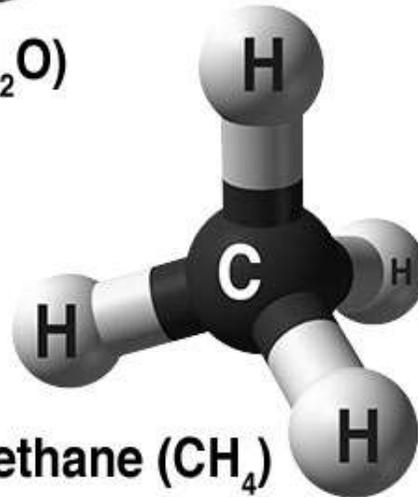
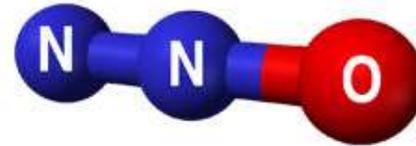
- ▶ Most climate scientists agree the main cause of the current global warming trend is human expansion of the "greenhouse effect"¹ — warming that results when the atmosphere traps heat radiating from Earth toward space.
- ▶ Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to changes in temperature are described as "forcing" climate change. Gases, such as water vapor, which respond physically or chemically to changes in temperature are seen as "feedbacks."
- ▶ Gases that contribute to the greenhouse effect include:



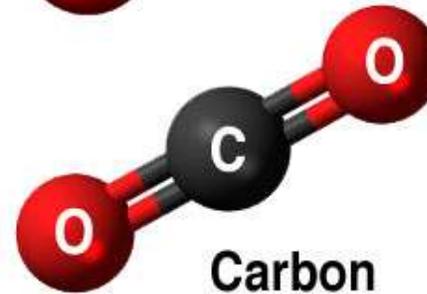


Water vapor (H_2O)

Nitrous oxide (N_2O)



Methane (CH_4)



Carbon dioxide (CO_2)

- ▶ Water vapor. The most abundant greenhouse gas, but importantly, it acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect.
- ▶ Carbon dioxide (CO₂). A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO₂ concentration by more than a third since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change.

GASES AFFECT US...

- ▶ Methane. A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule-for-molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere.
- ▶ Nitrous oxide. A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.
- ▶ Chlorofluorocarbons (CFCs). Synthetic compounds entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also greenhouse gases.

- ▶ On Earth, human activities are changing the natural greenhouse. Over the last century the burning of fossil fuels like coal and oil has increased the concentration of atmospheric carbon dioxide (CO₂). This happens because the coal or oil burning process combines carbon with oxygen in the air to make CO₂. To a lesser extent, the clearing of land for agriculture, industry, and other human activities has increased concentrations of greenhouse gases.
- ▶ The consequences of changing the natural atmospheric greenhouse are difficult to predict, but certain effects seem likely:
- ▶ On average, Earth will become warmer. Some regions may welcome warmer temperatures, but others may not.

HOT, HOT, HOT?

- ▶ The current warming trend is of particular significance because most of it is extremely likely (greater than 95 percent probability) to be the result of human activity since the mid-20th century and proceeding at a rate that is unprecedented over decades to millennia.
- ▶ Earth-orbiting satellites and other technological advances have enabled scientists to see the big picture, collecting many different types of information about our planet and its climate on a global scale. This body of data, collected over many years, reveals the signals of a changing climate.

TEMPERATURE CHANGE



- ▶ The heat-trapping nature of carbon dioxide and other gases was actually demonstrated in the mid-19th century. Their ability to affect the transfer of infrared energy through the atmosphere is the scientific basis of many instruments flown by NASA. There is no question that increased levels of greenhouse gases must cause the Earth to warm in response.
- ▶ Ice cores drawn from Greenland, Antarctica, and tropical mountain glaciers show that the Earth's climate responds to changes in greenhouse gas levels. Ancient evidence can also be found in tree rings, ocean sediments, coral reefs, and layers of sedimentary rocks. This ancient, or paleoclimate, evidence reveals that current warming is occurring roughly ten times faster than the average rate of ice-age-recovery warming.

THE EVIDENCE FOR RAPID CLIMATE
CHANGE IS COMPELLING...



- ▶ The planet's average surface temperature has risen about 1.1 degrees Celsius (2.0 degrees Fahrenheit) since the late 19th century, a change driven largely by increased carbon dioxide and other human-made emissions into the atmosphere.⁵ Most of the warming occurred in the past 35 years, with 16 of the 17 warmest years on record occurring since 2001. Not only was 2016 the warmest year on record, but eight of the 12 months that make up the year — from January through September, with the exception of June — were the warmest on record for those respective months.

IS IT ME OR IS IT HOT IN HERE?

- ▶ The Greenland and Antarctic ice sheets have decreased in mass. Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150 to 250 cubic kilometers (36 to 60 cubic miles) of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic kilometers (36 cubic miles) of ice between 2002 and 2005.
- ▶ *Image: Flowing meltwater from the Greenland ice sheet*

SHRINKING ICE SHEETS...



- ▶ Glaciers are retreating almost everywhere around the world — including in the Alps, Himalayas, Andes, Rockies, Alaska and Africa.
- ▶ *Image: The disappearing snowcap of Mount Kilimanjaro, from space.*

FROM NASA...



- ▶ Satellite observations reveal that the amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and that the snow is melting earlier



- ▶ Since the beginning of the Industrial Revolution, the acidity of surface ocean waters has increased by about 30 percent.
- ▶ This increase is the result of humans emitting more carbon dioxide into the atmosphere and hence more being absorbed into the oceans. The amount of carbon dioxide absorbed by the upper layer of the oceans is increasing by about 2 billion tons per year.

OCEAN ACIDIFICATION



- ▶ Global ice is melting...
- ▶ Both the extent and thickness of Arctic sea ice has declined rapidly over the last several decades...

[HTTPS://CLIMATE.NASA.GOV/INTERACTIVES/GLOBAL-ICE-VIEWER/#/](https://climate.nasa.gov/interactives/global-ice-viewer/#/)

- ▶ Is Solar irradiance the cause?
- ▶ It's reasonable to assume that changes in the sun's energy output would cause the climate to change, since the sun is the fundamental source of energy that drives our climate system.
- ▶ Indeed, studies show that solar variability has played a role in past climate changes. For example, a decrease in solar activity is thought to have triggered the Little Ice Age between approximately 1650 and 1850, when Greenland was largely cut off by ice from 1410 to the 1720s and glaciers advanced in the Alps.
- ▶ But several lines of evidence show that current global warming cannot be explained by changes in energy from the sun:
- ▶ Since 1750, the average amount of energy coming from the sun either remained constant or increased slightly.
- ▶ If the warming were caused by a more active sun, then scientists would expect to see warmer temperatures in all layers of the atmosphere. Instead, they have observed a cooling in the upper atmosphere, and a warming at the surface and in the lower parts of the atmosphere. That's because greenhouse gases are trapping heat in the lower atmosphere.
- ▶ Climate models that include solar irradiance changes can't reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.

YOU ARE MY SUNSHINE...



- ▶ **Not enough greenhouse effect:** The planet Mars has a very thin atmosphere, nearly all carbon dioxide. Because of the low atmospheric pressure, and with little to no methane or water vapor to reinforce the weak greenhouse effect, Mars has a largely frozen surface that shows no evidence of life.



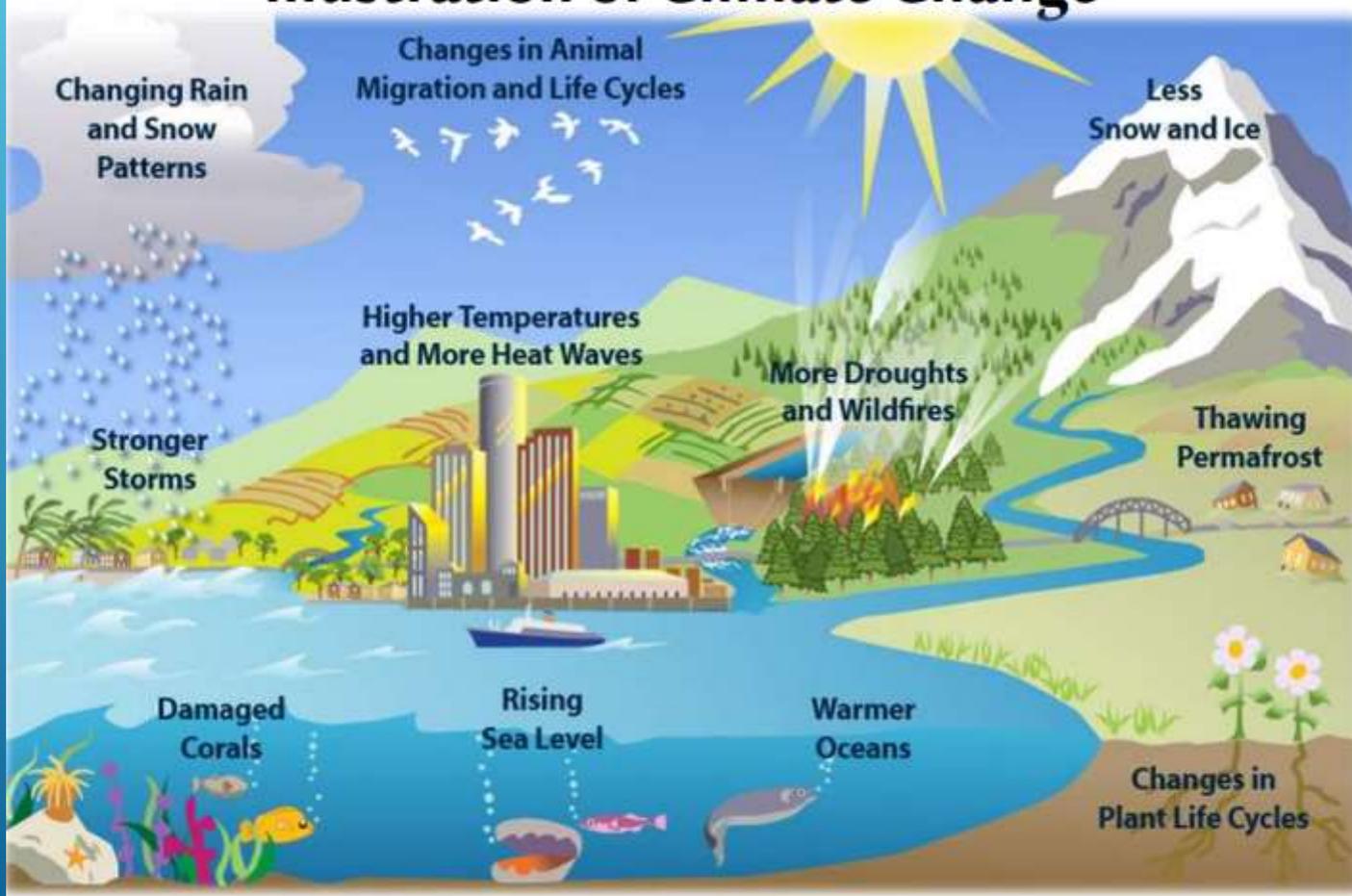
MARS...

- ▶ Too much greenhouse effect: The atmosphere of Venus, like Mars, is nearly all carbon dioxide. But Venus has about 154,000 times as much carbon dioxide in its atmosphere as Earth (and about 19,000 times as much as Mars does), producing a runaway greenhouse effect and a surface temperature hot enough to melt lead.

VENUS...



Illustration of Climate Change



- ▶ In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change, a group of 1,300 independent scientific experts from countries all over the world under the auspices of the United Nations, concluded there's a more than 95 percent probability that human activities over the past 50 years have warmed our planet.
- ▶ The industrial activities that our modern civilization depends upon have raised atmospheric carbon dioxide levels from 280 parts per million to 400 parts per million in the last 150 years. The panel also concluded there's a better than 95 percent probability that human-produced greenhouse gases such as carbon dioxide, methane and nitrous oxide have caused much of the observed increase in Earth's temperatures over the past 50 years.

THE ROLE OF HUMAN ACTIVITY



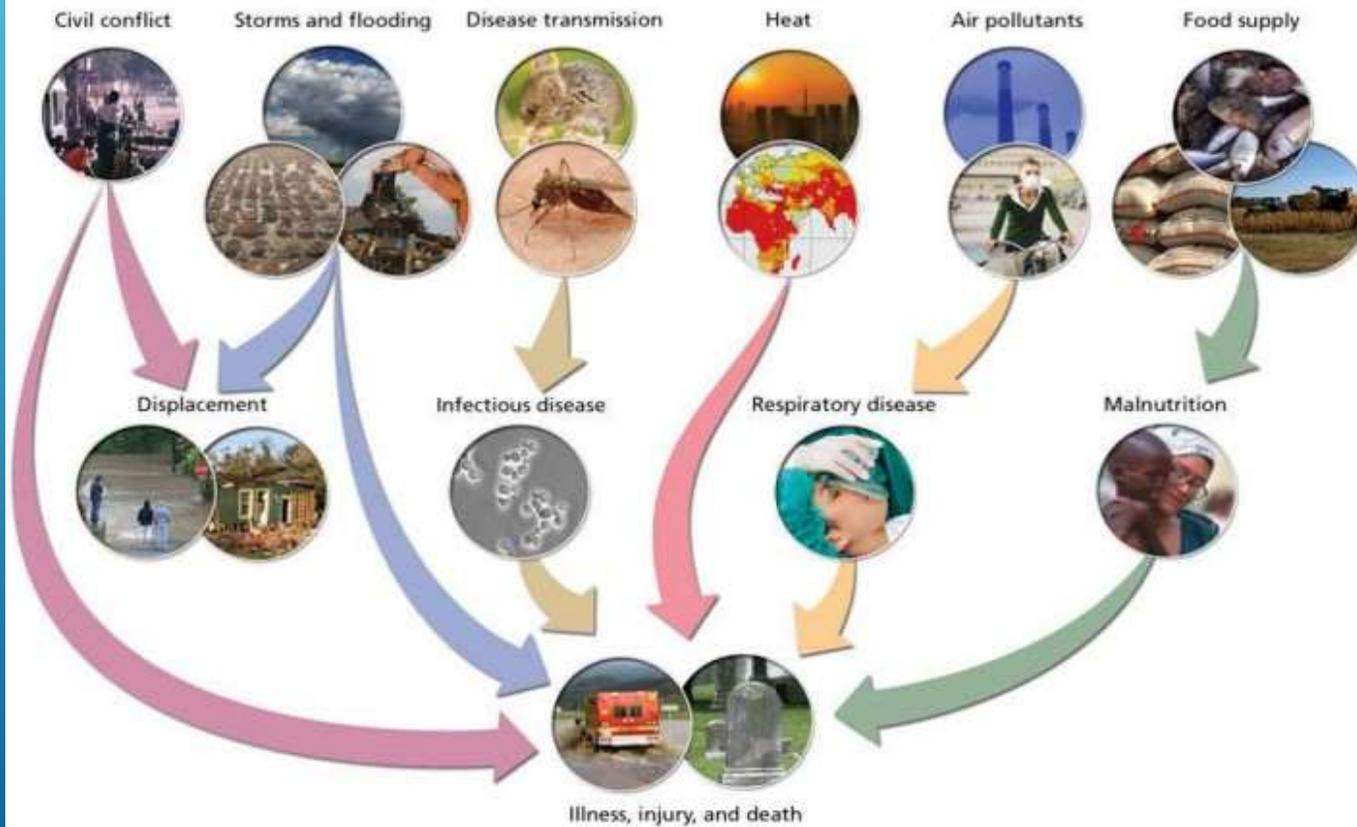
THE CONSEQUENCES OF CLIMATE CHANGE...



▶ Taken as a whole, the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time.

- INTERGOVERNMENTAL PANEL ON
CLIMATE CHANGE

Health related challenges



- ▶ Floods
- ▶ Cyclones and Storm Surges and Hurricanes will become stronger and more intense
- ▶ Salinity Intrusion
- ▶ Extreme Temperature and Drought
- ▶ Changes in precipitation patterns
- ▶ The Arctic Ocean is expected to become essentially ice free in summer before mid-century.
- ▶ Habitat loss for wildlife
- ▶ Declining plant productivity
- ▶ Food security
- ▶ Habitable land for both humans and all life forms
- ▶ Frost-free season (and growing season) will lengthen
- ▶ Land loss (coastal deterioration) as sea level will rise 1-4 feet by 2100

EFFECTS?

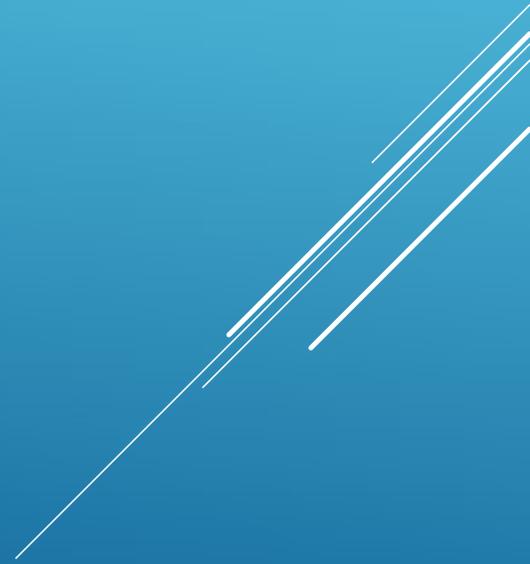
▶ <https://climate.nasa.gov/interactives/climate-time-machine>

▶ <https://climate.nasa.gov/interactives/climate-time-machine>

SOME ANIMATIONS/VISUALIZATIONS...

A decorative graphic consisting of several parallel white lines of varying lengths, slanted diagonally from the bottom right towards the top right, set against the blue background.

DISCUSS!



References

- ▶ Nasa
- ▶ Gabriele C. Hegerl, "Detecting Greenhouse-Gas-Induced Climate Change with an Optimal Fingerprint Method," *Journal of Climate*, v. 9, October 1996, 2281-2306
- ▶ V. Ramaswamy et.al., "Anthropogenic and Natural Influences in the Evolution of Lower Stratospheric Cooling," *Science* 311 (24 February 2006), 1138-1141
- ▶ B.D. Santer et.al., "Contributions of Anthropogenic and Natural Forcing to Recent Tropopause Height Changes," *Science* vol. 301 (25 July 2003), 479-483.
- ▶ In the 1860s, physicist John Tyndall recognized the Earth's natural greenhouse effect and suggested that slight changes in the atmospheric composition could bring about climatic variations. In 1896, a seminal paper by Swedish scientist Svante Arrhenius first predicted that changes in the levels of carbon dioxide in the atmosphere could substantially alter the surface temperature through the greenhouse effect.
- ▶ National Research Council (NRC), 2006. *Surface Temperature Reconstructions For the Last 2,000 Years*. National Academy Press, Washington, D.C.
- ▶ <http://earthobservatory.nasa.gov/Features/GlobalWarming/page3.php>
- ▶ R. Kwok and D. A. Rothrock, "Decline in Arctic sea ice thickness from submarine and ICESAT records: 1958-2008," *Geophysical Research Letters*, v. 36, paper no. L15501, 2009