



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Dr Alissa Flatley
ACNA4007 – Physical Landscape and the Geosphere



Weather and Climate

Wonderful weather...



You don't
have to work
in weather
and climate
to use...
weather and
climate



Weather versus Climate

WEATHER

Tells you what to wear each day



CLIMATE

Tells you what types of clothes to have in your closet



Earth's Climate

- ... is the general weather over a long period, including rainfall, temperature, snow or any other weather condition (MetOffice, 2023)

- We usually define a region's climate over 30 years

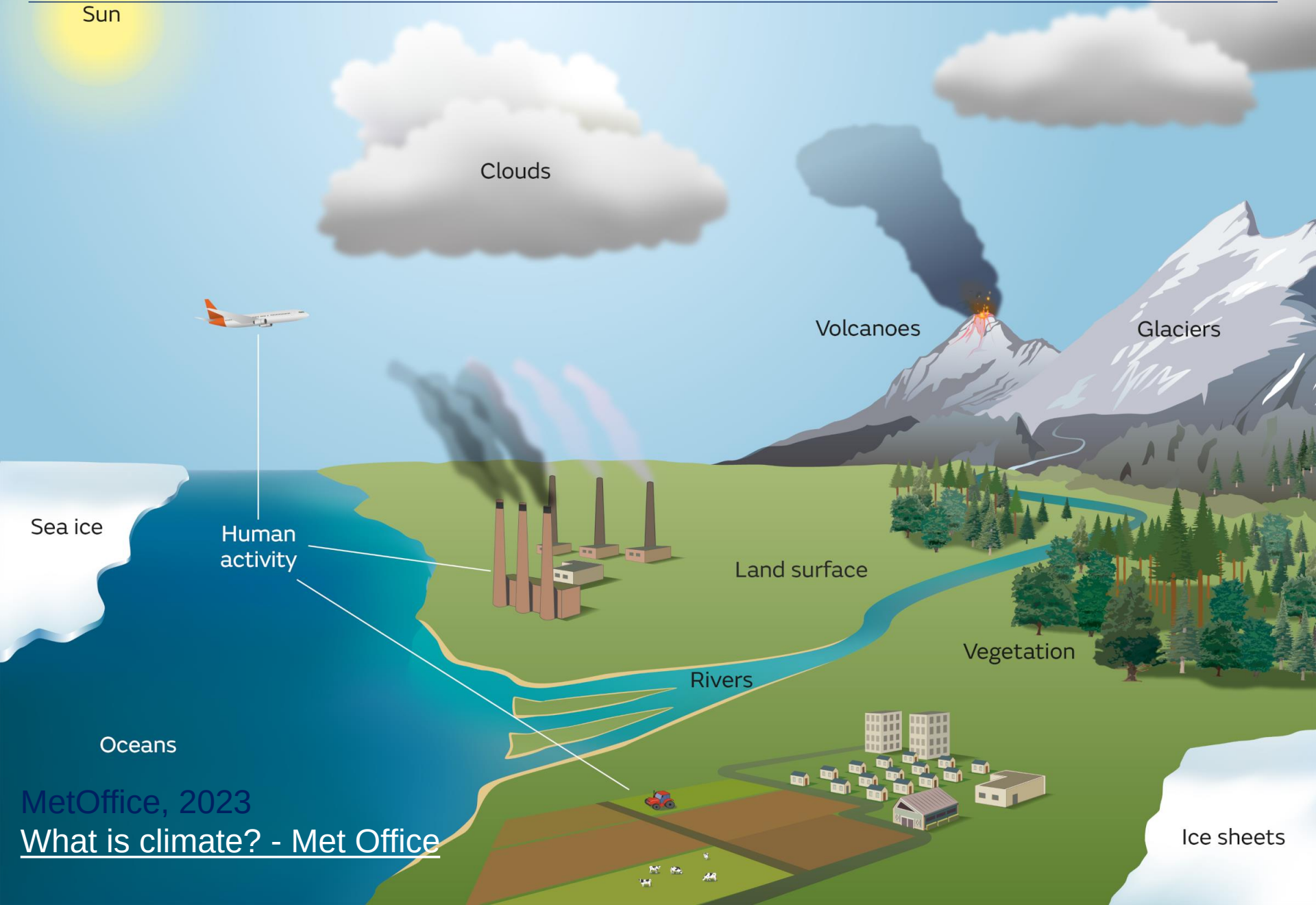
- The Earth's climate has many components

- In the (recent) past, glaciers have covered more than one third of Earth's surface...

... providing invaluable information about past climates

<https://www.youtube.com/watch?v=C3Jwnp-Z3yE>

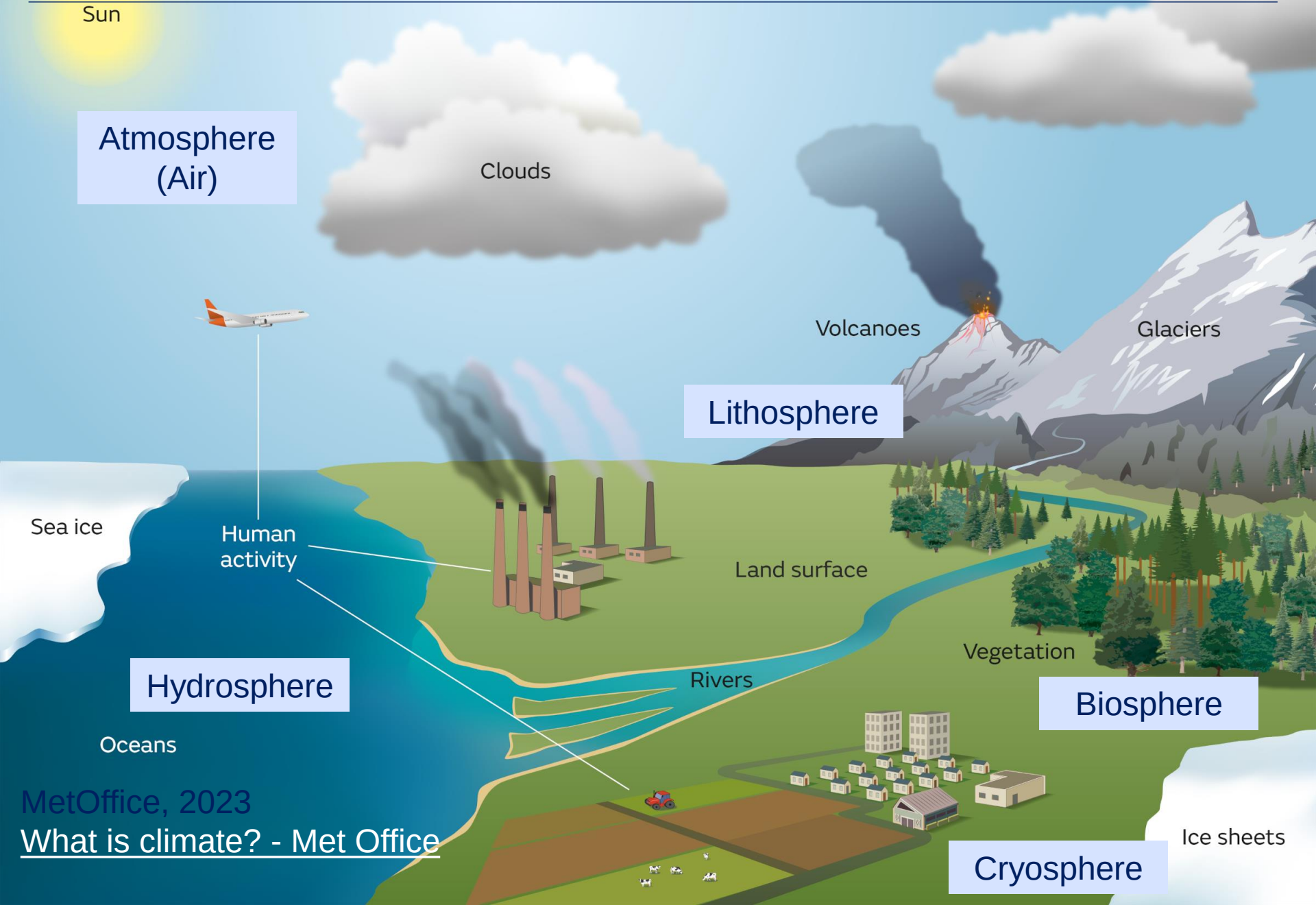
Components of the climate system



MetOffice, 2023

What is climate? - Met Office

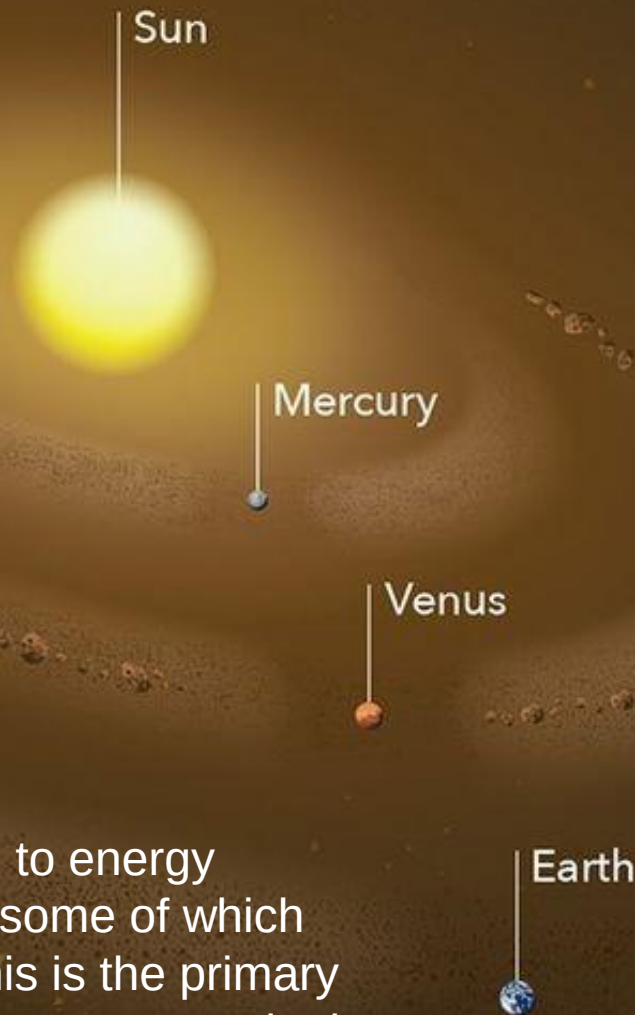
Components of the climate system



MetOffice, 2023

What is climate? - Met Office

Solar radiation



Solar radiation refers to energy produced by the Sun, some of which reaches the Earth. This is the primary energy source for most processes in the atmosphere, hydrosphere, and biosphere.

Interactions of solar radiation

Garrison,
Oceanography

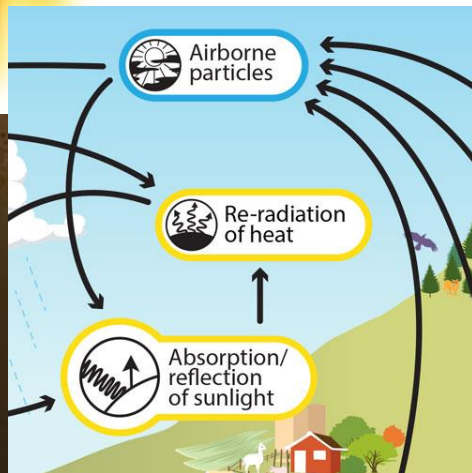
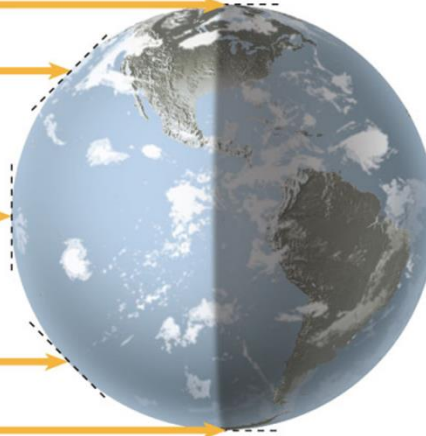
This ray strikes parallel to surface.

Rays strike surface at angle.

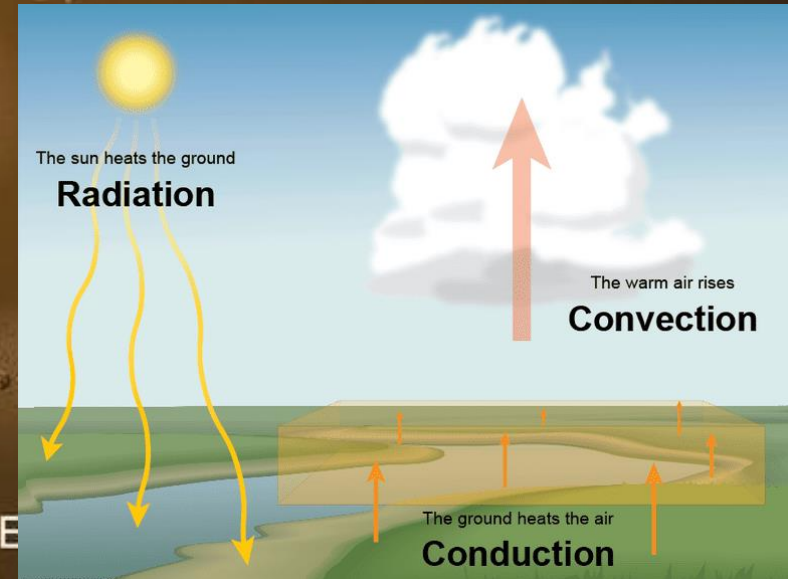
This ray strikes perpendicular to surface.

Ray strikes surface at angle.

This ray strikes parallel to surface.



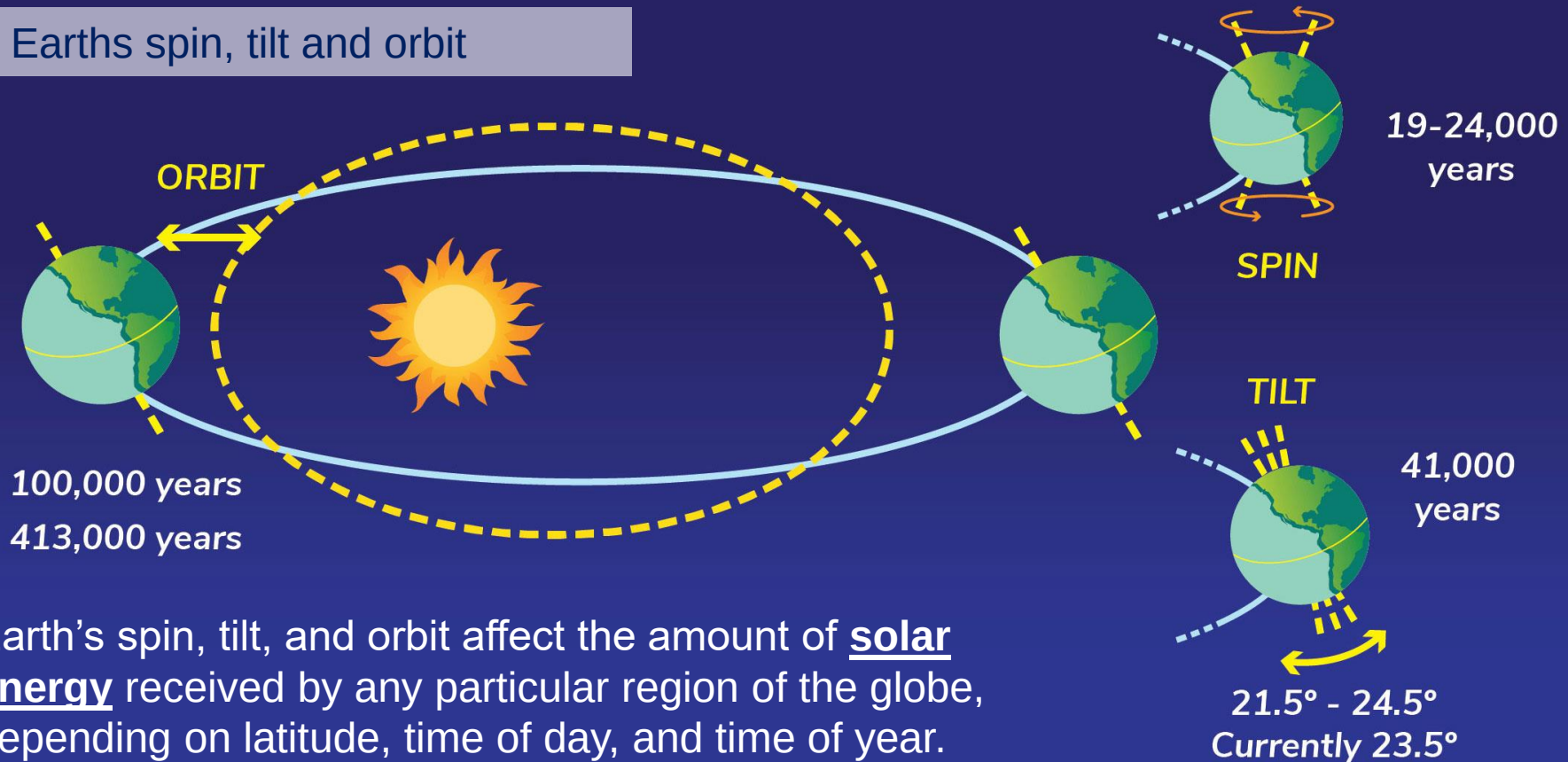
- The Earth's climate system depends entirely on the Sun for its energy. Solar radiation warms the atmosphere and is fundamental to atmospheric composition.



- The distribution of solar heating across the planet produces global wind patterns and contributes to the formation of clouds, storms, and rainfall

Earth's spin, tilt and orbit

- Earth's spin, tilt and orbit



- Earth's spin, tilt, and orbit affect the amount of solar energy received by any particular region of the globe, depending on latitude, time of day, and time of year.

- Small changes in the angle of Earth's tilt and the shape of its orbit around the Sun cause changes in climate over a span of 10,000 to 100,000 years, and are not causing climate change today.

Milankovich Cycles

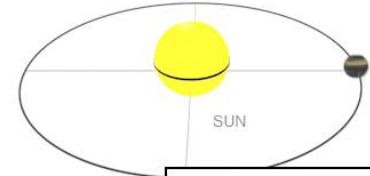
Milankovitch cycles provide a strong framework for understanding **long-term** changes in Earth's climate, including the beginning and end of Ice Ages throughout Earth's history.

[Milankovitch \(Orbital\) Cycles and Their Role in Earth's Climate – Climate Change: Vital Signs of the Planet \(nasa.gov\)](https://climate.nasa.gov/milankovitch-cycles)

[Milutin Milankovitch \(nasa.gov\)](https://climate.nasa.gov/milankovitch-cycles)

Orbital Cycles

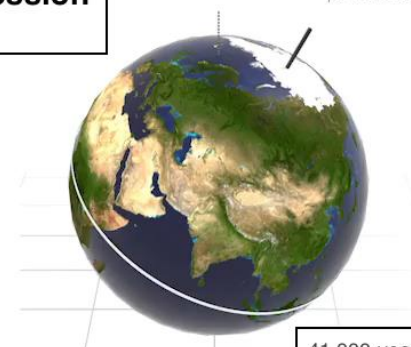
Three periodic motions in Earth's orbit, known as Milankovitch cycles, contribute a predictable amount of variation to Earth's climate over time frames of tens of thousands to hundreds of thousands of years.



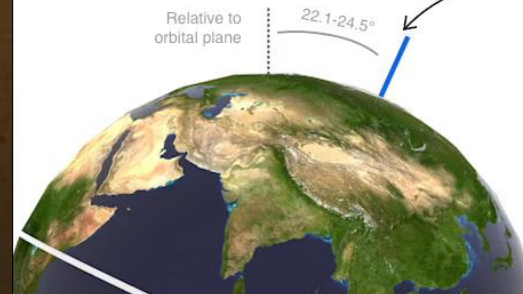
100,000-year cycles
Changes in Eccentricity
(Orbit Shape)

*Changes in eccentricity exaggerated so the effect can be seen. Earth's orbit shape varies between 0.0034 (almost a perfect circle) to 0.058 (slightly elliptical).

26,000-year cycles
Axial Precession
(Wobble)



41,000-year cycles
Changes in Obliquity
(Tilt)



climate.nasa.gov

Structure of the atmosphere

Thermosphere 53–375 Miles

In the thermosphere, molecules of oxygen and nitrogen are bombarded by radiation and energetic particles from the Sun, causing the molecules to split into their component atoms and creating heat. The thermosphere increases in temperature with altitude because the atomic oxygen and nitrogen cannot radiate the heat from this absorption.

HUBBLE SPACE TELESCOPE
370 Miles

WEATHER SATELLITES
250 Miles

INTERNATIONAL SPACE
STATION
250 Miles

Mesosphere 31–53 Miles

Studying the mesosphere is essential to understanding long-term changes in the Earth's atmosphere and how these changes affect climate. Since the mesosphere is responsive to small changes in atmospheric chemistry and composition, it could provide clues for scientists, such as how added greenhouse gases may contribute to a change in temperature or water composition in the atmosphere.

SOUNDING ROCKET
50–1,500 Miles

BARREL, NASA
SUPER-PRESSURE BALLOON
20.8 Miles

Stratosphere 10–31 Miles

The ozone layer lies within the stratosphere and absorbs ultraviolet radiation from the Sun.

Troposphere 0–10 Miles

The troposphere is the layer of the Earth's atmosphere where all human activity takes place.

Thermosphere 53–375 Miles

In the thermosphere, molecules of oxygen and nitrogen are bombarded by radiation and energetic particles from the Sun, causing the molecules to split into their component atoms and creating heat. The thermosphere increases in temperature with altitude because the atomic oxygen and nitrogen cannot radiate the heat from this absorption.

Mesosphere 31–53 Miles

Studying the mesosphere is essential to understanding long-term changes in the Earth's atmosphere and how these changes affect climate. Since the mesosphere is responsive to small changes in atmospheric chemistry and composition, it could provide clues for scientists, such as how added greenhouse gases may contribute to a change in temperature or water composition in the atmosphere.

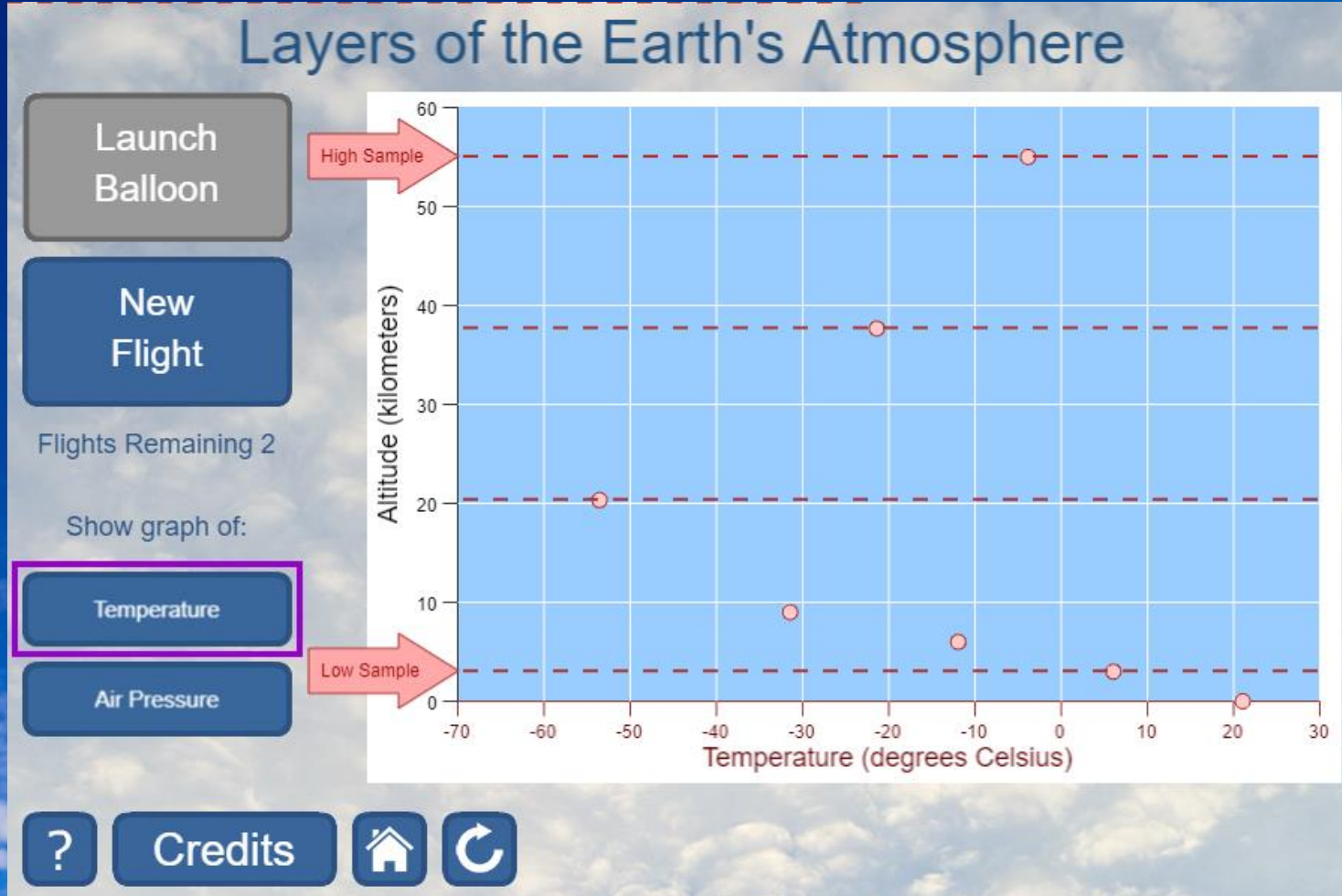
Stratosphere 10–31 Miles

The ozone layer lies within the stratosphere and absorbs ultraviolet radiation from the Sun.

Troposphere 0–10 Miles

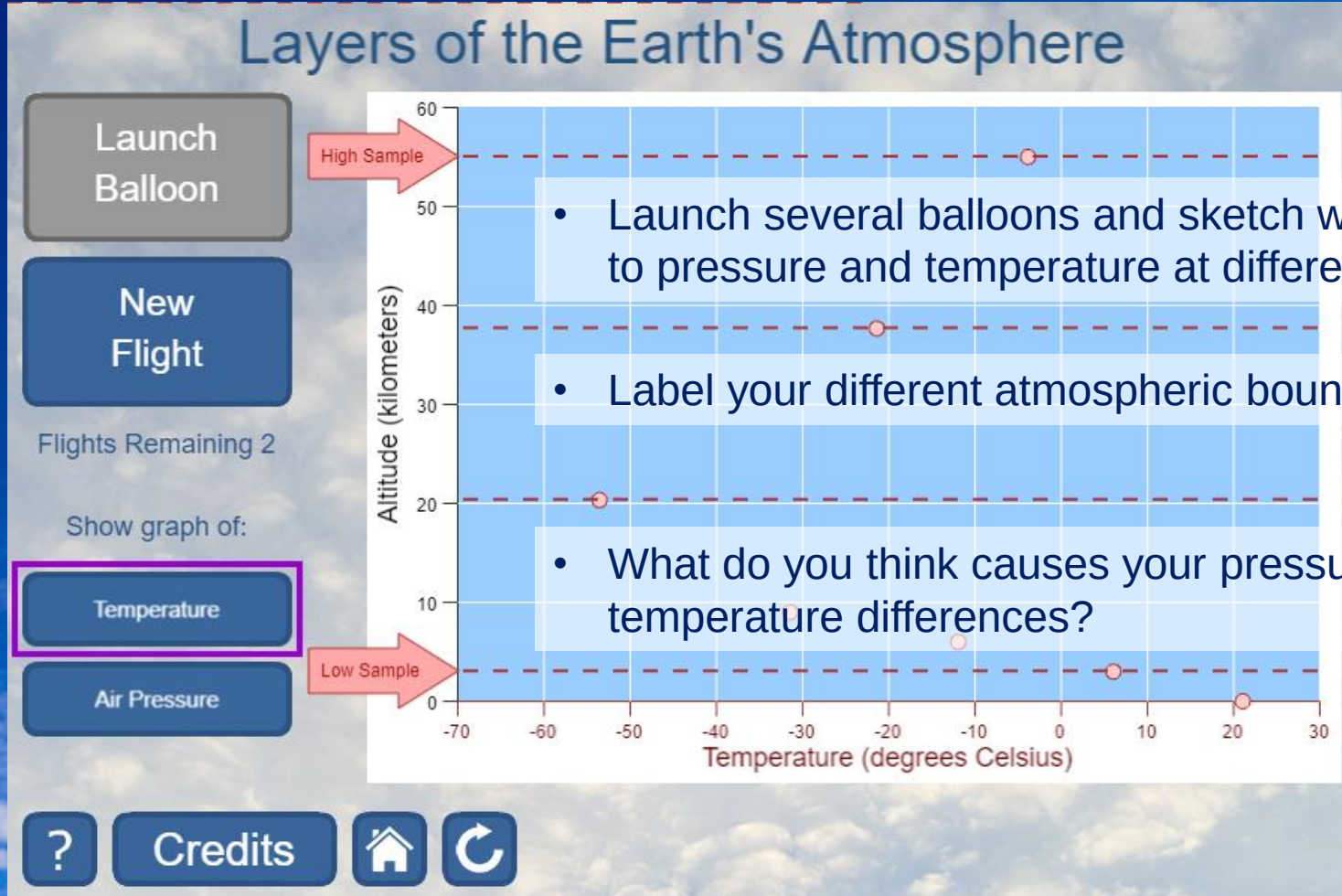
The troposphere is the layer of the Earth's atmosphere where all human activity takes place.

Weather balloons



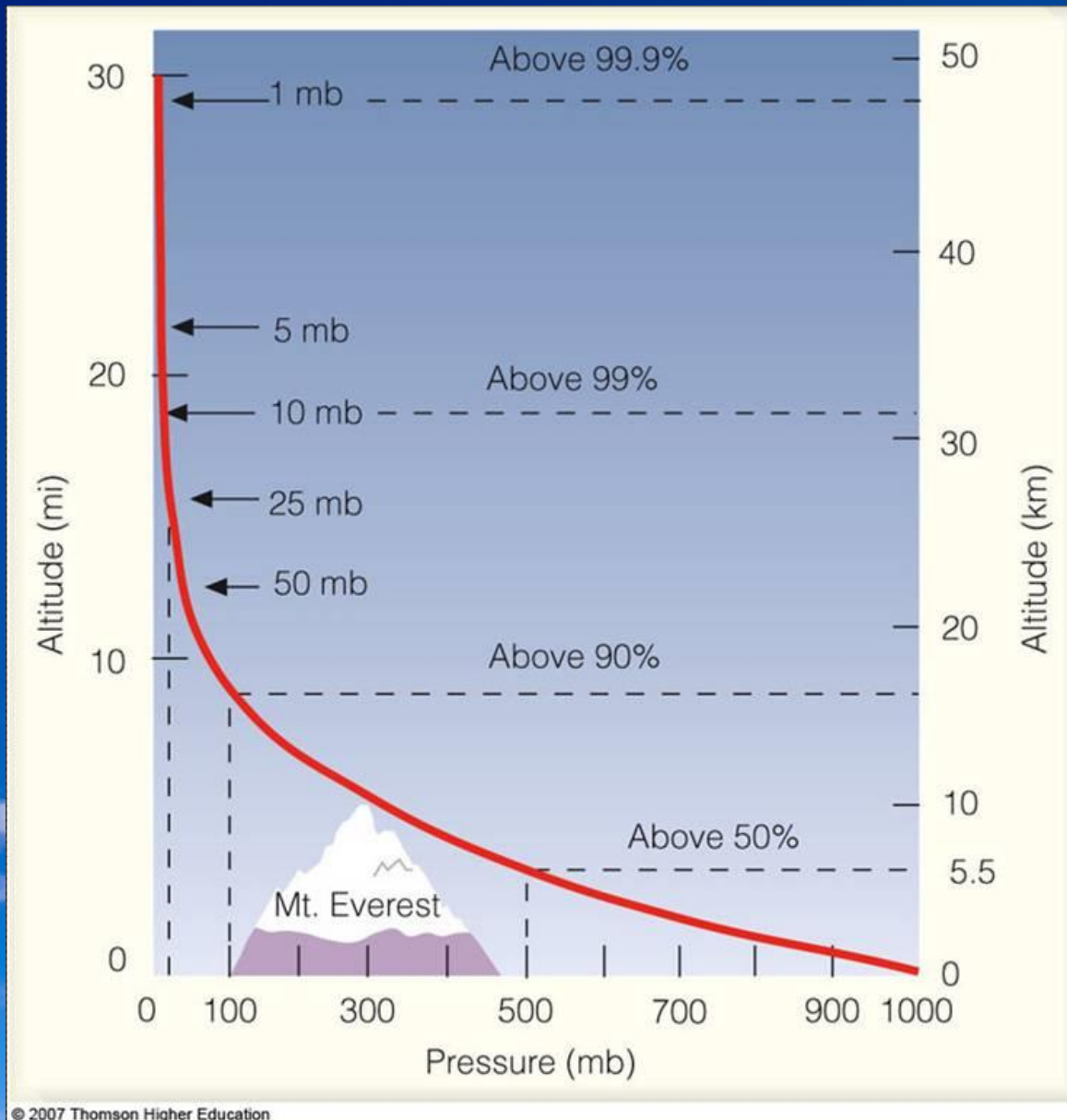
- Virtual Ballooning: [Virtual Ballooning to Explore the Atmosphere | Center for Science Education \(ucar.edu\)](https://www.ucar.edu/virtual-ballooning)

Weather balloons



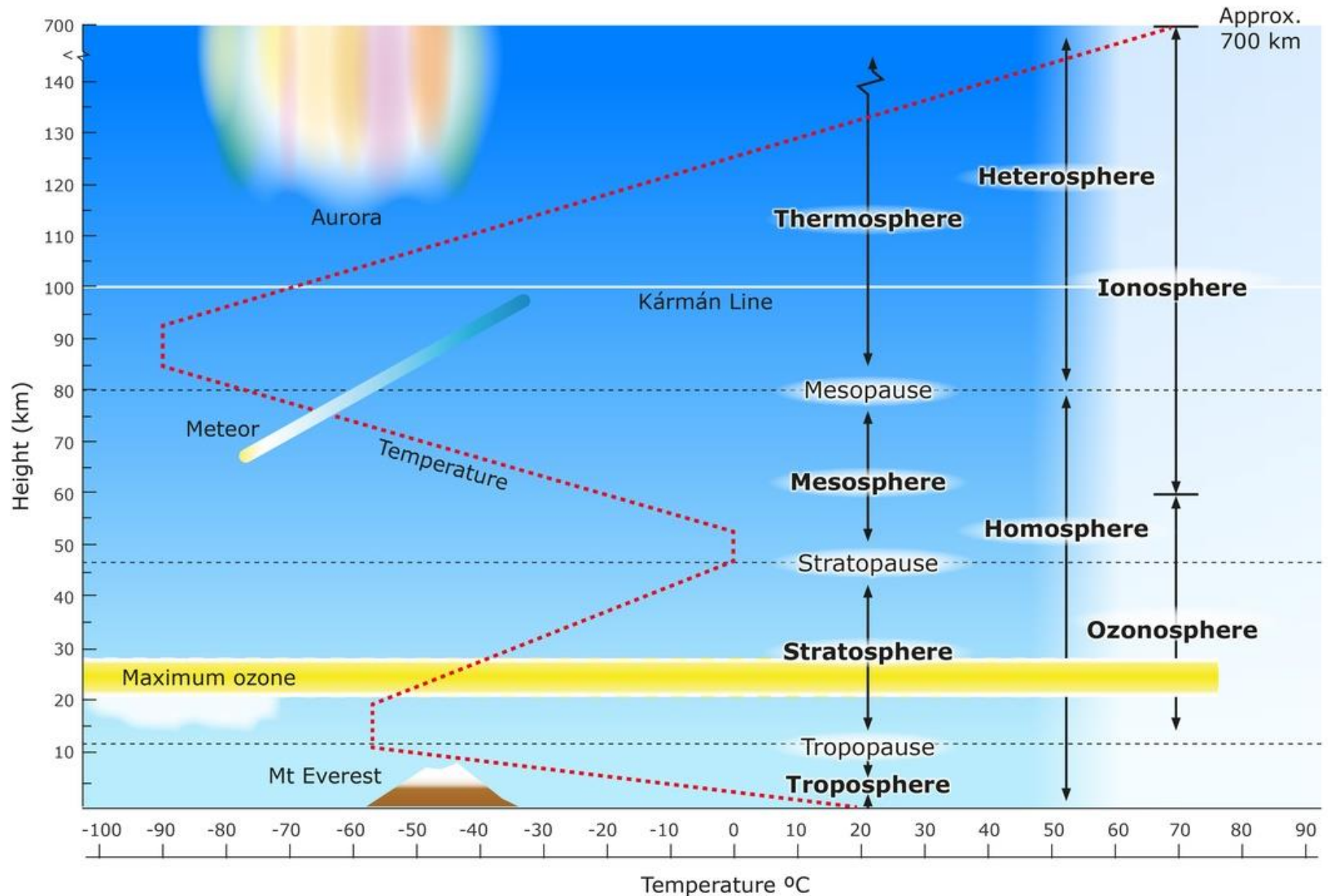
- Virtual Ballooning: [Virtual Ballooning to Explore the Atmosphere | Center for Science Education \(ucar.edu\)](https://www.ucar.edu/virtual-ballooning)

Vertical structure of the atmosphere

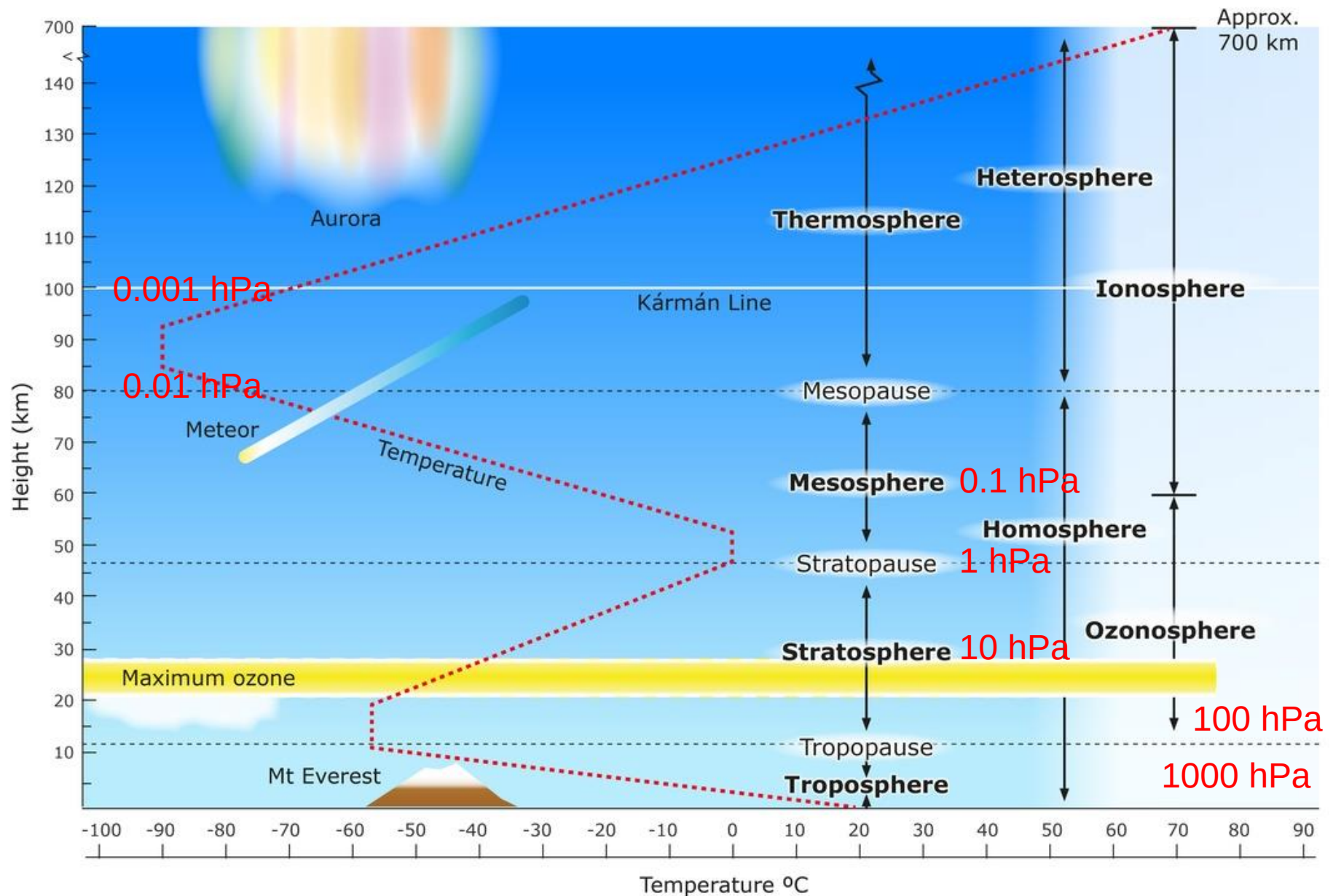


- Can also be expressed as pressure (mb)

Vertical structure of the atmosphere



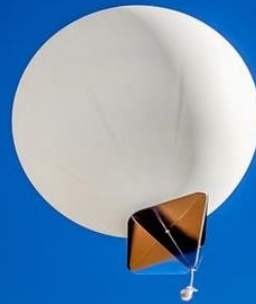
Vertical structure of the atmosphere



Stratosphere

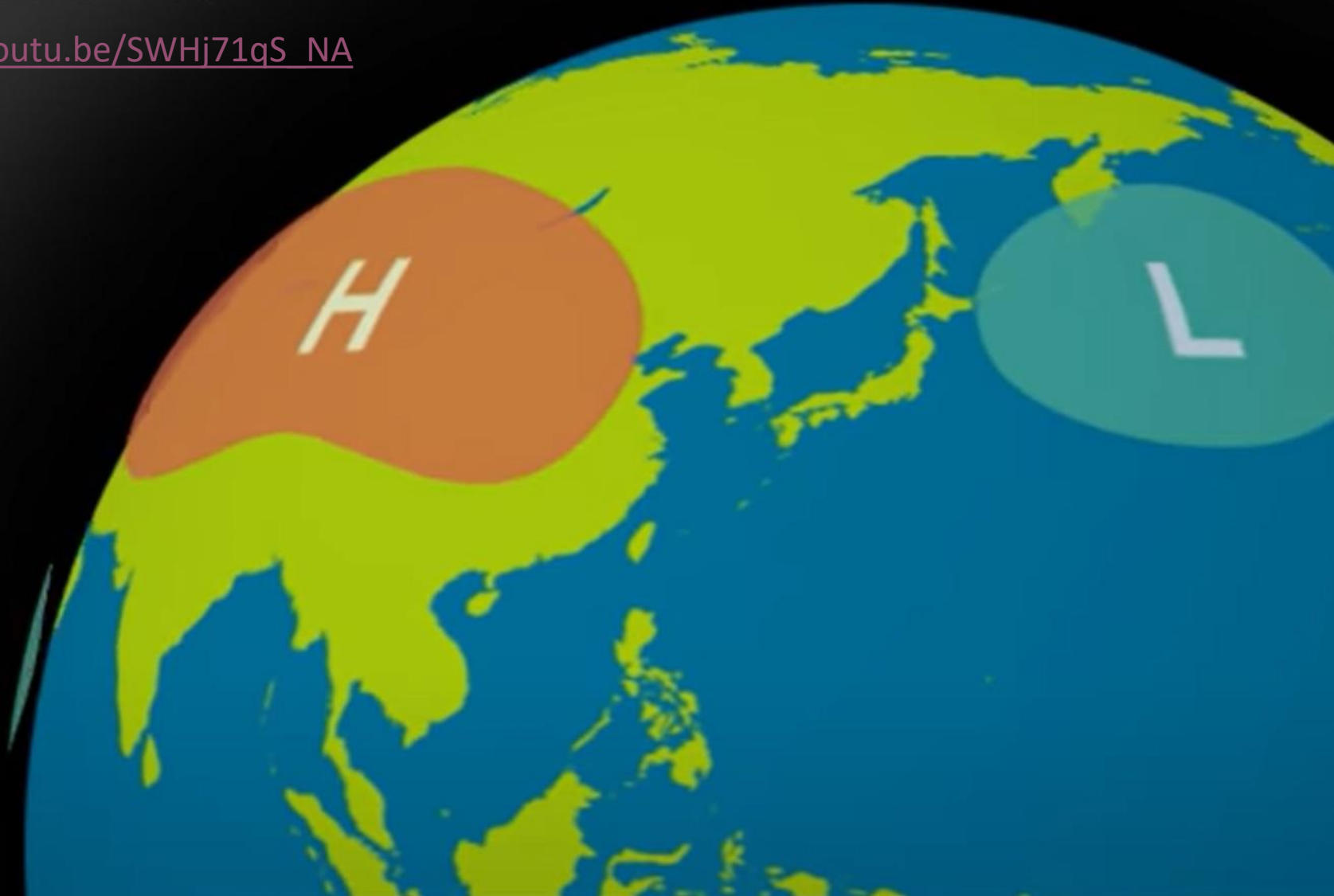
The Stratosphere

This extends upwards from the tropopause to about 50 km. It contains much of the ozone in the atmosphere. The increase in temperature with height occurs because of **absorption of ultraviolet (UV) radiation from the sun by this ozone**.



Temperatures in the stratosphere are highest over the summer pole, and lowest over the winter pole. By absorbing dangerous UV radiation, the ozone in the stratosphere protects us from skin cancer and other health damage.

https://youtu.be/SWHj71qS_NA



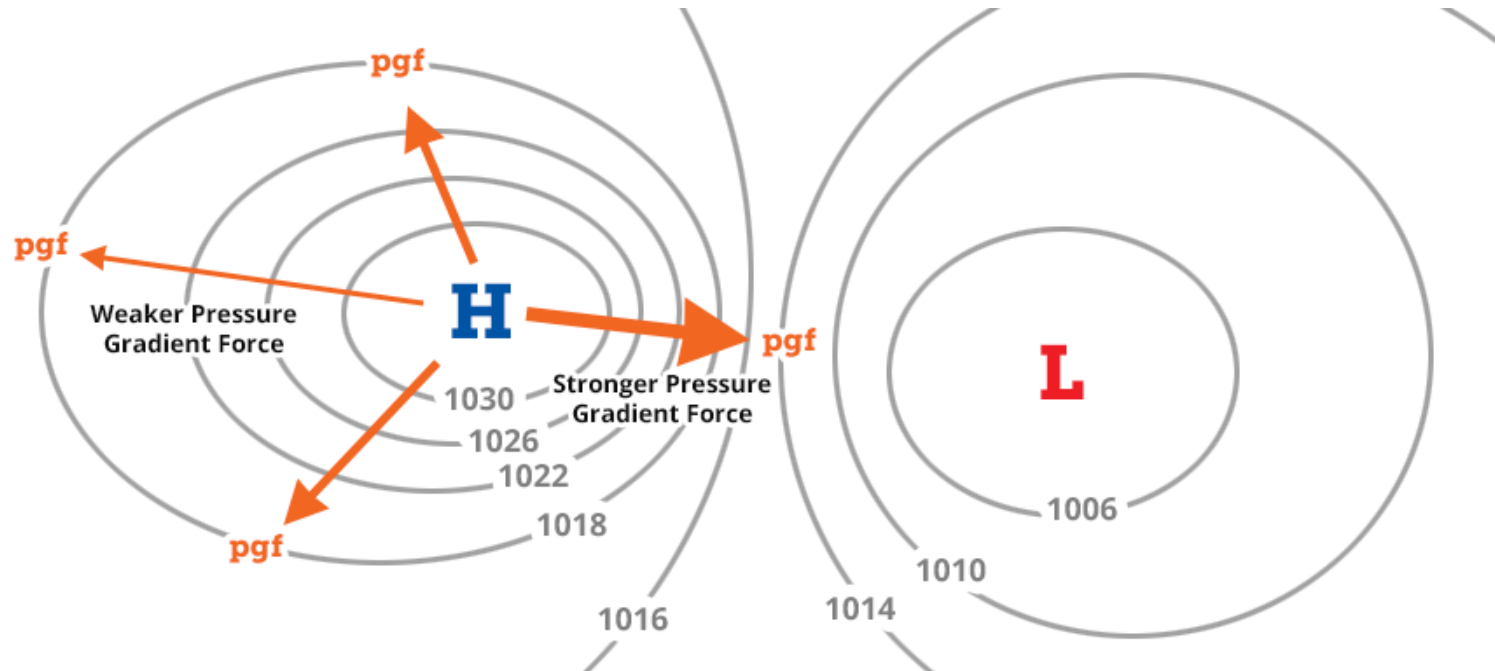
- There are also differences in pressure on the earth's surface caused by ascending and descending air parcels.

Pressure Gradient Force

Atmospheric pressure by itself is not a force. However, the difference between atmospheric pressures of different air masses does create a force.

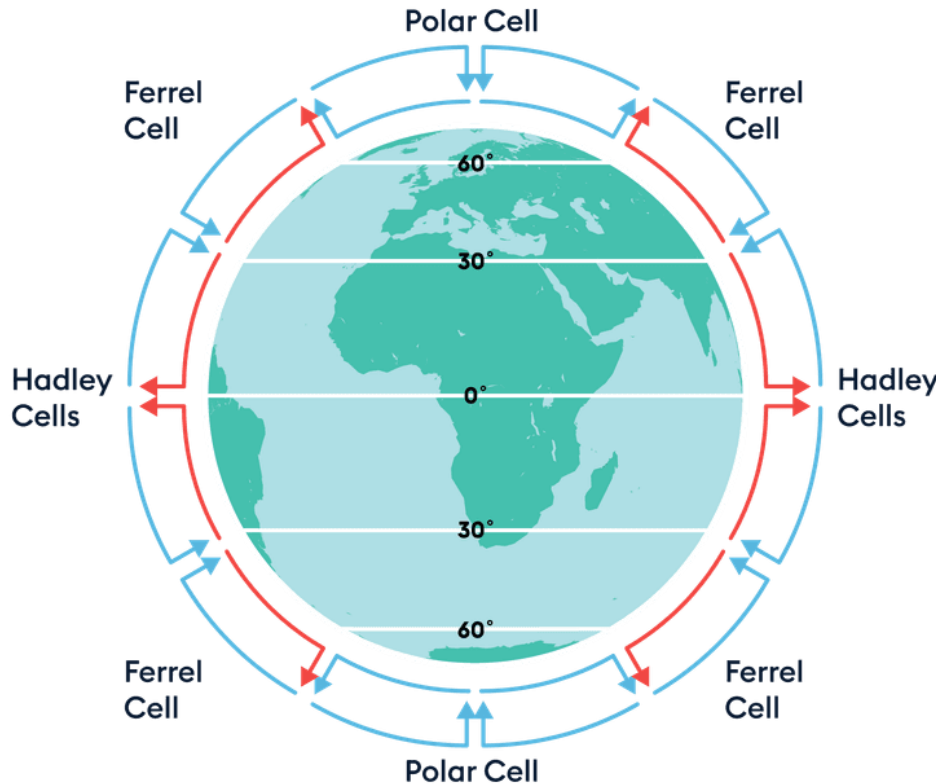
Pressure Gradient Force

This **pressure gradient force** (pgf) is the rate of change of *pressure* over a given distance.



The force acts from areas of high *pressure* to low *pressure*. If no other forces act upon an *air parcel*, it would move toward the lower *pressure*.

High and Low Pressure

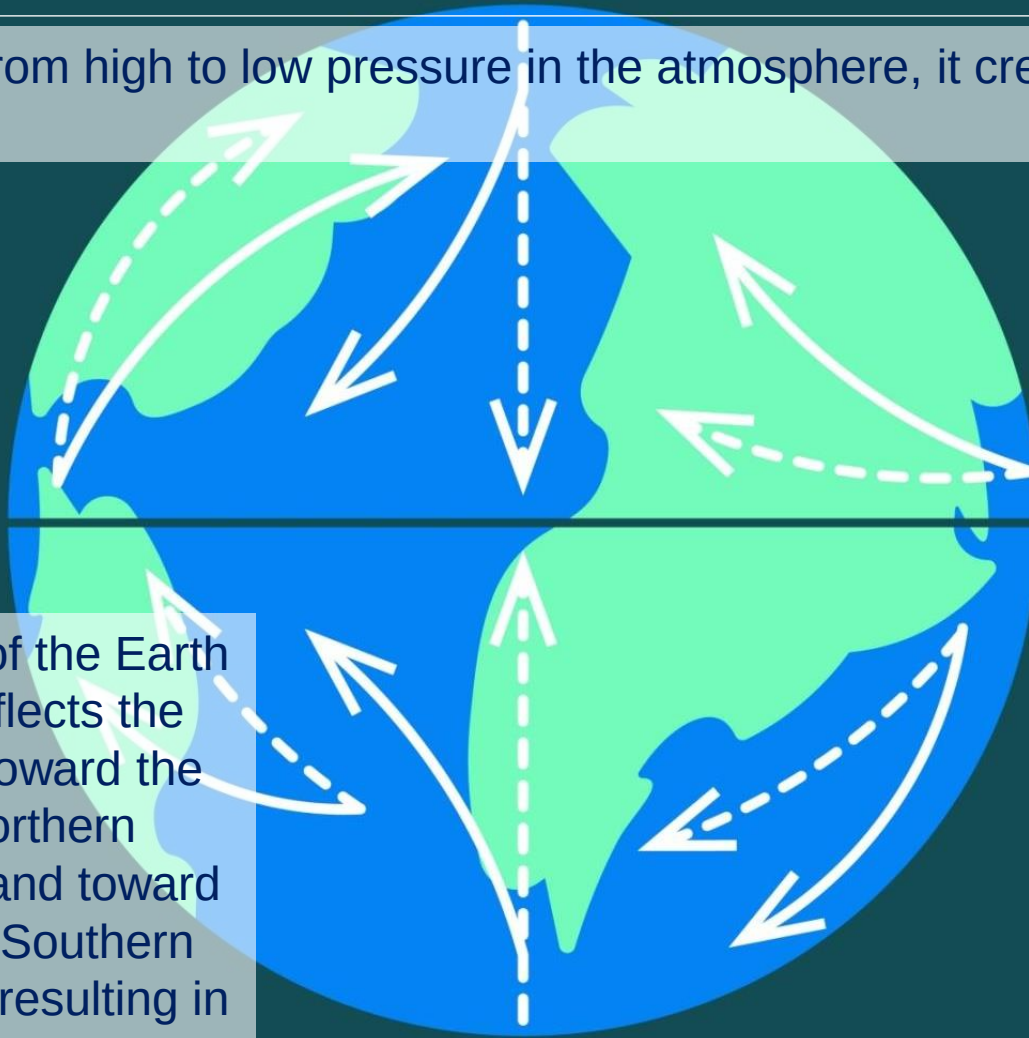


- The combination of rising and falling air, in addition to the Earth's rotation creates a series of cells.
- There are **three cells in each hemisphere**.
- Either side of the equator is the Hadley cell, with the Ferrell cell next and then the Polar cell at the top and bottom of the planet.

Coriolis Effect

- As air blows from high to low pressure in the atmosphere, it creates *the Coriolis force*.

- The rotation of the Earth on its axis deflects the atmosphere toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere, resulting in curved paths.



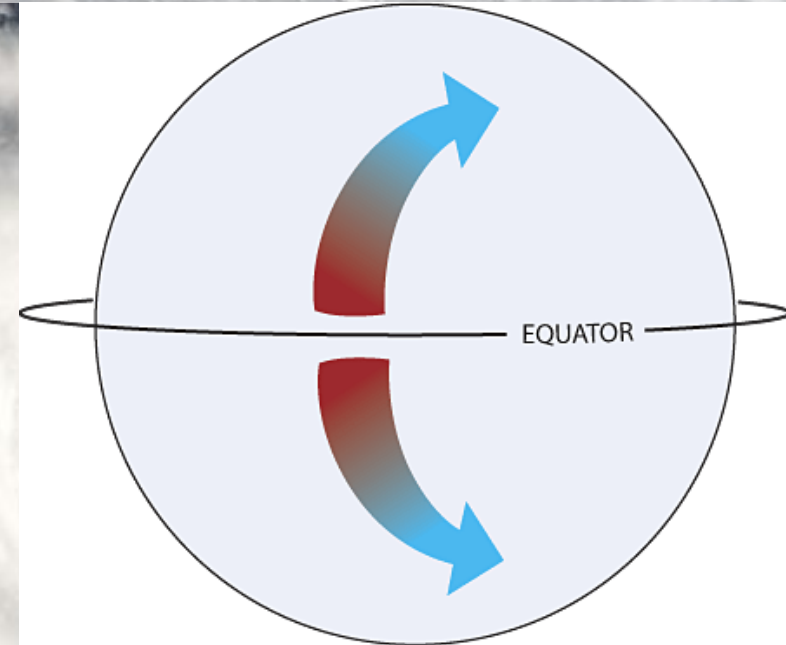
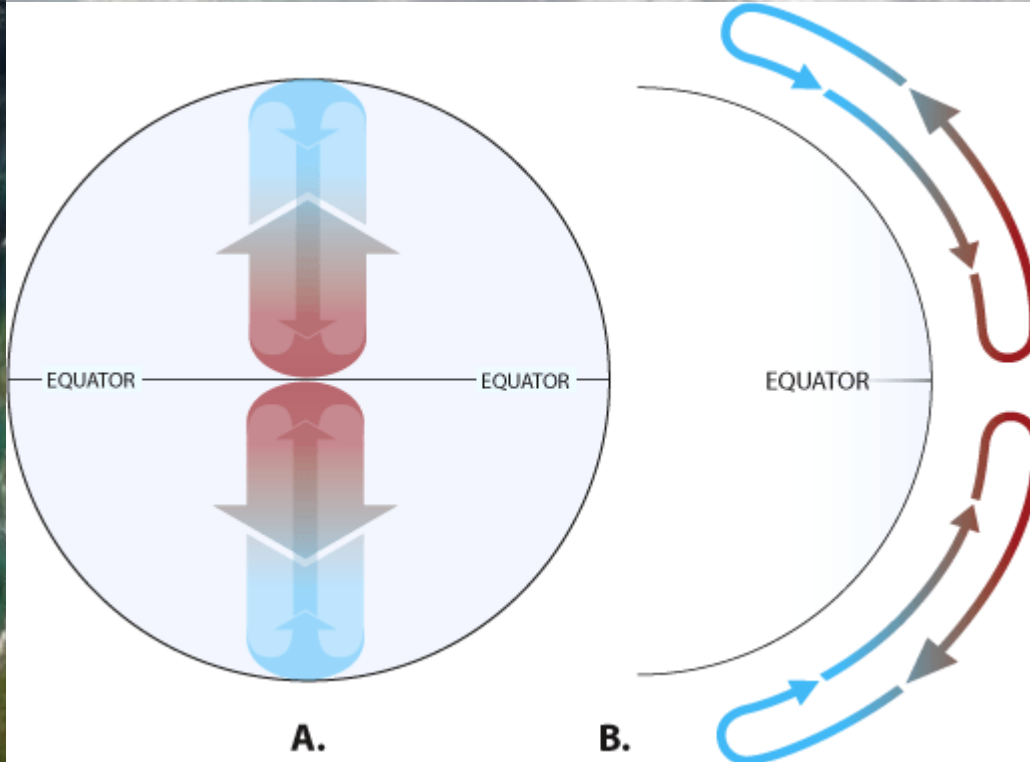
Starting direction



Changed direction

Coriolis Effect

- As air blows from high to low pressure in the atmosphere, it creates ***the Coriolis force***.

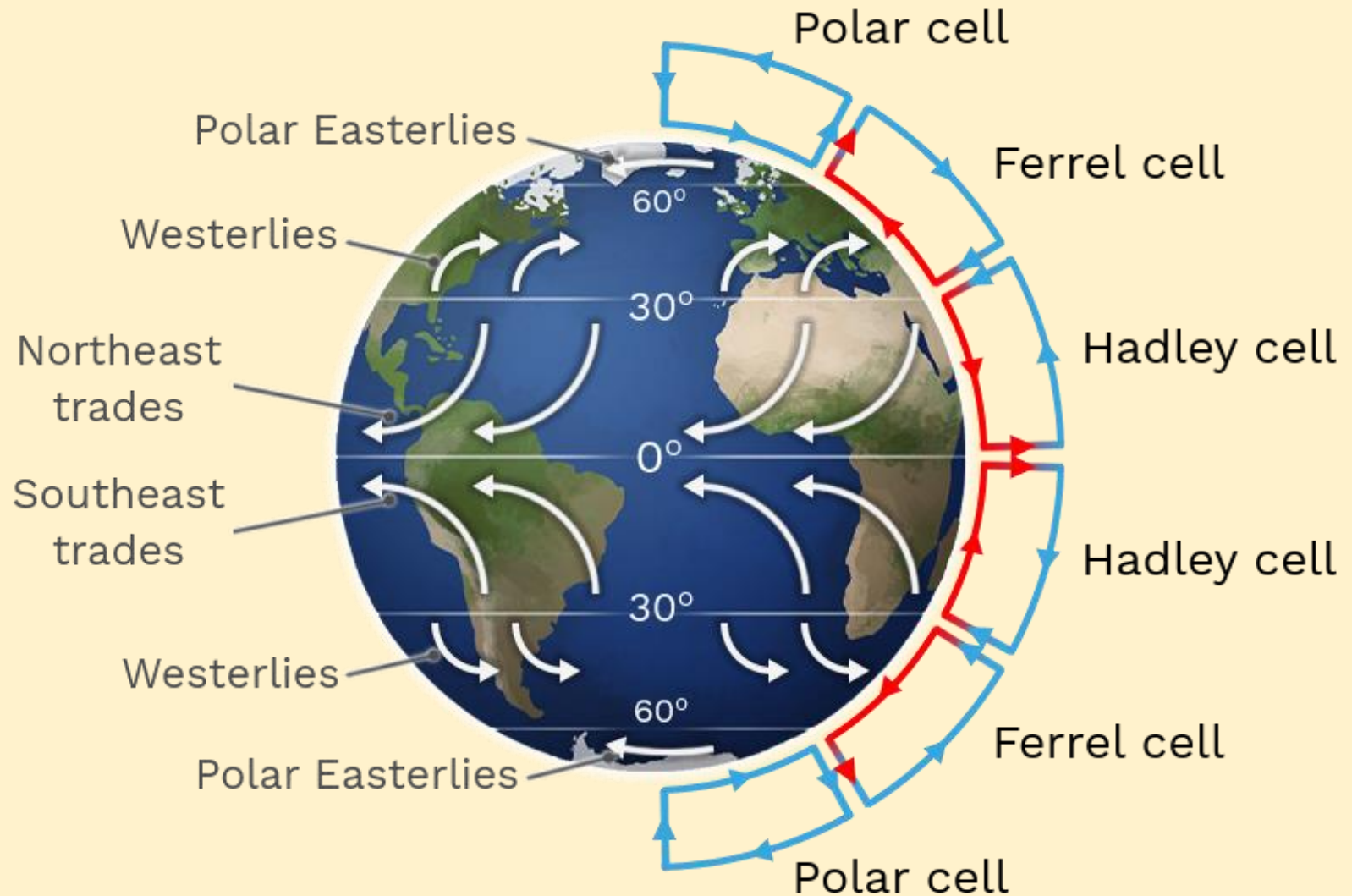


- Without Earth's rotation**

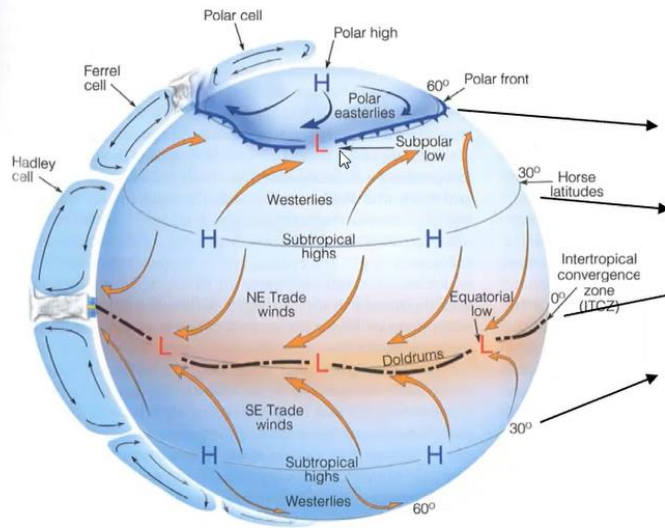
- With Earth's rotation**

Coriolis Effect

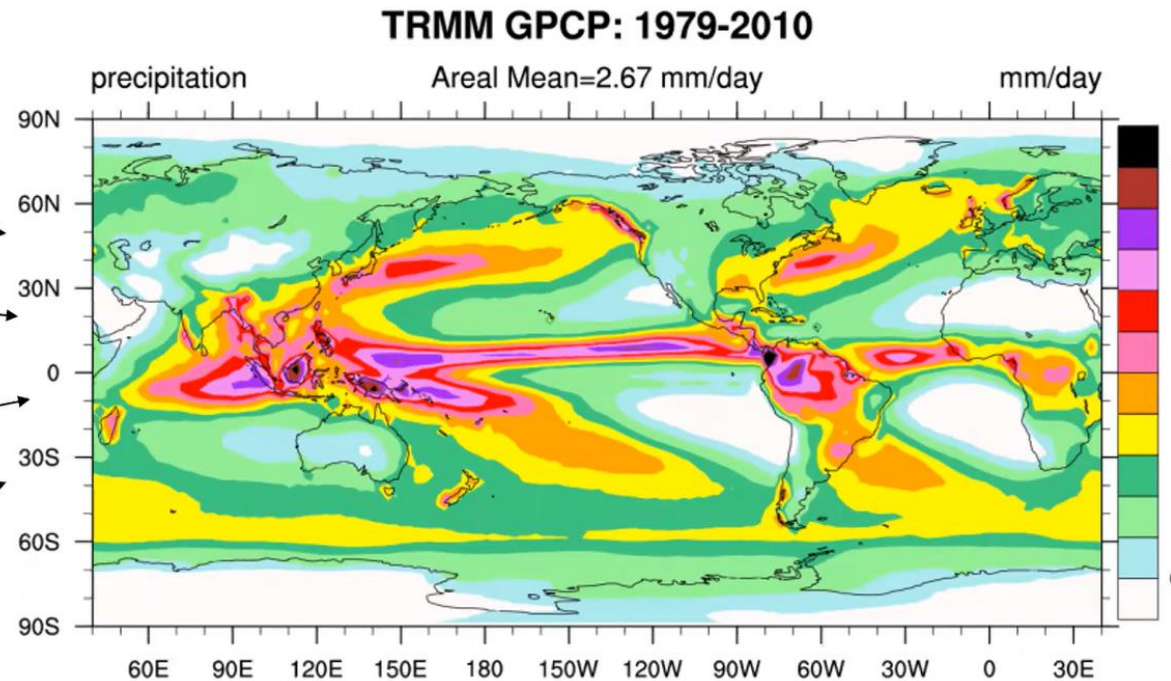
- These things in combination create *the global air circulation patterns*



High and Low Pressure



Notice how the pattern of lows and highs in this simplified plot is east-west symmetrical



But this plot of real Earth precipitation distribution is not east-west symmetrical... due to continents

Oceans – Specific Heat Capacity

Heat capacity is the amount of energy required to change the temperature of the water by a given amount.



Water has high specific heat capacity

Oceans – Specific Heat Capacity

Heat capacity is the amount of energy required to change the temperature of the water by a given amount.

The ocean is a heat buffer. It takes a long time to heat or cool the world's oceans.



Water has high specific heat capacity

Oceans – Specific Heat Capacity



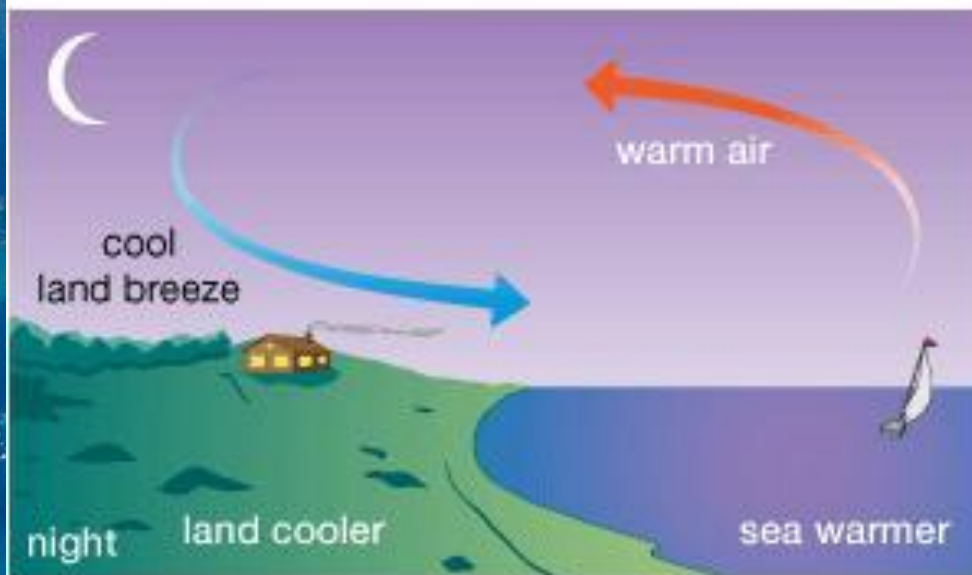
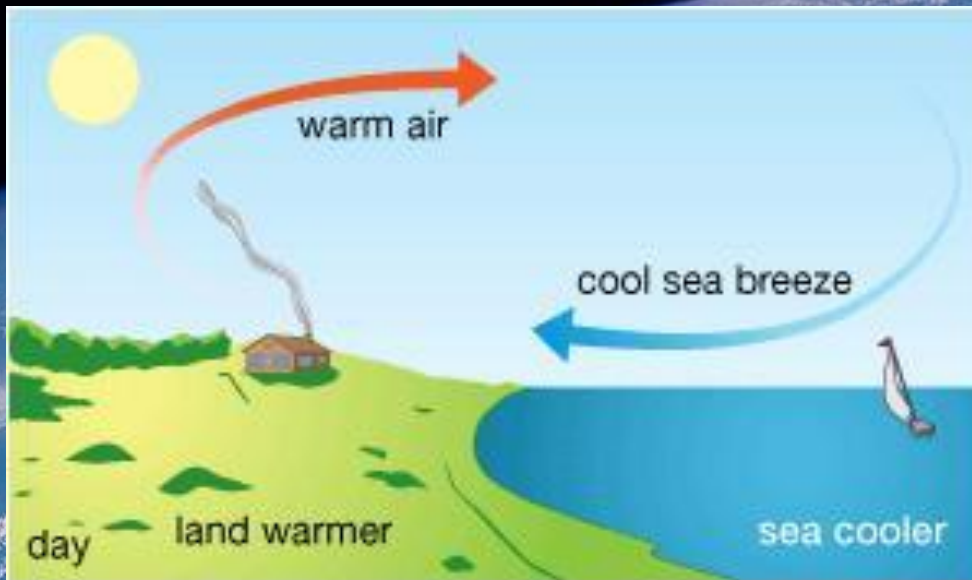
Heat capacity is the amount of energy required to change the temperature of the water by a given amount.

The ocean is a heat buffer. It takes a long time to heat or cool the world's oceans.

Water's polarity and its hydrogen bonds mean it takes a lot of energy to change the temperature, even by 1 degree.

Water has high specific heat capacity

Oceans

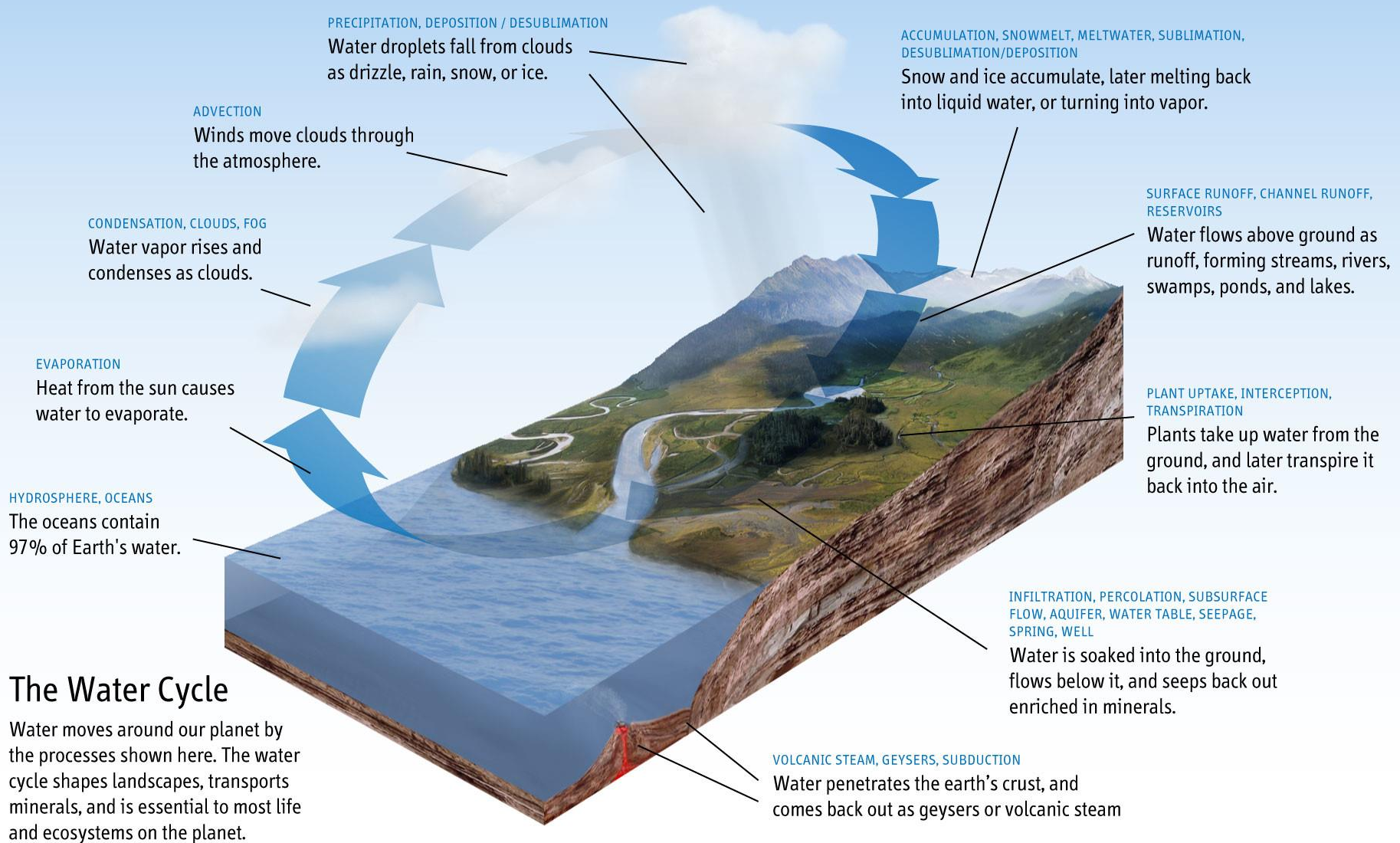


© 2010 Encyclopædia Britannica, Inc.

Heat capacity is the amount of energy required to change the temperature of the water by a given amount.

The ocean is a heat buffer. It takes a long time to heat or cool the world's oceans.

Water's polarity and its hydrogen bonds mean it takes a lot of energy to change the temperature, even by 1 degree.



Water Cycle v1.11 (2018) was created by Ehud Tal. Contact info at ehudtal.com



The water cycle

Weather related disasters

[Calculating the Cost of Weather and Climate Disasters | News | National Centers for Environmental Information \(NCEI\) \(noaa.gov\)](#)



Weather related disasters

[Calculating the Cost of Weather and Climate Disasters | News | National Centers for Environmental Information \(NCEI\) \(noaa.gov\)](#)

In pairs, make a list of the top weather and climate disasters.
How much do you think each event costs?

Weather related disasters

[Calculating the Cost of Weather and Climate Disasters | News | National Centers for Environmental Information \(NCEI\) \(noaa.gov\)](#)

1. **Tropical cyclones** have the highest average cost per event of **\$20.3 billion**.
2. **Drought/heat waves** have an average cost of **\$10.0 billion** per event.
3. **Wildfires** have an average cost of **\$6.2 billion** per event.
4. **Flooding** events have an average cost of **\$4.7 billion** per event.
5. **Winter storms** have an average cost of **\$4.1 billion** per event.
6. **Freezes** have an average cost of **\$3.7 billion** per event.
7. **Severe storms** have an average cost of **\$2.3 billion** per event, but are the most frequent disaster type.

Weather vs Climate

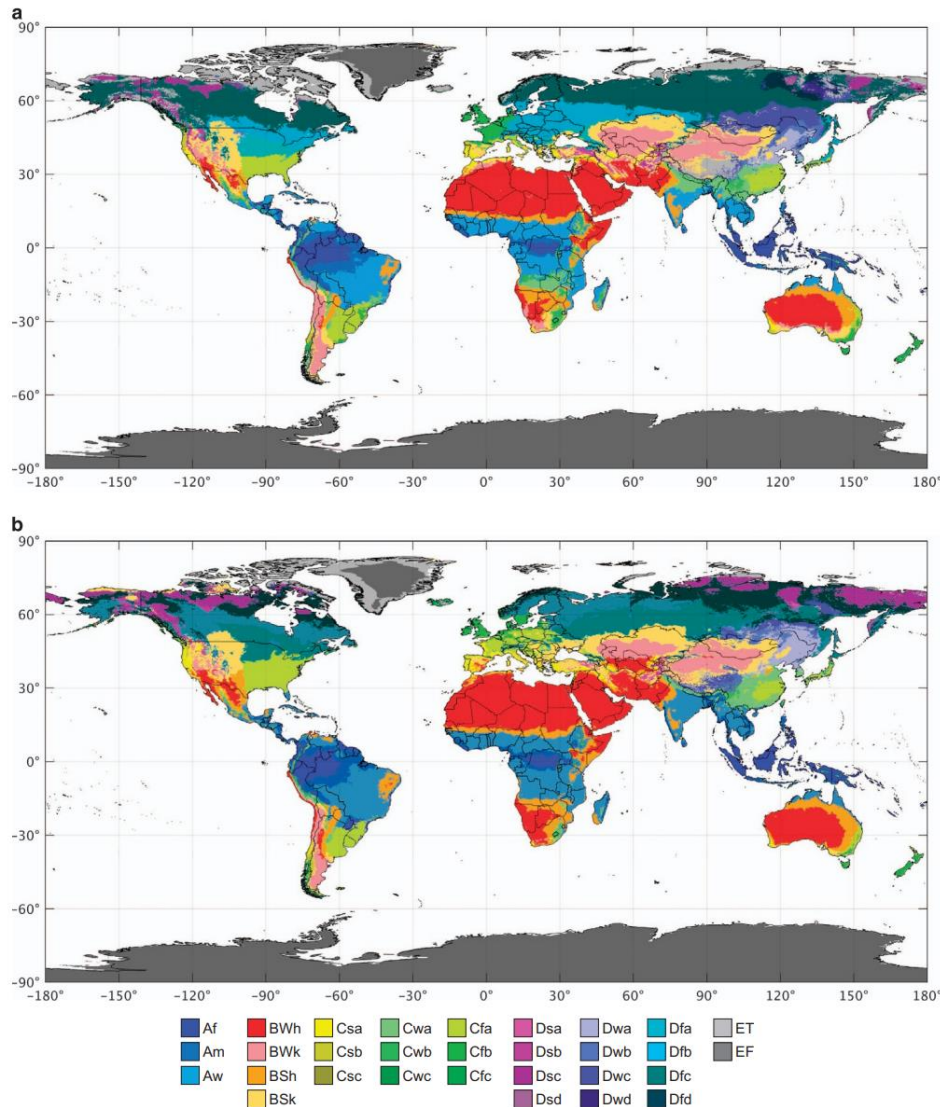
- Determined: Over time
- Looked at by the years
- Reported as an average
- Depends on the location on Earth
- Weather makes up climate

**Measures
conditions
in the
atmosphere**

- Determined: daily
- Looked at by the minutes, hour, day, week
- Reported as a forecast
- Depends on the weather occurring mainly to the west
- Climate helps you determine the weather

Climatic Zones

- Köppen-Geiger Climate Zones



[Present and future Köppen-Geiger climate classification maps at 1-km resolution | Scientific Data \(nature.com\)](#)

New and improved Köppen-Geiger classifications. Part (a) shows the present-day map (1980–2016) and panel (b) the future map (2071–2100). The color scheme was adopted from Peel et al.

Climate variables

- Some meteorological variables that are commonly measured are as follows:



Natural causes – internal variability

1

Ocean circulation

2

Ocean-atmosphere exchange

Life

3

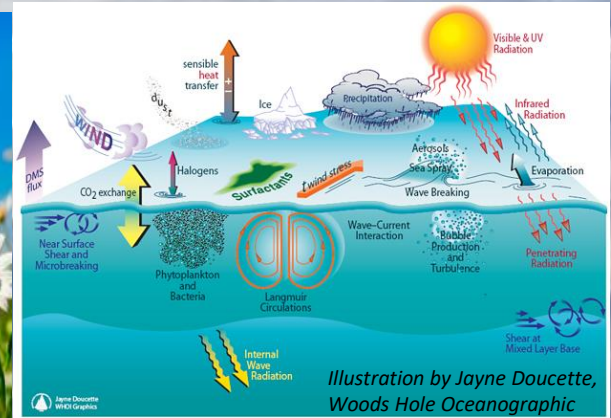
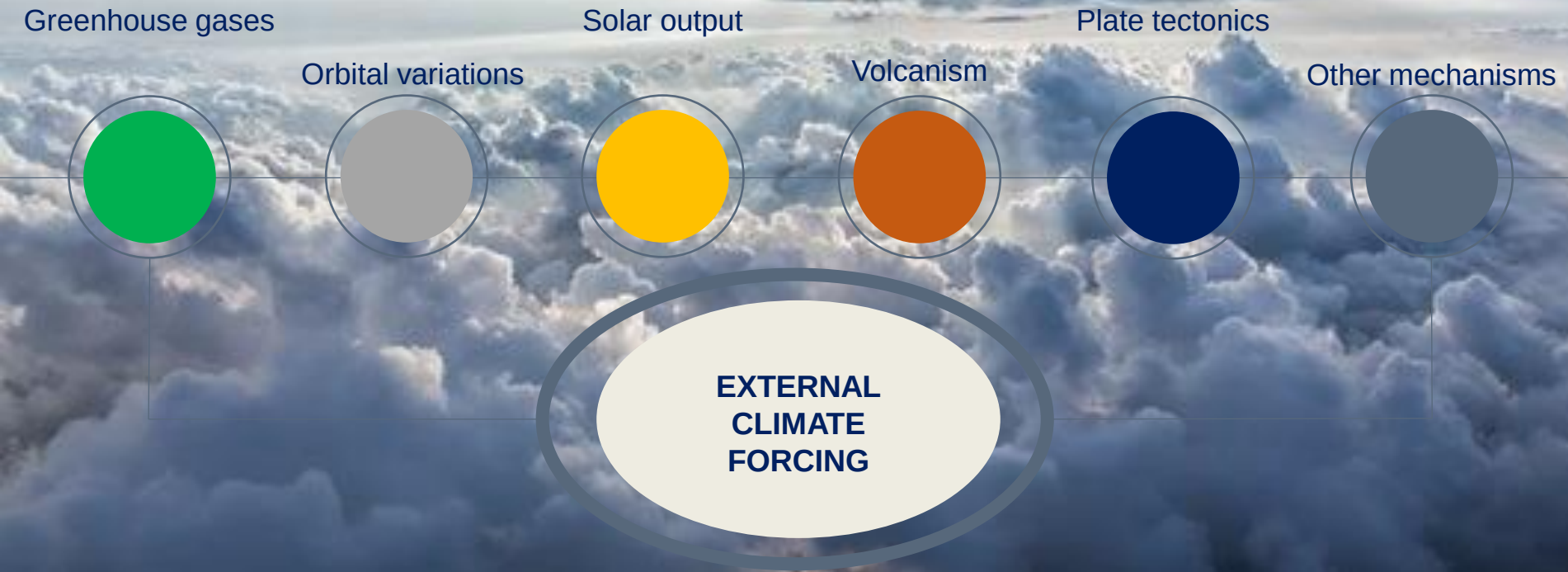


Illustration by Jayne Doucette,
Woods Hole Oceanographic
Institution

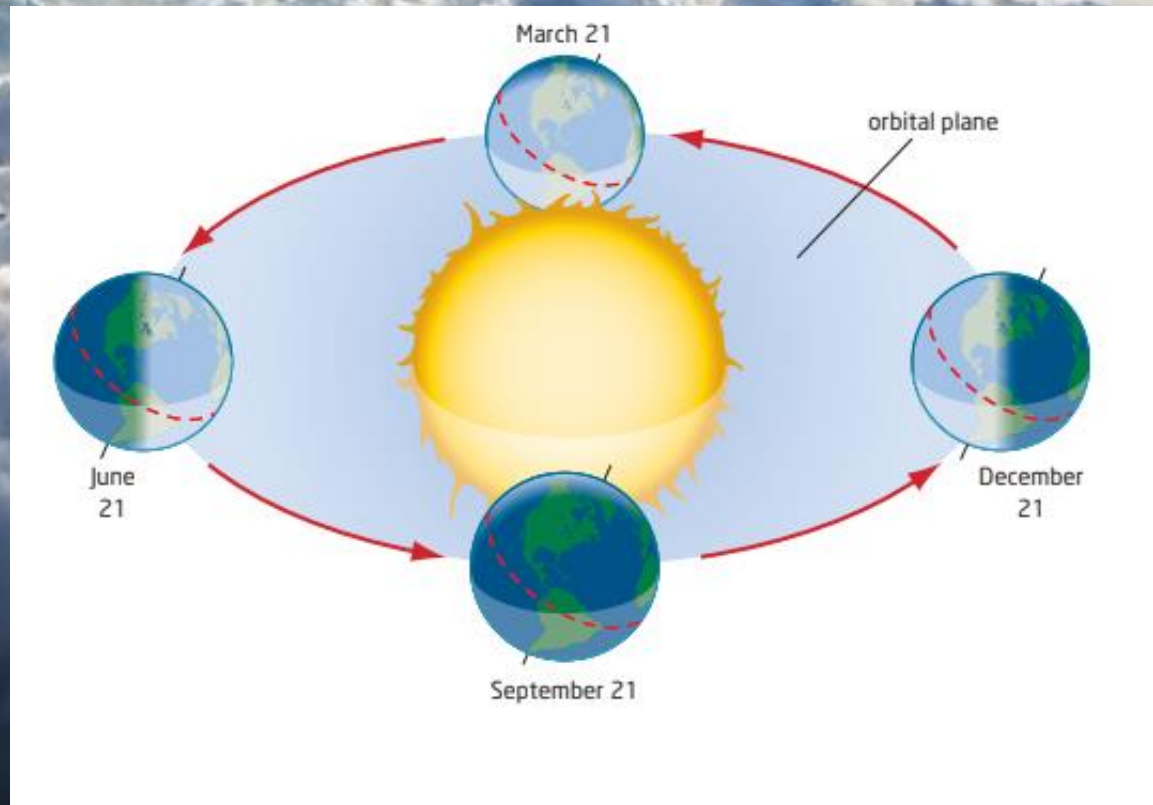


Natural causes – External forcing



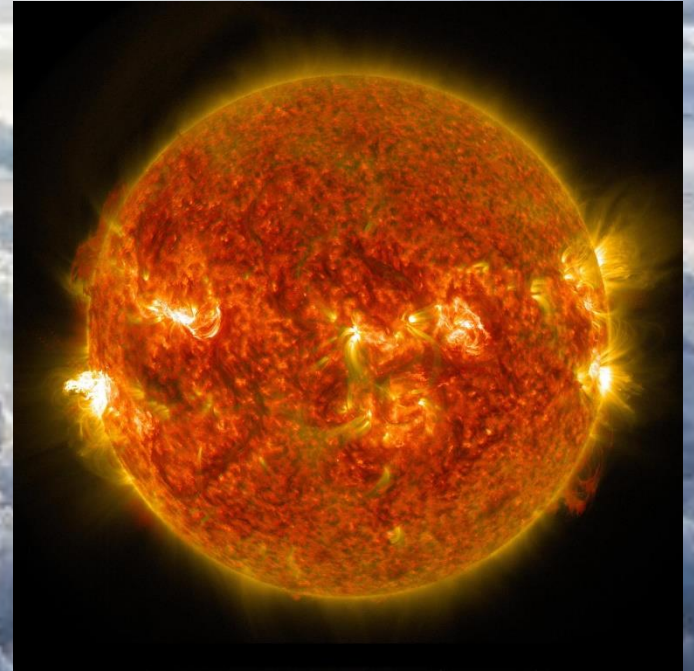
Natural causes – Orbital variation

- Shifts and wobbles in the Earth's orbit can trigger changes in climate such as the beginning and end of ice ages.
- More tilt = warmer summers and colder winters
- Less tilt = cooler summers and milder winters
- Orbital shifts are so gradual that they can only be observed over thousands of years - not decades or centuries.



Natural causes – solar output

- The Sun is the source of energy for the Earth's climate system.
- The Sun's energy output appears constant from an everyday point of view, small changes over an extended period of time can lead to climate changes.



Source: Swiss National Science Foundation

Natural causes – solar output

- A decrease in solar activity was 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.



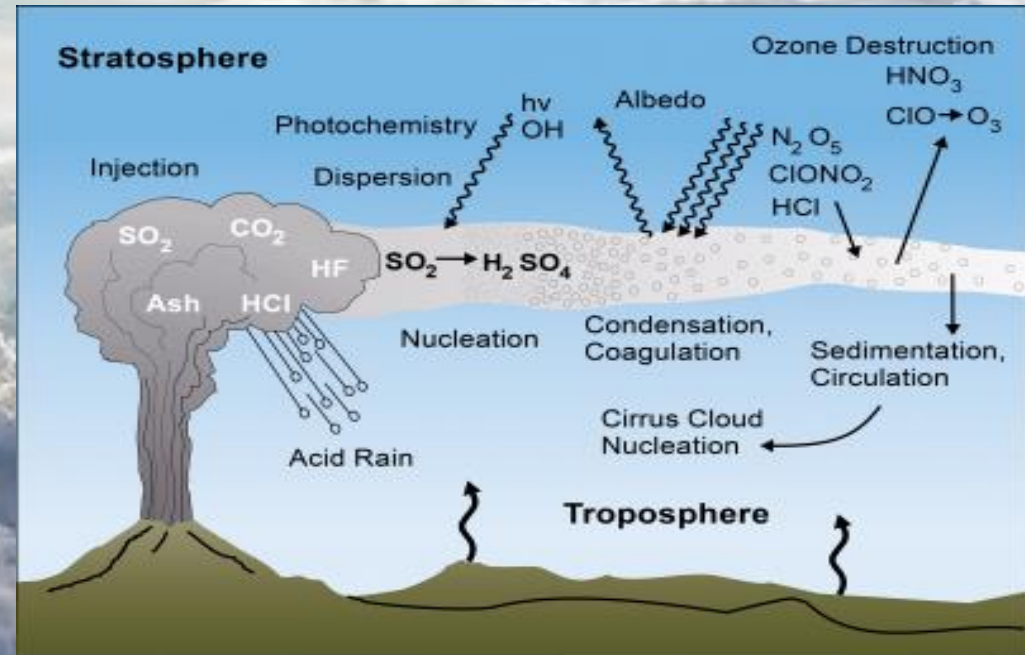
The Frozen Thames, by Abraham Hondius (c.1625–1691)



Pompenburg with Hofpoort in winter, by Bartholomeus Johannes van Hove (1790-1880)

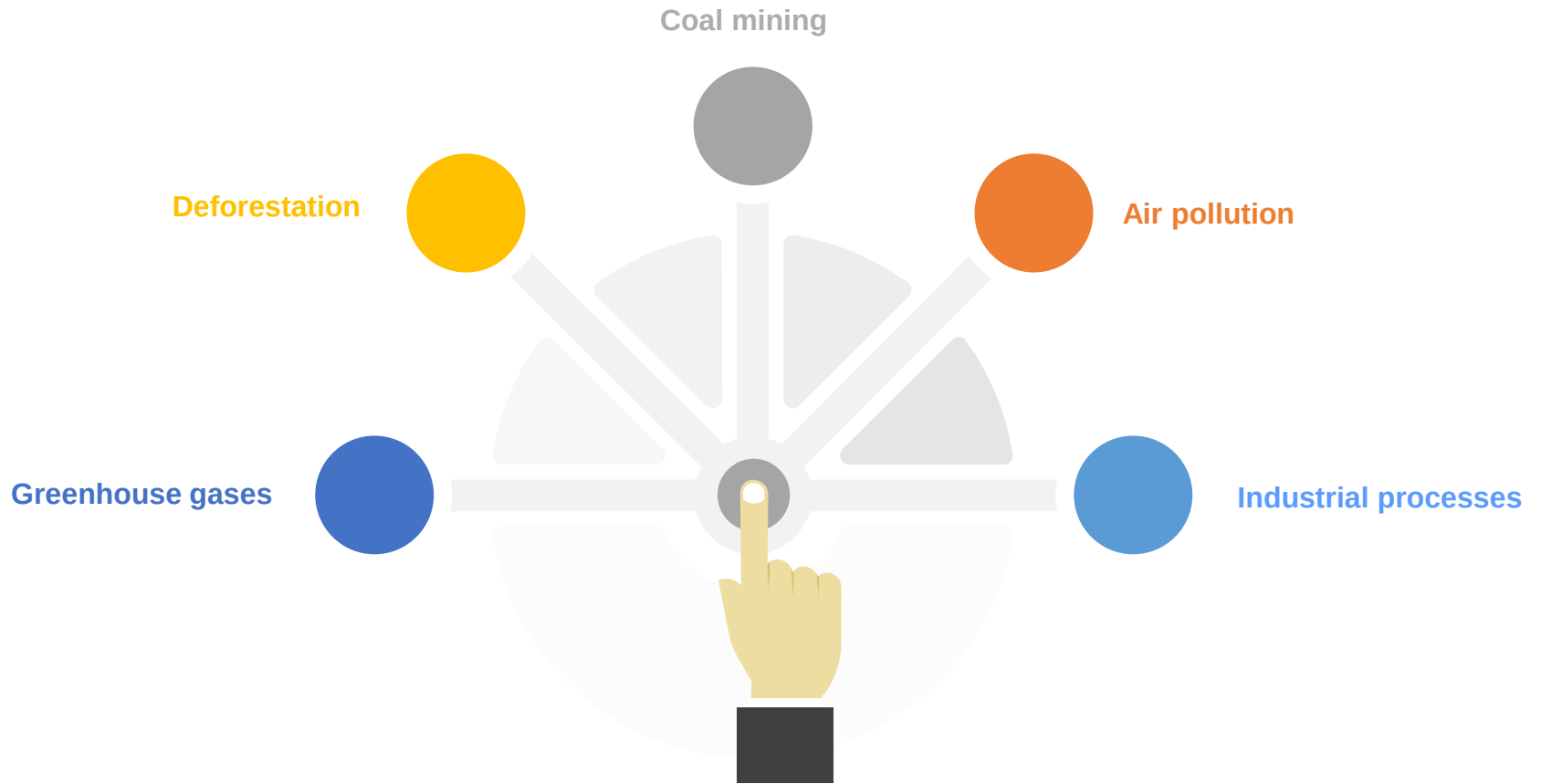
Natural causes - volcanism

- Volcanic eruption throws out an enormous amount of particles and other gases that effectively shield us from the Sun to lead to a period of global cooling.



Source: <https://earthdata.nasa.gov/learn/sensing-our-planet/volcanoes-and-climate-change>

Anthropogenic causes



Greenhouse gases

- Greenhouse gases are those that absorb and emit infrared radiation in the wavelength range emitted by Earth.

- Solar radiation passes through the clear atmosphere.
- Most radiation is absorbed by the Earth surface and warms it.
- Some solar radiation is reflected by the Earth and the atmosphere.

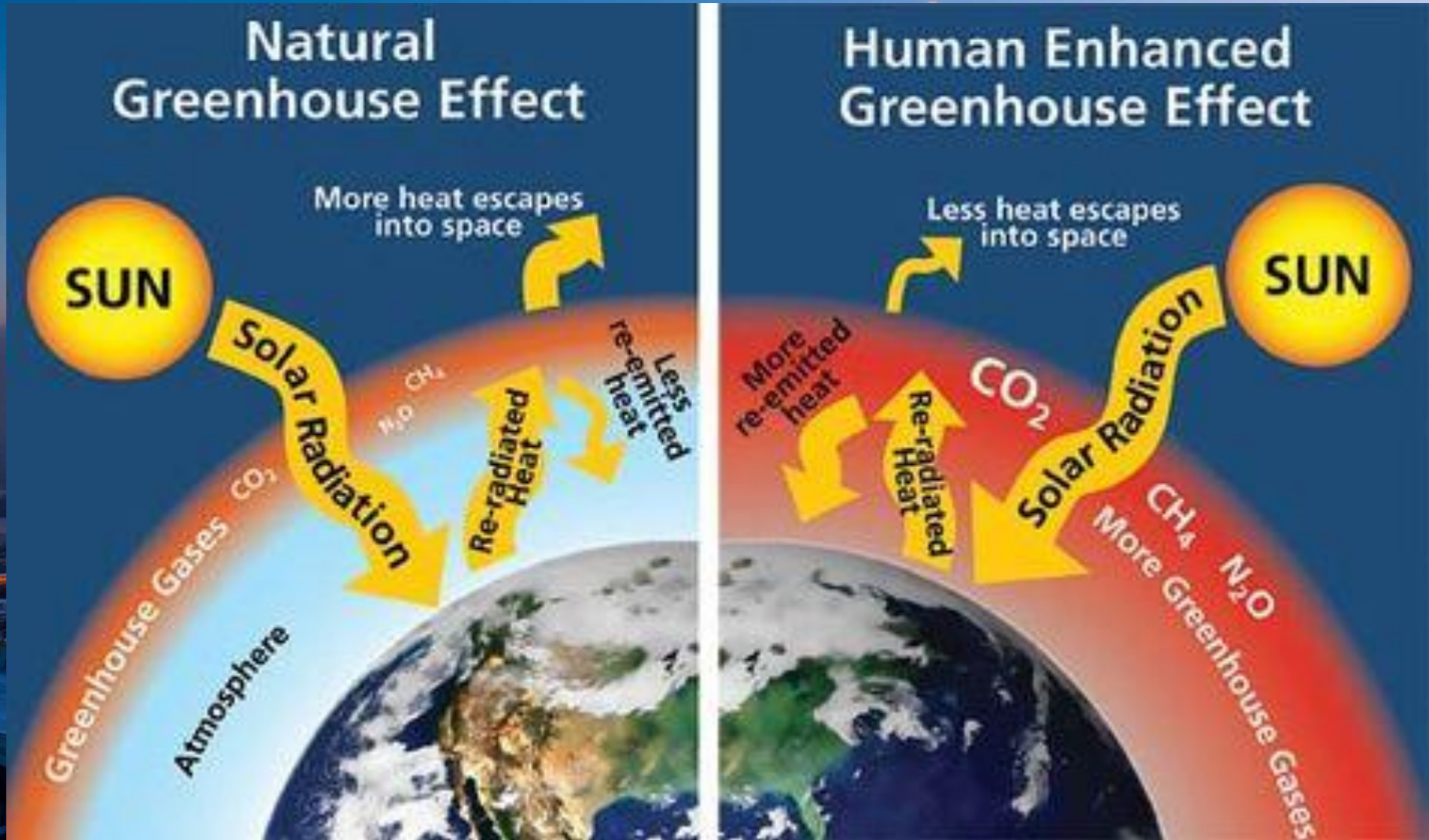


- Infrared radiation is emitted from the Earth surface.
- Some of the infrared radiation passes through the atmosphere and some is absorbed and re-emitted in all molecules. The effect of this is to warm the Earth surface and the lower atmosphere.

The burning of fossil fuels like coal, oil, and gas for electricity, heat, and transportation is the primary source of human-generated emissions.

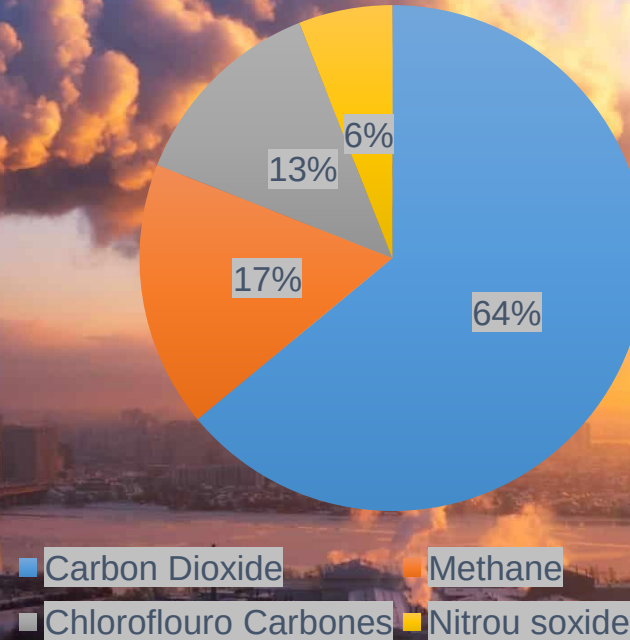
Greenhouse gases

- Human enhanced greenhouse gases effect



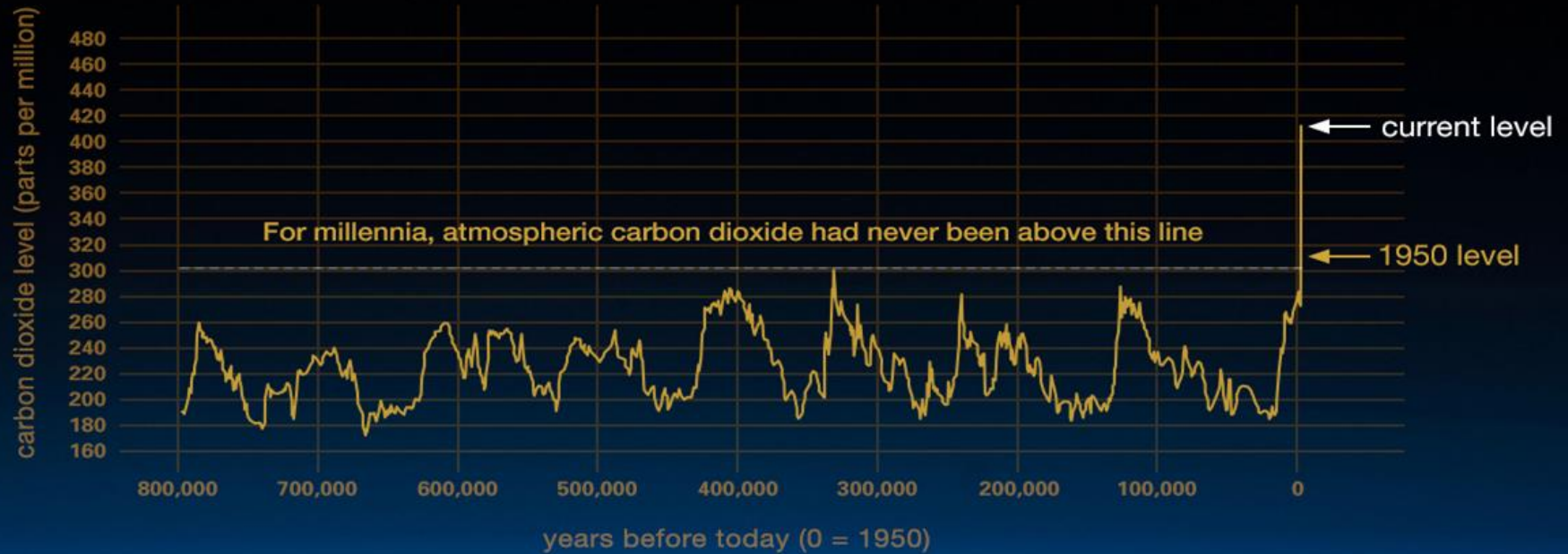
Greenhouse gases

- CO₂ concentration in the atmosphere is currently 40% higher than it was when industrialisation began.
- Other greenhouse gases are emitted in smaller quantities, but they trap heat far more effectively than CO₂, and in some cases are thousands of times stronger.



Source: https://ec.europa.eu/clima/change/causes_en

Greenhouse gases – Carbon Dioxide



Sources: Credit: Luthi, D., et al., 2008; Etheridge, D.M., et al. 2010; Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO₂ record.
<https://climate.nasa.gov/evidence/>

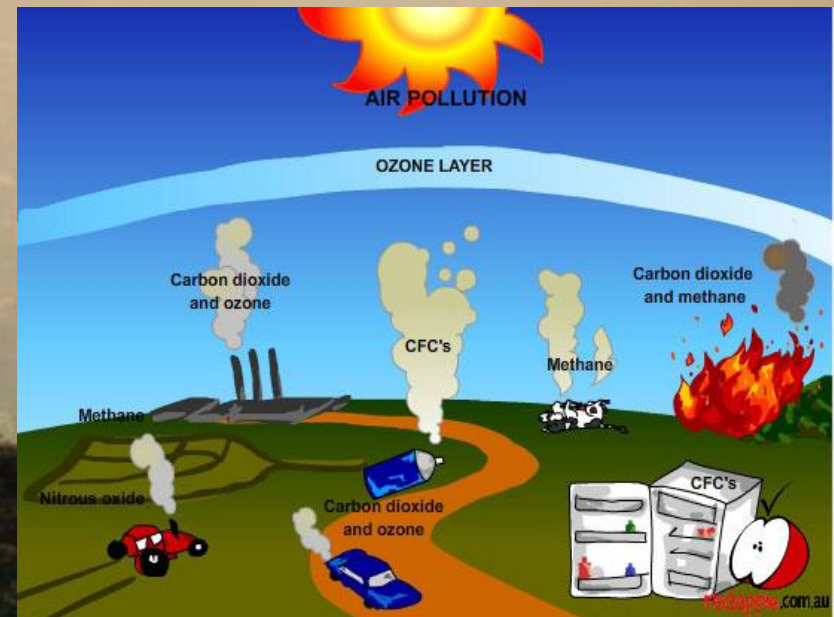
Deforestation

- Deforestation is the permanent removal of trees to make room for something besides forest.
- This can include clearing the land for agriculture or grazing, or using the timber for fuel, construction or manufacturing.



Air Pollution

- Air pollution is caused by fertiliser use, livestock production, and certain industrial processes that release fluorinated gases.
- Pollutants in the air can produce serious environmental issues and contribute to climate change. The major concerns include:
 - The ability of pollutants to trap too much heat in the atmosphere
 - The mixture of gases with moisture in the atmosphere which produces damaging acid rain
 - The increase in unnatural ozone levels
 - The presence of particles in the atmosphere that block sunlight



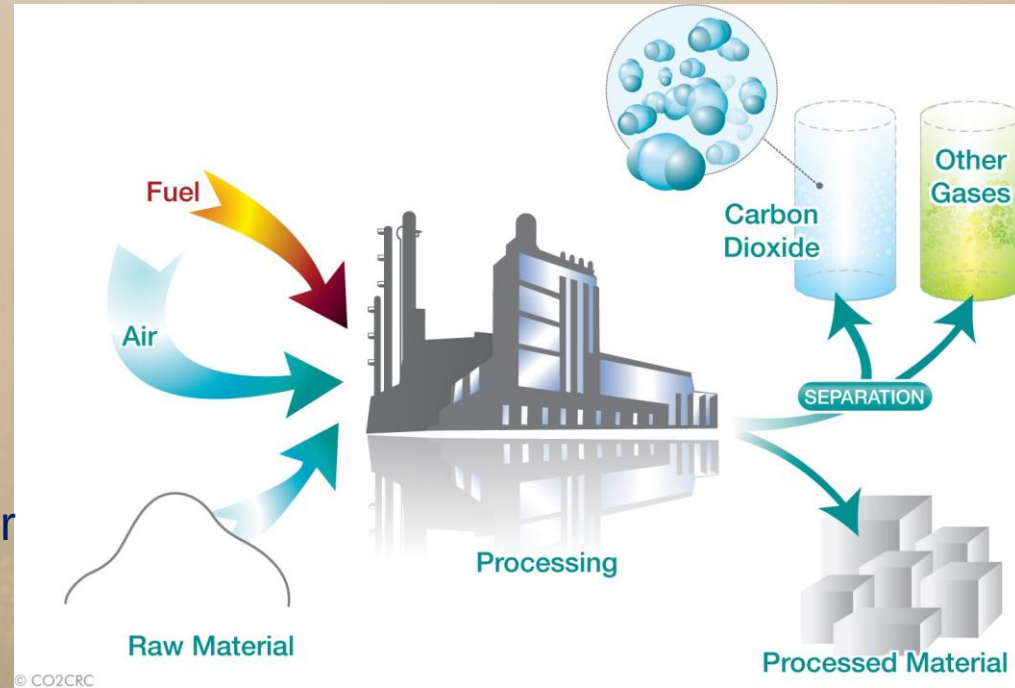
Mining

- Coal mining releases methane, a potent greenhouse gas. Methane emissions from coalmines has a global warming potential 21 times greater than that of carbon dioxide over a 100-year timeline (Source IPCC).



Industrial processes

- These total emissions for industrial process are comprised of: (Fischedick, Roy et al. 2014)
- Direct energy-related CO₂ emissions for industry
- Indirect CO₂ emissions from production of electricity and heat for industry
- Process CO₂ emissions
- Non-CO₂ GHG emissions
- Direct emissions for waste/wastewater



Source: CO2CRC.com

Consequences of climate change

- **Changes in:**
- Glaciers and ice sheets
- Sea level change
- Sea ice
- Heavy rainfall across the globe
- Extreme Drought
- Decline in Crop productivity
- Changes in ecosystems
- Hurricanes
- Rise in temperature
- Acidification of seawater

Photo credit UCSUSA



Photo credit AFP

Photo credit David Paul Morris, Bloomberg



Activity:

Provide a short summary of how these impact the physical landscape?

- **Changes in:**
- Glaciers and ice sheets
- Sea level change
- Sea ice
- Heavy rainfall across the globe
- Extreme Drought
- Decline in Crop productivity
- Changes in ecosystems
- Hurricanes
- Rise in temperature
- Acidification of seawater

Photo credit UCSUSA



Photo credit David Paul Morris, Bloomberg



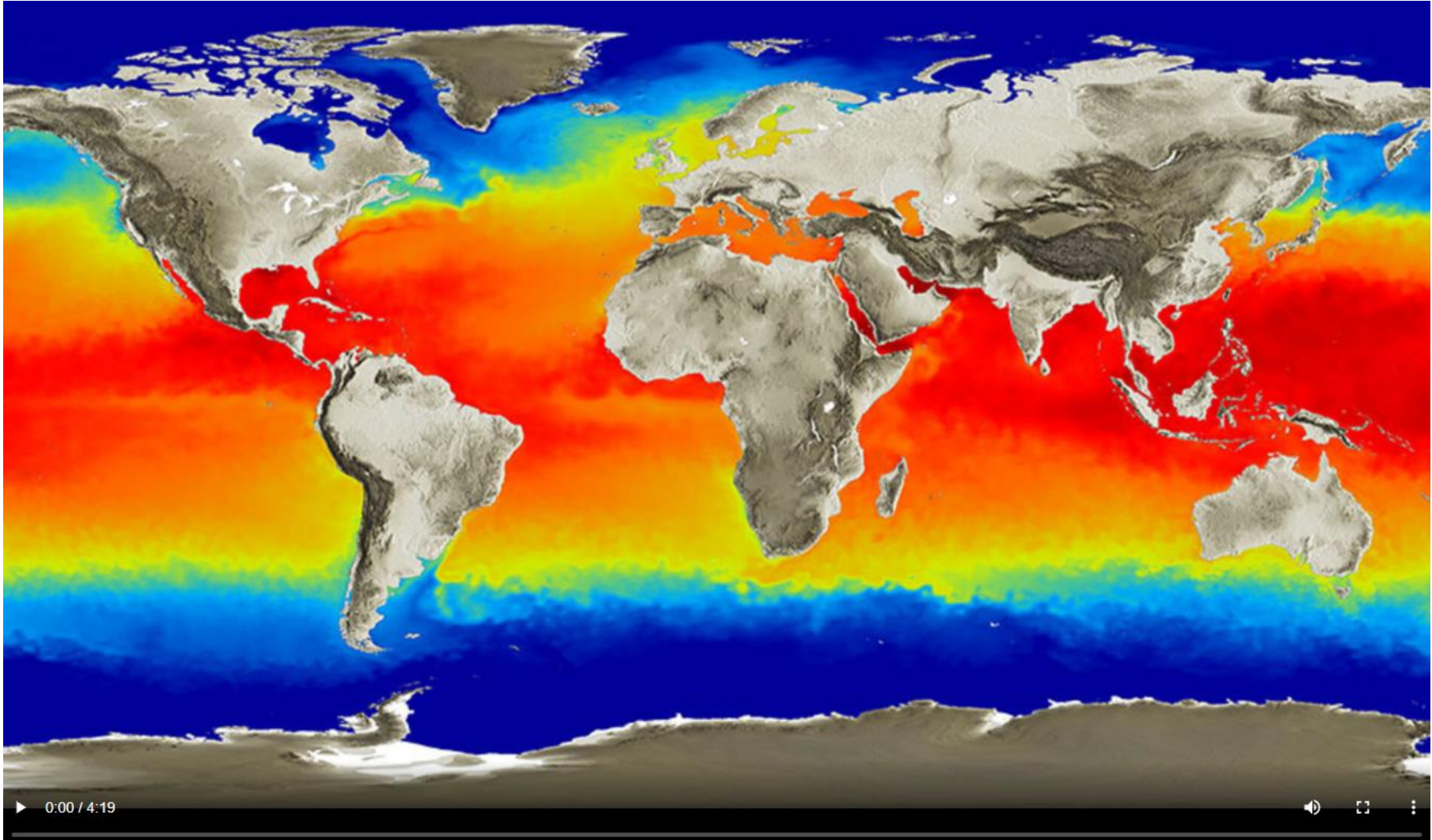
Photo credit AFP



Prepare a short presentation for the class.

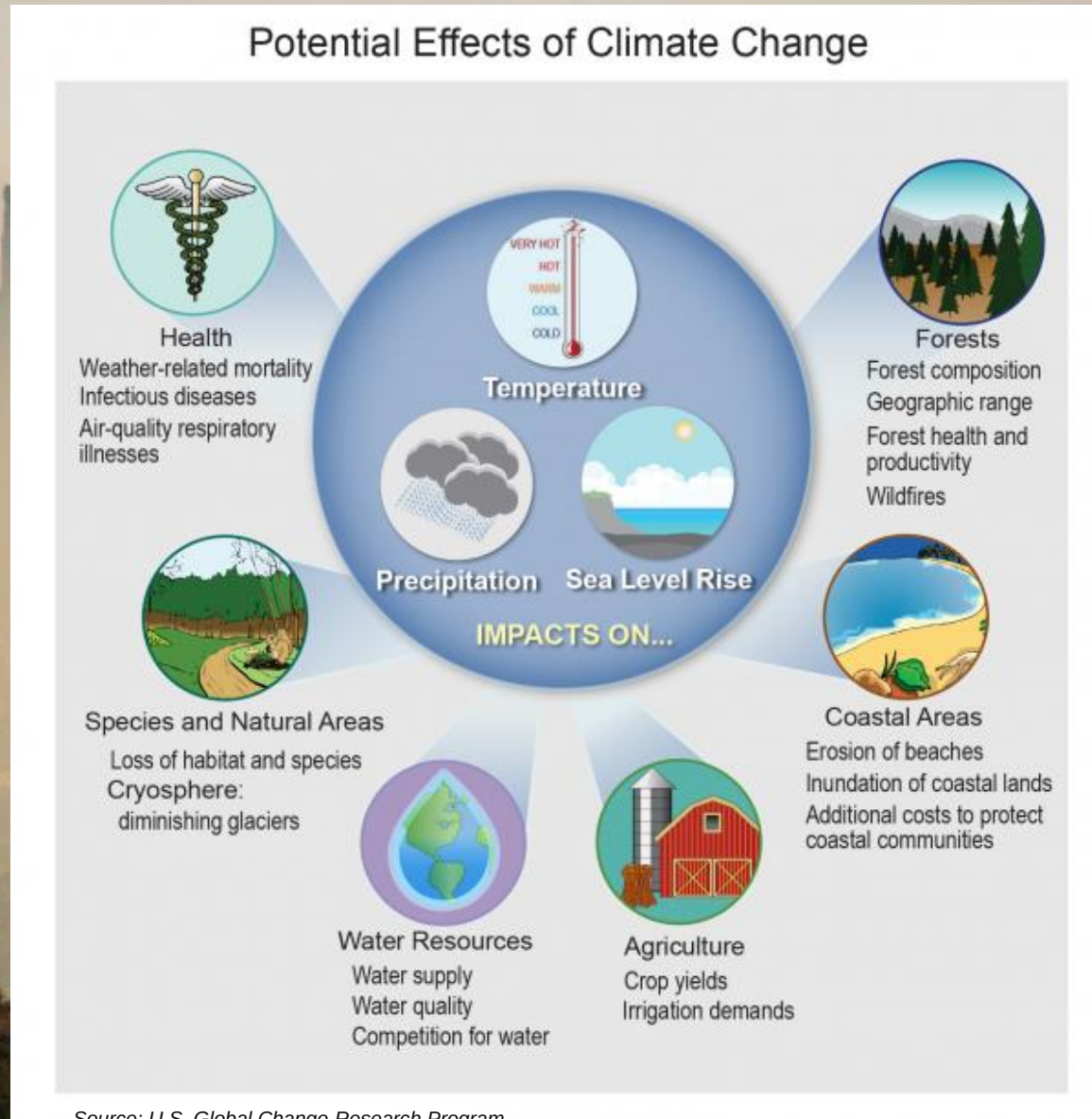
Consequences of climate change

[Source: ESA](#)



Why measuring climate change?

- We measure climate change to understand climate, climate variability and climatic changes at the local, national, and regional, and global levels;
- To understand better how climate change affects our social systems;
- To better plan adaptation measures to tackle the potential or actual impacts of climate change.

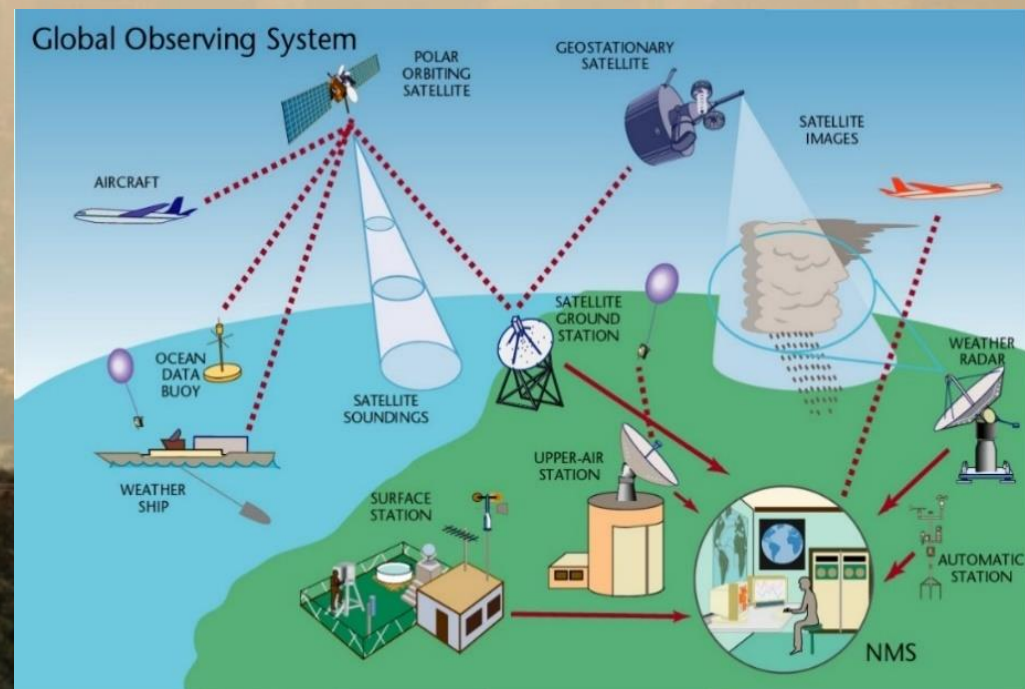


How climate change is measured over time

- Earth-orbiting satellites, remote meteorological stations, and ocean buoys are used to monitor present-day weather and climate.
- Paleoclimatology data from natural sources like ice cores, tree rings, corals, and ocean and lake sediments
- Scientists use this data as an input into sophisticated climate models that predict future climate trends with impressive accuracy.



Source: WMO: <https://public.wmo.int/en/programmes/global-observing-system>

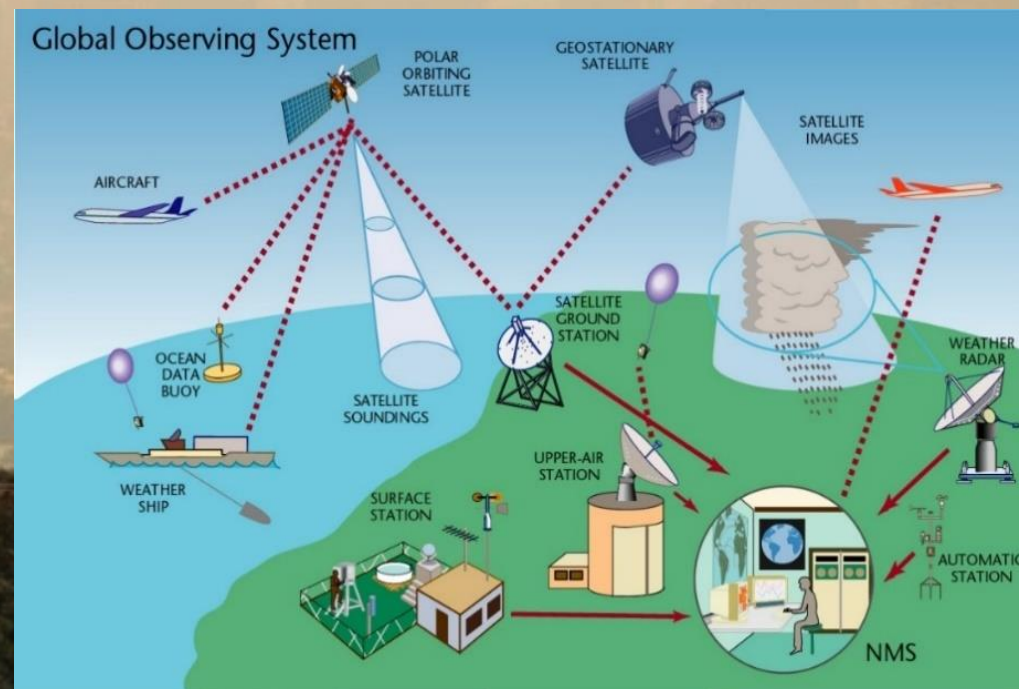


How climate change is measured over time

- Earth-orbiting satellites, remote meteorological stations, and ocean buoys are used to monitor present-day weather and climate.
- Paleoclimatology data from natural sources like **ice cores**, tree rings, corals, and ocean and lake sediments
- Scientists use this data as an input into sophisticated climate models that predict future climate trends with impressive accuracy.



Source: WMO: <https://public.wmo.int/en/programmes/global-observing-system>

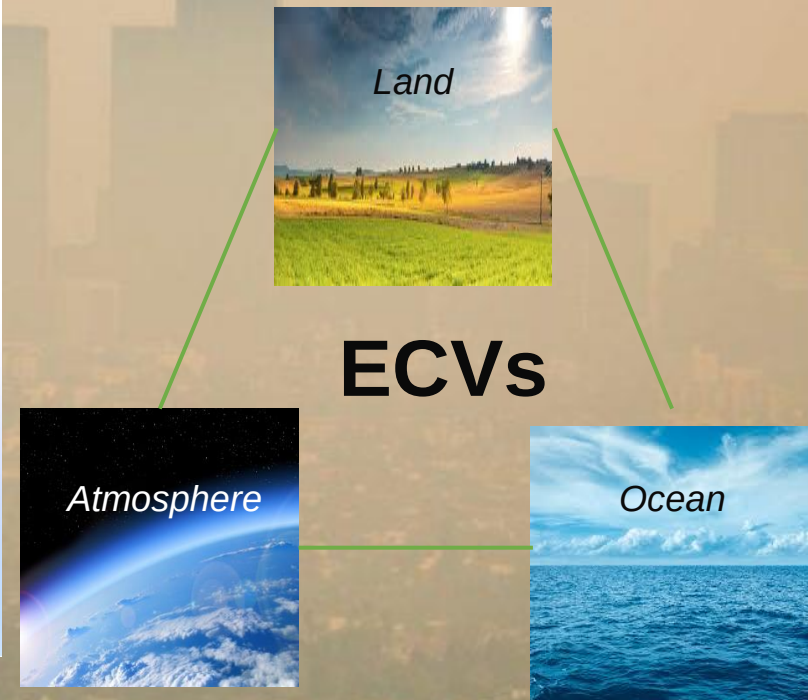
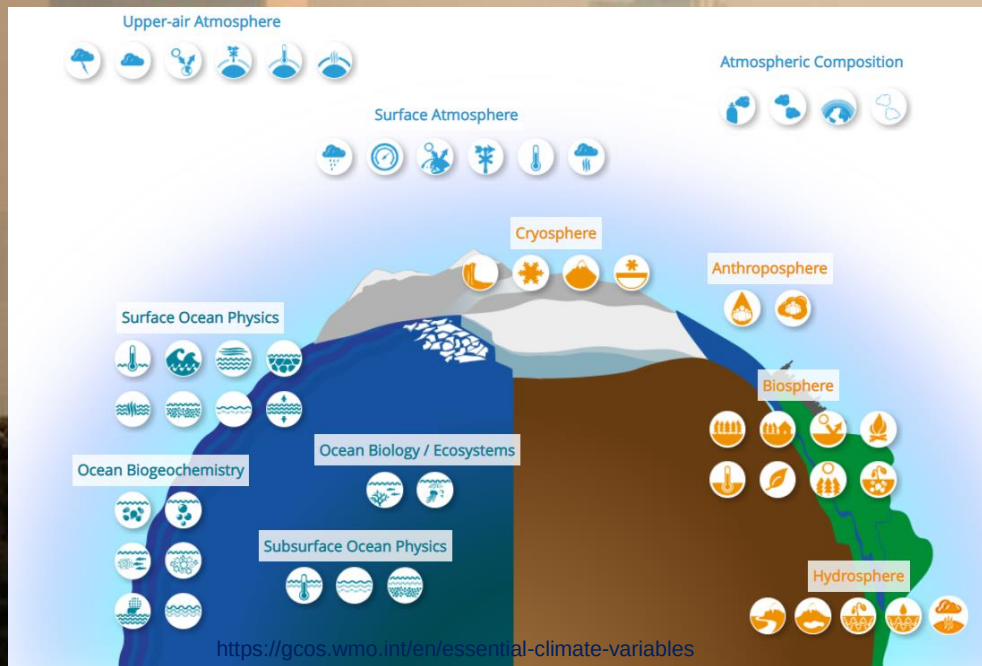


Essential Climate Variables

- Essential climate variables (ECVs) are physical, chemical, or biological variables or a group of linked variables that critically contributes to the characterisation of the Earth's climate.
- **Relevance:** The variable is critical for characterising the climate system and its changes.
- **Feasibility:** Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
- **Cost effectiveness:** Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

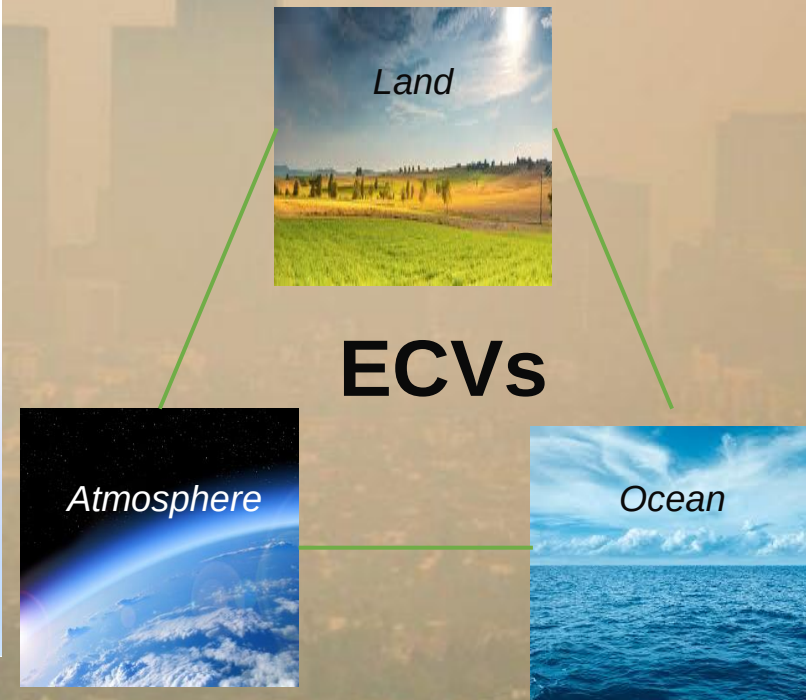
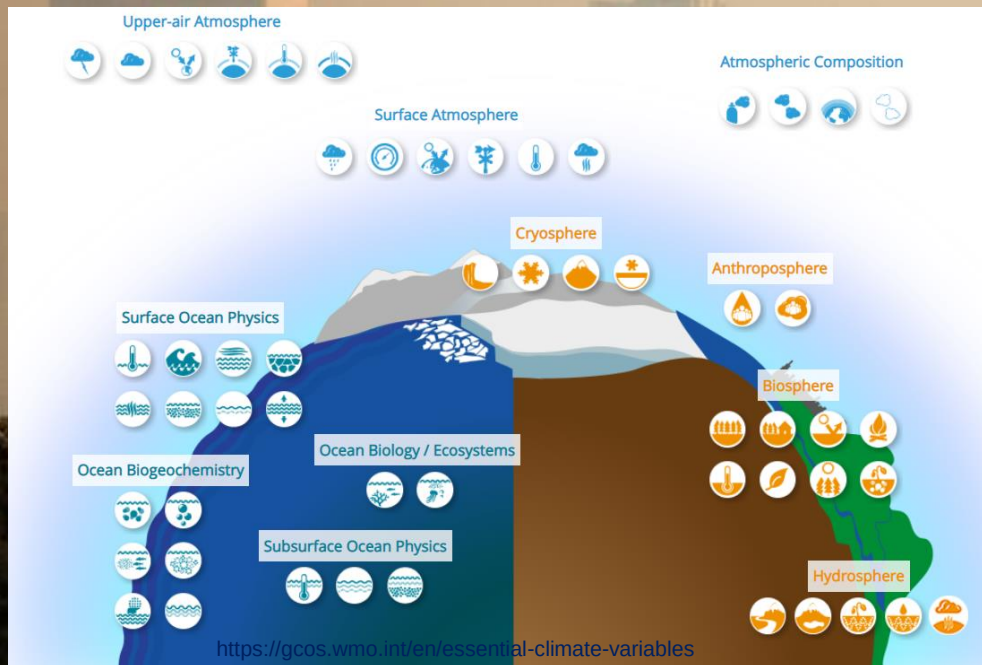
Essential Climate Variables

- ECV data records are intended to provide reliable, traceable, observation-based evidence for a range of applications, including monitoring, mitigating, adapting to, and attributing climate changes.



Essential Climate Variables

- ECV data records are intended to provide reliable, traceable, observation-based evidence for a range of applications, including monitoring, mitigating, adapting to, and attributing climate changes.



GCOS | WMO

- Click on the following link and choose an ESV. Summarise key information

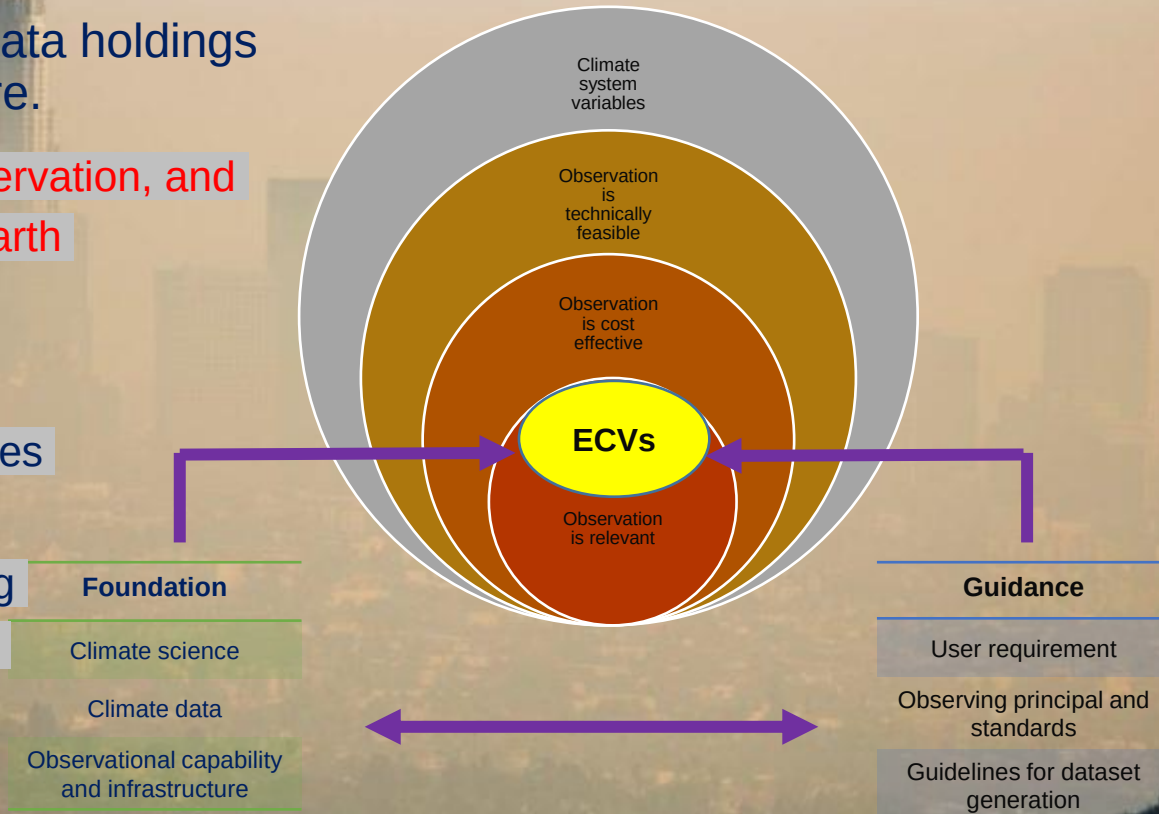
More than a list of variables

- Building on existing science, data holdings and observational infrastructure.

Guidance is provided on their observation, and the generation of products from Earth observation.

They provide one basis for an organised assessment of capabilities and needs.

Organisation could be by observing a network, physical/chemical cycle or societal benefit area.



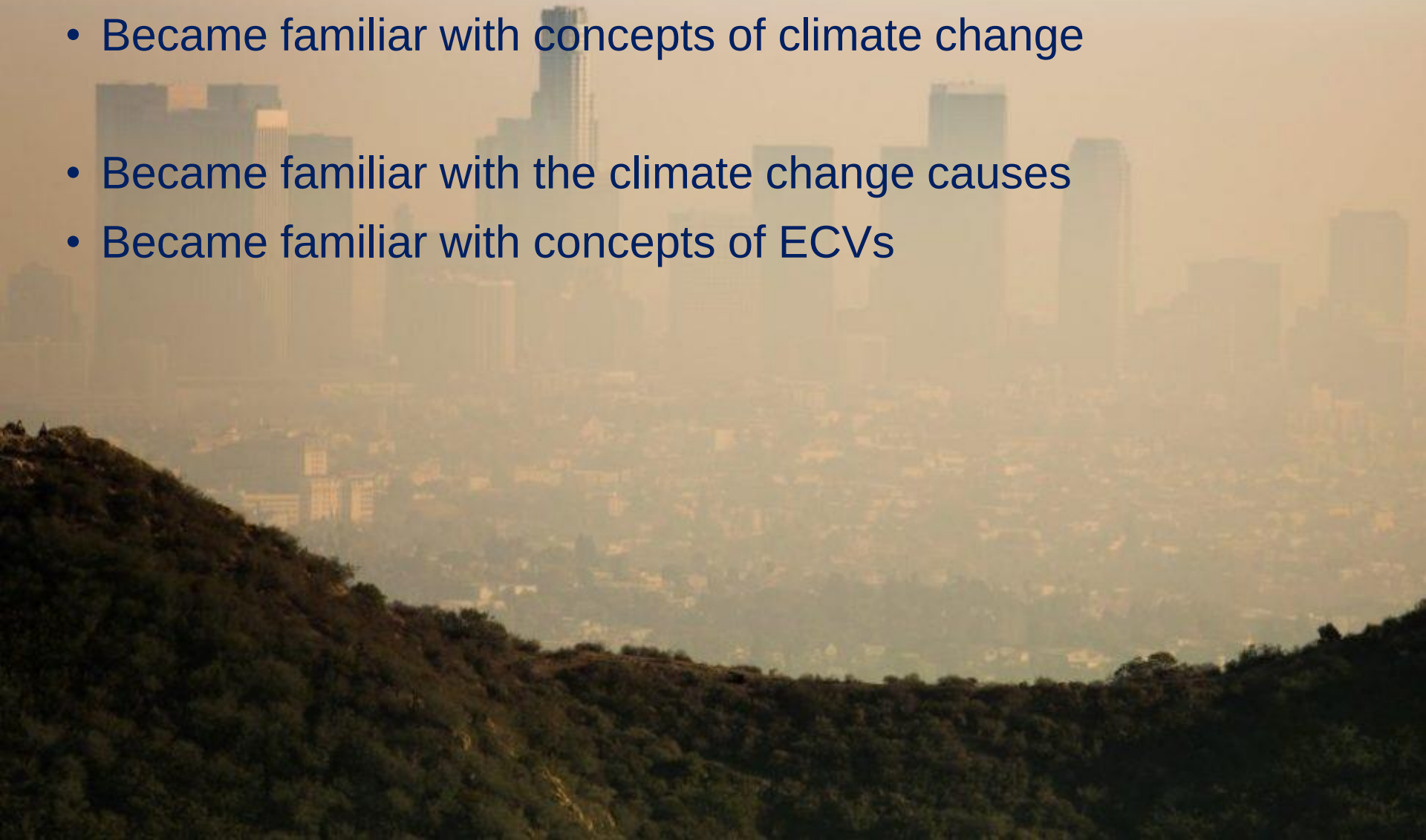
Reference: *Bojinski et al., 2014*

Essential Climate Variables

ATMOSPHERE	OCEAN	LAND
SURFACE	PHYSICS	Above-Ground Biomass
Precipitation	Ocean Surface Heat Flux	Albedo
Pressure	Sea Ice	Anthropogenic Greenhouse Gas Fluxes
Surface Radiation Budget	Sea Level	Anthropogenic Water Use
Surface Wind Speed and Direction	Sea State	Fire
Temperature	Sea Surface Salinity	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)
Water Vapour	Sea Surface Temperature	
UPPER-ATMOSPHERE	Subsurface Currents	Glaciers
Earth Radiation Budget	Subsurface Salinity	Groundwater
Lightning	Subsurface Temperature	Ice Sheets and Ice Shelves
Temperature	Surface Currents	Lakes
Water Vapour	Surface Stress	Land Cover
Wind Speed and Direction	BIOGEOCHEMISTRY	Land Surface Temperature
COMPOSITION	Inorganic Carbon	Latent and Sensible Heat Fluxes
Aerosols Properties	Nitrous Oxide	Leaf Area Index
Carbon Dioxide, Methane and other Greenhouse Gases	Nutrients	Permafrost
	Ocean Colour	River Discharge
Cloud Properties	Oxygen	Snow
Ozone	Transient Tracers	Soil Carbon
<u>Precursors</u>	BIOLOGY/ECOSYSTEMS	
	Marine Habitat Properties	Soil Moisture
	Plankton	

Summary

- Understood the difference between weather and climate
- Became familiar with concepts of climate change
- Became familiar with the climate change causes
- Became familiar with concepts of ECVs



Data clinic

- Let's get this sorted! 😊

