# CLIMATE CHANGE

LECTURE 1

## DIFFERENCE BETWEEN CLIMATE AND WEATHER

**Weather** describes atmospheric conditions over a **short** period of time (minutes to weeks), while **climate** describes atmospheric conditions over a **long** period of time (years to centuries). Climate is a reflection of average weather over time and space.

Weather is constantly changing, whereas climate, the long-term average of weather, undergoes more gradual change and is easier to predict.

## FACTORS AFFECTING EARTH’S CLIMATE

1. Earth's **proximity** to the sun and **elliptical** orbit – solar **radiation**.

2. **Angle** of Earth's axis, which leads to climatic differences at different **latitudes**.

3. Earth's [**albedo**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%201/lesson1.html), which affects the amount of **solar energy** that gets absorbed by Earth's surface.

4. The number and type of **molecules in Earth's atmosphere**, which interact with [**electromagnetic radiation**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%201/lesson1.html).

5. Earth's **ocean and atmospheric currents**, which **transfer** huge amounts of **energy** around the globe and influence weather patterns.

6. The [**biosphere**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%201/lesson1.html), which contributes to atmospheric **gas concentrations** and affects Earth's **albedo**.

## FACTORS AFFECTING EARTH’S WEATHER

1. **Mountains affect precipitation** and evaporation patterns. One side of a mountain range is generally humid and rainy, while the other side is arid.
2. **Water bodies play a large role in regulating local climates**. A region's proximity to the ocean affects its average temperature and precipitation.
3. Components of the landscape, such as **vegetation and rock cover, affect the amount of energy that reaches Earth's surface**.
4. Geothermal vents, **volcanoes, living creatures, and vegetation** contribute to the **gases** and particles in our atmosphere. Some of these affect the climate as a whole, while others have regionally specific impacts.

## PARTS OF THE ATMOSPHERE

1. **Troposphere(temp decreases with height)** – **Greenhouse gases are found in this layer. 85%** of the mass of the atmosphere is found in the troposphere. It gets colder with increasing altitude, as fewer molecules are present to absorb infrared radiation from the sun and the surface of the Earth.
2. **Stratosphere(temp increases with height) -**  **Conversion of UV to thermal energy** through a series of **photochemical reactions** involving sunlight, Oxygen and **Ozone** whose rate depends on altitude. These reactions shield the Earth from damaging UV radiation.
3. **Mesosphere(temp decreases with height) -**

* Temperature in this region decreases with altitude and falls as low as -100 °c.
* **Meteoroids** enter this region and burn up on collision with gases.
* Upper mesosphere, **noctilucent ('night shining') clouds**, composed primarily of water ice, form during the **summer months** at **high latitudes**. They appear as bright clouds visible throughout the night.

1. **Thermosphere** – Aurora Borealis ( Northern lights )

* Auroral arcs – length : thousands of kms, width: 1km at altitudes: 100-400 km
* Produced when energetic electrons enter the thermosphere and excite primarily **Oxygen** and **Nitrogen** atoms. The excited atoms emit energy as light, some of which is visible.

**Green – oxygen**

**Blue, purple – atomic and molecular Nitrogen**

* Aurora are created by electrons response to the earth's magnetic field, the dance of the aurora is a result of **subtle shifts in the magnetic field** and the effect this has on the paths of electrons.

1. **Exosphere –** Consists of mainly hydrogen and Helium

## COMPONENTS OF THE ATMOSPHERE

Nitrogen – 78%

Oxygen – 21%

Argon, CO2 (0.03 – 0.04)– less than 1% of the mixture

## REGIONAL CLIMATE DIFFERENCES

The temperature in **El Aziza, Libya** reached **57.8ºC** in **September 1922** - the hottest ever measured on Earth. The coldest temperature measured on Earth was thousands of km’s away in **Vostok, Antarctica, -89ºC in 1983**.

Regional climates are closely dependent on each other. **Heat energy** is **transferred** between regions via **currents and trade winds**; additionally, **water that evaporates in one region often condenses as precipitation in another.**

## TEMPORAL CLIMATE DIFFERENCES

The biggest concern with climate change today is the rate at which it is occurring and the potential for it to continue accelerating.

The world is getting **warmer** on average. Factors such as **precipitation and evaporation** are also changing, and changes in one region often affect climatic patterns elsewhere in the world. "**Global Climate Change**" is descriptive of broader climate factors than just temperature, and is thus a more appropriate term.

The term "**Greenhouse Effect**" compares the insulating properties of Earth's atmosphere to a greenhouse.

LECTURE 2

## ICE CORE DATING

**Paleoclimatology** is the study of past climates.

Ice cores contain clues about **past concentrations of gases in our atmosphere**. [Ice cores](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html) are long cylinders of ice that are drilled out of glaciers and permanent polar ice sheets, where ice builds up year after year without melting. Most cores come from **Antarctica, Greenland, or high altitudes in the Andes and Himalayas.**

Ice cores are core samples taken from undisturbed glacial ice

Samples are normally 10-13cm in diameter, and are cut into 1m lengths for processing and transportation purposes.

A complete site sample can define a climate that is 100,000 to 400,000 years old.

## ANALYSIS

## Ice cores are shipped to clean labs (left) for examination. To maintain purity, only qualified technicians perform the analysis. Half of the core is divided into multiple sections to be analyzed, while the other half is stored in archives. The divided segments are then put through a variety of experiments to gain an understanding of the climatic history held in the ice.

## IMPORTANCE OF ICE CORES

Ice cores are '**Atmosphere Fossils**' that reveal an extensive record of:

* Temperature
* Atmospheric Composition
* CO2 Concentrations
* Concentrations of compounds like CH4, N2O and fifty other chemical species have also been determined
* Evidence of Volcanic Eruptions

## COLLECTION PROCESS

Extracting ice core samples requires a specialized drill. The drill cuts away ice around the desired core. The core, ranging from 4-6m in length, is retrieved once the drill has cut as deep as possible.  
  
Complications arise as the drill goes deeper, due to an increase in pressure from the ice sheet. To overcome this issue, a fluid fills the void as the drill is removed, preventing the core hole from collapsing. Since researchers are looking for trace quantities of various compounds, the fluid must be cleaned off.

## PRESERVATION

The samples need to be kept at very cold temperatures so a freezer truck is used, with a back up waiting in case the first truck fails.  
Once at the storage facility, the sample is stored in sealed 1m segments.

The ice core storage facilities have demanding requirements to properly preserve the samples. An example of this facility is the **National Ice Core Laboratory located in Denver, Colorado**. **Room temperature of -35oC.**

## UNDERSTANDING

The snow in Antarctica does not melt, but becomes **compressed when additional snow falls on top of it. Snow crystals compact together until they form a solid ice matrix, trapping air in tiny bubbles. These bubbles contain gases from our atmosphere long ago.**

After a core is taken, its **layers are dated** and a sample representing a **specific time period** is crushed into small pieces to allow all the **gas bubbles to break down** and the gas to escape.  The gases are often separated by [**gas chromatography**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html) and **carbon dioxide concentration** is measured by either [**infrared spectroscopy**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html) **or** [**mass spectrometry**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html).

We cannot directly measure past atmospheric temperatures from ice cores, but we can obtain data that acts as a [**proxy**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Glossary/Definitions/proxy.html) measurement for global temperatures. A proxy is a record that is interpreted, using scientific principles, to represent a historical variable that cannot be directly measured. The **most commonly used proxy data from ice cores are isotopic ratios**.

I**sotope ratios of water molecules** in ice samples can be measured to determine historical temperatures. **Elements with the same atomic number but different mass numbers are called** [**isotopes**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html)**.**

Most water molecules are made of two atoms of hydrogen (with an atomic mass of 1u) and one atom of oxygen (with an atomic mass of 16u).  However, approximately **one in every five hundred** water molecules contains the heavier isotope of oxygen (**18O**); an even smaller fraction of molecules contain the heavier isotope of hydrogen ([**deuterium**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html)).   
These heavier molecules have **lower** [**vapour pressure**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html)**s, which means that they evaporate less readily than regular water molecules**. This principle allows isotope ratios from ancient ice to be used as a proxy for temperature data.

When water in oceans and lakes evaporates into the atmosphere, water molecules composed of lighter isotopes evaporate more readily than those with heavier isotopes. As a result, water vapor in the atmosphere is isotopically lighter than ocean water.

**Water molecules containing light oxygen evaporate slightly more readily than water molecules containing a heavy oxygen atom. At the same time, water vapor molecules containing the heavy variety of oxygen condense more readily. As air cools by rising into the atmosphere or moving toward the poles, moisture begins to condense and fall as precipitation. At first, the rain contains a higher ratio of water made of heavy oxygen, since those molecules condense more easily than water vapor containing light oxygen. The remaining moisture in the air becomes depleted of heavy oxygen as the air continues to move poleward into colder regions. As the moisture reaches the upper latitudes, the falling rain or snow is made up of more and more water molecules containing light oxygen.**

During ice ages, cooler temperatures extend toward the equator, so the water vapor containing heavy oxygen rains out of the atmosphere at even lower latitudes than it does under milder conditions. The water vapor containing light oxygen moves toward the poles, eventually condenses, and falls onto the ice sheets where it stays. The water remaining in the ocean develops increasingly higher concentration of heavy oxygen compared to the universal standard, and the ice develops a higher concentration of light oxygen. Thus, high concentrations of heavy oxygen in the ocean tell scientists that light oxygen was trapped in the ice sheets. The exact oxygen ratios can show how much ice covered the Earth.

***Ocean waters rich in heavy oxygen: => cooler temperatures***

Conversely, as temperatures rise, ice sheets melt, and freshwater runs into the ocean. Melting returns light oxygen to the water, and reduces the salinity of the oceans worldwide. Higher-than-standard global concentrations of light oxygen in ocean water indicate that global temperatures have warmed, resulting in less global ice cover and less saline waters. Because water vapor containing heavy oxygen condenses and falls as rain before water vapor containing light oxygen, higher-than-standard local concentrations of light oxygen indicate that the watersheds draining into the sea in that region experienced heavy rains, producing more diluted waters. Thus, scientists associate lower levels of heavy oxygen (again, compared to the standard) with fresher water, which on a global scale indicates warmer temperatures and melting, and on a local scale indicates heavier rainfall.

***Ocean waters rich in light oxygen: => warmer temperatures***

*https://earthobservatory.nasa.gov/Features/Paleoclimatology\_OxygenBalance/*

When water vapor then condenses to form precipitation, heavier isotopes condense more readily than lighter ones, causing the 18O/16O and D/H ratios of precipitation to be less than that of ocean water, but greater than that of the water vapor. This process is often referred to as **isotopic fractionation.**

Stable isotope ratios are highest in ocean water, lowest in water vapor and clouds, and intermediate in precipitation. This is due to isotopic fractionation that occurs during the processes of evaporation and condensation.

Precipitation contains fewer heavy isotopes than oceans and lakes. When glaciers expand from additional rain and snow, however, the **precipitation can remain locked in place** for centuries, causing glaciers to act as reservoirs of **isotopically light water**. How different a glacier's isotopic ratios are from the ocean depends greatly on **temperature; colder temperatures mean that fewer heavy isotopes are able to evaporate and the differences in isotopic abundances become more pronounced**. **As the temperature gets colder, therefore, the 18O/16O and D/H ratios of the ice decrease.**

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## HOW TO DATE AN ICE CORE

1. Counting the annual layers (left) marked by differences in 18O, similar to counting tree rings to determine the age of the tree.

Markers for the annual layers – temperature differences.

Temperature differences depend primarily on oxygen isotopes.

Each year begins O18 rich -> O18 poor -> O18 rich

1. Calibration by known historic events like volcanic eruptions and weapons testing.

**Volcanic eruptions -> ash in the atmosphere -> precipitates out**.

When determining the age of a newly extracted core relative to a previously dated ice core, researchers look for similar markers such as similar ash layers. The researched locates these markers and correlates the date with that of the recorded eruption.

**Layers corresponding to the era of atmospheric nuclear weapons tests demonstrate a decrease in 36-Cl concentration.**

Disadvantage : if reference items area dated incorrectly, then ice core data produced is also incorrect.

1. Dating the gas captured in the ice. This is done by retrieving the trapped gas and using either 14C or 36Cl dating techniques to determine the age of the gas.

## LAB PROCESS

* cut away a sample from the ice core at a certain depth.
* melt down the sample at room temperature and place the resulting water in a vial.
* add pure carbon dioxide with a known isotopic ratio to the vial
* maintain at 40°C for five hours

This allows oxygen-18 isotopes to transfer from the water to the carbon dioxide in a process called equilibration

C16O2 + H218O ←→ C16O18O + H216O

The18O isotopes have been transferred from the water to carbon dioxide, giving CO2 the

original isotopic ratio of the water from the ice core.

* Run the CO2 through a **mass spectrometer** and determine the 18O/16 ratio of the sample from the ratio of the intensities of peaks ***44 and 46***.

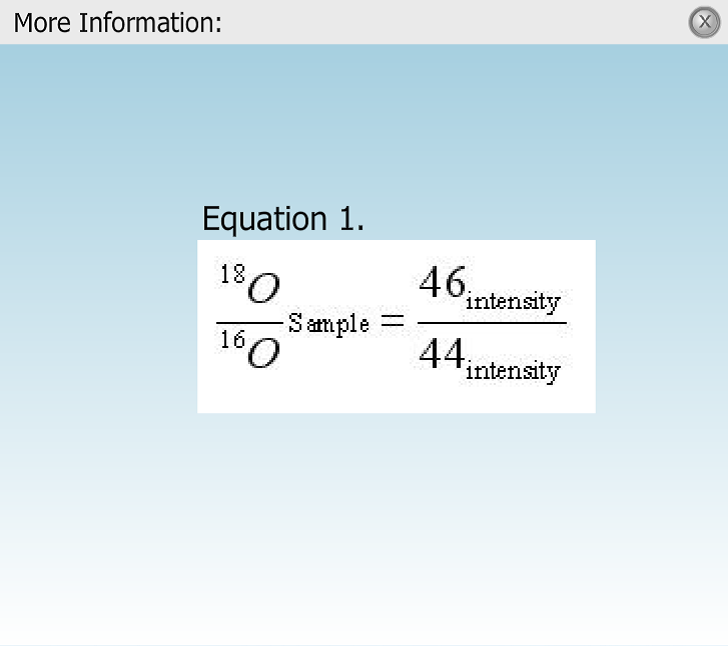
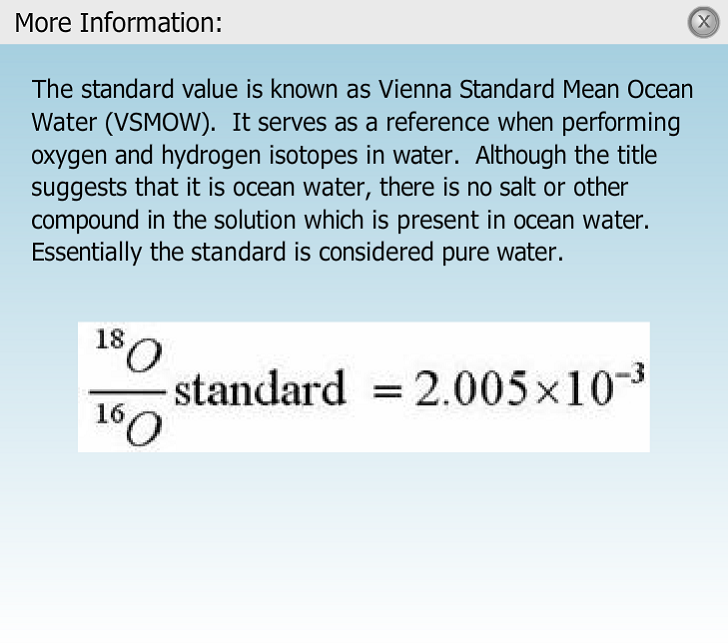
An equation can then be used to relate this to the original atmospheric temperature at the time that the ice formed. These equations vary depending on location, as the relationship between isotopic abundance and temperature is slightly different in each climate.

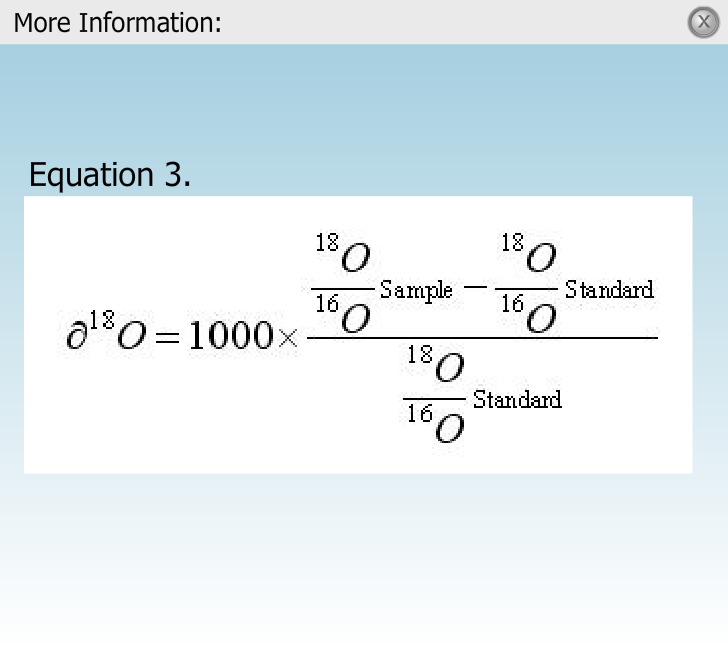
Rsample is the ratio calculated experimentally.

Rstandard is the Vienna Standard Mean Ocean Water (VSMOW) value : 0.00200520. This value is based on the 18O/16O isotopic ratios of pure water.

δ18O = [(Rsample – Rstandard) ⁄Rstandard] x 1000

## EQUATIONS



**As drilling locations change, the relationship also changes. δ values are not affected solely by temperature variations.**

## ATMOSPHERIC CO2 – FOSSIL FUELS AND PHOTOSYNTHESIS

The gas must be expelled from the ice cores for experimental analysis; this is done by crushing the sample under vacuum. **The gas bubbles trapped in the ice are not exactly the same age as the ice surrounding them due to the naturally slow process of gas entrapment.**

Fossil fuels are derived from fossilized plants.

**Through the process of photsynthesis plants more readily take up the isotope 12C.**

The preference causes the 13C/12C ratio to be lower than the atmospheric 13C/12C ratio.

The 13C/12C ratio of the atmosphere decreases as more CO2 from burning fossil fuels is introduced.

With 'very high confidence' it can be understood that human activities, since 1750, are responsible for the increase in concentration of CO2 in the atmosphere.

## ADVANTAGES AND DISADVANTAGES

* less uncertainty involved
* Evidence available freely and in many places to reconstruct conclusion
* Warming and increasing impurity levels both tend to favor biological activity or chemical reactions that could
* obscure the environmental record in ice cores.
* At sufficiently great depth and pressure, the bubbles in ice cores disappear as solid air clathrates (lattices that trap gas) develop.

## QUESTIONS

1. **Over what part of the world would you expect to find a higher 18O/16O ratio in clouds? Why?**

*Stagnant water bodies in areas of heavy precipitation. heavy isotopes condense easily and collect here.*

1. **Why does the isotopic composition of ice in Antarctica change due to temperature changes elsewhere*?* What will happen to the proportion of heavy isotopes in the ice in Antarctica if global temperatures rise?**

*Proportion of heavy isotopes will increase in Antarctica when temperature increases globally due to run off from rivers and seas in warmer areas into the oceans and reach the poles.*

1. **How are the layers of ice within the cores dated? What characteristics of ice core layers signify when events, such as volcanic eruptions, have occurred? What type of laboratory technique is used to characterize isotopes in ice? How does this technique work?**

*Dated using 3 techniques :*

* *Dating the gas captured in the ice*
* *Calibrating with known events in history like volcanoes and weapon testing.*
  + *Concentration of Cl in layers dated corresponding to time periods involving volcanic eruptions is low.*
* *Marking with annual layers*

*Mass spectrometer is used to find peaks at 44 and 46 in the Carbon dioxide formed by exchange of 18O and 16O from the ice to the CO2. The ratio is then calculated and put into an equation to get the value of delta 18O.*

1. **What are some possible reasons for historical fluctuations in atmospheric gas concentrations?**

*This happens because of variation in the sources and sinks of gases.  
Animals exhale carbon dioxide, volcanoes release sulfur and nitrogen compounds, soil organisms produce nitrous oxide, and dead plant material releases methane. Living plants fix carbon dioxide through photosynthesis. Changes in plant or animal populations affect atmospheric gas concentrations.*

*Sink - Any process, activity or mechanism that removes a greenhouse gas, an aerosol or one of their precursors from the atmosphere.*

## HISTORICAL AND CURRENT TEMPERATURE TRENDS

Although the planet's climate has always fluctuated, the rate of change has become more dramatic since the Industrial Revolution. This suggests that recent changes have [anthropogenic](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html) origins.

Anomaly - A difference from the mean for a given time period.

Ice Age - An ice age or glacial period is characterised by a long-term reduction in the temperature of Earth's climate, resulting in the growth of continental ice sheets and mountain glaciers.

Glacial Period - A time in earth's history, often lasting thousands of years, in which average temperature is cooler and glaciers are advancing, generally occupying much of earth's surface.

Interglacial Period - A time in earth's history, often lasting thousands of years, in which average temperature is warmer and glaciers are generally retreating and do not dominate the landscape. We are currently living in an interglacial period. The previous interglacial, from approximately **129 to 116 kya**, is referred to as the Last Interglacial.

Greenhouse Gas (GHG) - Gases in the atmosphere, both natural and anthropogenic, that are capable of absorbing and re-emitting infrared radiation. Water vapour, carbon dioxide, nitrous oxide, methane, and ozone are the primary greenhouse gases in Earth's atmosphere.

## Atmospheric gas concentrations

They can be interpreted from ice cores. Carbon dioxide, methane and nitrous oxide are three commonly measured gases that influence climate.

Important sources of carbon dioxide include fossil fuel combustion, plant and animal respiration, and ocean-atmosphere exchange. Sources of methane include natural gas, wetlands, livestock, and landfills. Sources of nitrous oxide include agriculture, manure, industrial processes and waste management practices.

## SHORT AND LONG TERM REVERSALS

there’s so much variability in the climate that you can expect the short term trends to reverse from time to time, even as the world warms up in the long term. One way to assess evidence like this is to ask how often a reversal like this has happened before.

<http://explainingclimatechange.ca/Climate%20Change/javascript/HistoricClimateChange/getting%20started/Climate%20Change%20and%20the%20Long%20Term.pdf>

## RELATIONSHIP BETWEEN GAS AND TEMPERATURE TRENDS

An increase in temperature can increase the number of living CO2 sources on our planet.

Between 138,000 and 126,000 years before present (YBP), temperature changes preceded changes in CO2 levels. This suggests that temperature changes caused changes in CO2 concentration. On the other hand, between 340,000 and 323,000 YBP, CO2 increases preceded changes in temperature.

The data reveals a correlation between CO2 concentrations and temperature. Generally, CO2 concentrations are high when temperature is high, and vice versa. This correlation could be due to one factor causing another, but causation is not clearly demonstrated in the data.

The first [industrial revolution](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%202/lesson2.html) began in the mid 18th century, and since then technology has been quickly evolving to meet our desires for energy, food, travel, and communication. Human inventions have released anthropogenic compounds into our environment, resulting in previously unseen rises in atmospheric gas concentrations and temperature.

Until 250 years ago, the highest rate of temperature increase recorded was approximately 0.003°C per year. For the last 10 years, the rate of temperature change has been approximately 0.017°C

LECTURE 3

## TEMPERATURE AND ENERGY IN THE ATMOSPHERE

There are three types of energy transfer that play a role in climatic processes:

[**Convection**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html): The transfer of energy by the movement of molecules in fluids (liquids or gases that flow). This lizard feels convection as a cool breeze. - Wind currents and ocean currents

[**Radiation**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html): The transfer of energy by electromagnetic waves. The lizard feels radiation from rays of [visible](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html) and [ultraviolet light](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html) coming from the sun.

[**Conduction**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html): The transfer of energy through direct contact and collisions between neighboring molecules. The lizard pictured above feels heat energy transferring directly from the warm rock to his underbelly, increasing the average kinetic energy of the particles that make up his body. - An example of conduction is the transfer of energy through soil. Particles within the soil collide with each other directly, transferring kinetic energy.

## MODELS OF EARTHS ATMOSPHERE

1. Greenhouse model

A greenhouse maintains a healthy, comfortable temperature by absorbing radiant energy from the sun, emitting [infrared energy](http://explainingclimatechange.ca/Climate%20Change/Lessons/Glossary/Definitions/infrared%20radiation.html) (heat) and preventing the loss of that heat through convection.

The Earth's surface is warmer than the outer atmosphere, just as the inside of a greenhouse is warmer than outside. **Earth's atmosphere does not 'trap' heat by stopping convection like a greenhouse does. 'greenhouse gases' in our atmosphere absorb outgoing energy and re-radiate it back towards the Earth, transferring energy to nitrogen and oxygen molecules in our atmosphere, increasing their kinetic energy.**

1. Blanket model

A blanket or sleeping bag keeps the wearer warm by preventing convection of the heat energy the wearer produces. This model suggests that the atmosphere acts as a 'blanket of air' that prevents heat loss.

## PROPERTIES OF GASES

Climatic processes depend on molecular-level interactions among gases.

Characteristics of gas molecules that affect their behaviour:

* Atomic mass
* Constituent atoms
* Distribution of positive and negative charges ( polarization )
* Strength of bonds

Gaseous molecules – covalent bond connection

## IDEAL GASES

For an ‘ideal’ gas, the volume of the gas particles is extremely small compared to the volume of the container and the gas molecules exert no intermolecular forces on one another. Real gases are never perfectly 'ideal', but their basic properties can still be described using the ‘ideal' gas model. In an ideal gas:

* Gas particles are in **continuous, random motion** and collide with other particles
* The temperature of a gas is proportional to the average **kinetic energy** of the gas molecules
* At the same temperature the **average kinetic energy of a gas is the same** for all gases, regardless of their size or mass

PV = NRT R = (8.314 J/K/mol), and T is temperature (Kelvin).

## ABSORPTION AND EMISSION OF RADIATION

1. [visible light](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html) - sun, candles, and electrical sources.

2. [ultra-violet radiation](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html) - higher energy than visible light and is produced by the sun.

3. [Infrared radiation](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html). We feel infrared radiation as thermal radiation, or heat. Sources include the Earth’s core, the sun, and humans.

Infrared Spectroscopy - Used to determine connectivity patterns between atoms in molecules by measuring the absorption of infrared radiation as a function of the wavelength, which can reveal details about a molecule's composition. Also used to determine if a gas is a greenhouse gas.

**The infrared spectrum of a greenhouse gas demonstrates the wavenumbers at which molecules of that gas absorb IR.**

CFCs absorb IR that has a wavenumber of about 1000 cm-1. However, water absorbs IR of much higher wavenumbers (and higher energy), above 3500 cm-1.

## QUESTIONS

1. How does a microwave work?

Microwave ovens are so quick and efficient because they channel heat energy directly to the molecules inside food. A microwave oven cooks food because the water molecules inside it absorb the microwave radiation and thereby heat up and heat the surrounding food.

2. Influence of a. UV b. Infrared on CFC

a. CFCs do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break up CFC molecules is ultraviolet radiation. In the lower atmosphere, CFCs are protected from ultraviolet radiation by the ozone layer itself. CFC molecules thus are able to migrate intact up into the stratosphere. Although the CFC molecules are heavier than air, the air currents and mixing processes of the atmosphere carry them into the stratosphere.

Once in the stratosphere, the CFC molecules are no longer shielded from ultraviolet radiation by the ozone layer. Bombarded by the sunÕs ultraviolet energy, CFC molecules break up and release chlorine atoms. Free chlorine atoms then react with ozone molecules, taking one oxygen atom to form chlorine monoxide and leaving an ordinary oxygen molecule.

If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs would pose very little threat to the ozone layer. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom breaks up the chlorine monoxide, stealing the oxygen atom and releasing the chlorine atom back into the stratosphere to destroy more ozone. This reaction happens over and over again, allowing a single atom of chlorine to act as a catalyst, destroying many molecules of ozone.

b. CFC absorbs the most amount of infrared radiation than any other greenhouse gas.

3. In what region of the electromagnetic spectrum (in wavenumbers) does the Earth emit energy?

Wavelength : 10 micrometers.

## ATMOSPHERIC MOLECULAR INTERACTIONS

A molecule will absorb IR radiation if the distribution of charge on the molecule changes during a [vibration](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html). For [diatomic molecules](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html), if the two atoms are of different elements, the distribution of charge will change during a vibration. Therefore, all molecular substances, except for [homonuclear diatomic molecules](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html), can absorb IR radiation and act as greenhouse gases.

**Although nitrogen and oxygen cannot absorb IR, they can interact with greenhouse gas molecules such as carbon dioxide and water. N2 and O2 molecules gain energy through conduction when they collide with excited greenhouse gas molecules. This process is called** [**collisional de-excitation**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html)**.**

A greenhouse gas has the most impact when its absorption peaks overlap strongly with the wavenumbers of energy emitted by the Earth.

There are two ways that CO2 can lose the energy it has absorbed:

1) it can re-emit a photon in a random direction, or

2) it can collide with another molecule, such as oxygen or nitrogen, causing the other molecule to gain kinetic energy (move faster). This will lead to atmospheric heating.

## LAPSE RATE AND EARTHS RADIATIVE ENERGY BALANCE

Tropospheric lapse rate is the rate at which temperature decreases with increasing altitude.

The atmosphere is made up largely of naturally compressible gases – mostly nitrogen (N2) and oxygen (O2). The earth’s gravitational pull on these gases causes them to **compress** as you approach the surface of the earth. Since compression of gases causes heating, the earth’s atmosphere has a natural temperature profile, getting warmer as you move from the top of the atmosphere to the earth’s surface.

To maintain its energy balance, Earth must emit some of the energy it receives from the sun.

The **Earth primarily emits energy in the Infrared** **(IR) region**. Photons of IR energy excite greenhouse gas molecules, which then transfer their energy to surrounding nitrogen or oxygen molecules. Therefore, **Even though photons of IR get emitted from Earth, many of them get absorbed by greenhouse gas molecules in the troposphere and their energy ends up being absorbed rather than leaving Earth’s atmosphere.** The probability is very low that a photon close to Earth’s surface will escape directly into space. However, as we move higher in the troposphere, there are fewer molecules to absorb the IR photons, and the probability that the photons will escape increases.

**Effective Radiation Altitude** - The altitude at which IR photons have a high probability of escaping into space relative to the altitudes below it. Emission that takes place higher up in the troposphere does so at a lower temperature and therefore less energy is leaving the lower atmosphere. **As the effective radiation altitude increases, the troposphere retains more energy, causing tropospheric warming.**

As the CO2 concentration goes up, the effective radiation altitude increases.

As the effective radiation altitude increases, the temperature at which emissions occur is lower, and so more energy is trapped in the lower troposphere causing the temperature of Earth’s lower troposphere to rise.

Factors determining impact of a greenhouse gas:

1. The **lifetime** of the gas molecules in the atmosphere before they are [broken down](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%203/lesson3.html) or removed in some other way from the atmosphere.
2. The **concentration** of the gas in the atmosphere.
3. The **region of IR that the gas absorbs and how strongly the gas absorbs IR**, relative to the emission spectrum of the Earth (if a gas absorbs IR in a different region than the Earth emits, it may not cause atmospheric warming).

The **Global Warming Potential** of a gas is a comparison of its potential to increase atmospheric temperatures relative to an equivalent amount of CO2 gas. This measure is not based on concentrations, but focuses on the atmospheric lifetimes of gases and the region of their IR absorbance

LECTURE 4

## TEMPERATURE AND ENERGY IN THE ATMOSPHERE

**Radiation Balance** - The difference between total incoming and total outgoing energy. If this balance is positive, warming occurs; if it is negative, cooling occurs. Averaged over the globe and over long time periods, this balance must be zero to maintain a stable climate.

A perturbation of this global radiation balance is called **radiative forcing**.

The Earth's surface heats up by absorbing some of the radiation that reaches it from the sun. Earth is a [blackbody radiator](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html) of energy. It absorbs photons of [electromagnetic radiation](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html) and re-emits them at a different frequency.

## INCOMING SOLAR RADIATION

99% of Earth's incoming radiation comes from the sun, predominantly in the form of [ultraviolet](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html) (UV), [visible](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html) (vis) and [infrared](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html) (IR) radiation.

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**Sun: VISIBLE, infrared, UV**

**Earth: Infrared**

Surface temperature depends on:

1. incident energy -> distance, surface area

2. thickness of atmosphere

3. ice, soil – reflect radiation

30% of the energy that reaches the top of the Earth’s atmosphere is reflected away. This reflection of light away from the earth is due to [albedo](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html).

Aerosols can **reflect incoming energy** in several ways. Individual suspended particles can reflect incoming photons of light back out of the atmosphere. They can also [coalesce into raindrops](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%204/lesson4.html) and become constituents of light-reflecting clouds.

**If the Icelandic volcano Katla erupts, the particulate matter released may reflect enough solar energy that Earth's temperature will noticeably cool in the short term. In the long term, the gases it releases, such as SO2 and CO2, may have other climatic effects.**

Clouds play an important and complex role in the moderation of Earth's climate. They contribute to Earth's albedo by reflecting light and shading us from the sun. They also contain molecules that absorb infrared radiation and contribute to the greenhouse effect.

On increasing earths surface temperature, lesser amount of energy is reflected back.

Avg temp of earth – 15 degrees, but local weather : wide range. Global warming plays a role in regulating earths surface temperature

Enhanced Greenhouse Effect - The effect of increasing greenhouse gas concentrations in the atmosphere, which leads to an increase in temperature through increased absorption of the infrared radiation emitted by Earth.

Greenhouse Effect - The process by which greenhouse gases absorb thermal infrared radiation emitted by the Earth's surface. Greenhouse gases transfer their absorbed energy to other molecules through collisional de-excitation. This increases the kinetic energy of other molecules, such as nitrogen and oxygen, thereby increasing the temperature of the air.

LECTURE 5

## IMPACTS OF CLIMATE CHANGE

**Models are descriptions or representations of a phenomenon that help us to better understand that phenomenon. – not the real thing, has its limitations.**

**General circulation model (GCM)** – most advanced tool at present to model effect of increased greenhouse gases. – limited. Can only model relationships in the climate system as well as we understand them, difficult to model parts of the system that occur on a small scale.

All models used to predict the future are first tested against the past.

**Paleocene-Eocene Thermal Maximum (PETM)** - A period of maximum global temperatures lasting approximately 100,000 years at the boundary between the Palaocene and Eocene epochs. This period was characterized by a temperature anomaly of greater than 5°C, **high atmospheric CO2 and CH4 concentrations, carbon fluxes on the order of 2000 Gt C/year and widespread extinctions.** Scientists are studying this period intensively as it has some similarity with the current anthropogenic release of carbon into the atmosphere. - caused by the destabilization of [methane clathrate hydrates](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%205/lesson5.html). - movement of Earth's tectonic plates disrupted ocean circulation patterns, creating a warming of Arctic waters by about 1.0-2.5°C. This was enough warming to destabilize the arctic store of methane clathrate hydrates.

**IPCC Scenarios – intergovernmental panel on climates change.**

**SRES – special report: emissions scenario – report describing how human greenhouse emissions might change over the next century – provide necessary assumptions about economic growth, population growth, environmental policy and other factors influencing human interaction with climate.**

**Scenarios are grouped into general storylines**

Polar ice plays a vital role in the climate system due to its [albedo](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%205/lesson5.html). As the ice melts, less solar radiation is reflected into the atmosphere. This leads to increased temperature which then creates more ice melt. This is an example of a positive feedback loop in which a disturbance, in this case increasing temperature, results in an amplification of that disturbance

## CORAL REEFS

**The vibrant colours that attract both fish and humans are the result of a symbiotic relationship between invertebrate coral polyps and colourful zooxanthellae algae. Corals provide algae with protection and nutrients. In return, the algae provide the corals with sugars produced via photosynthesis.**

**Coral bleaching –** coral hosts cast out their algae, causes discolouring. Bleaching events are not lethal to corals but if it occurs over a prolonged time, the coral host will eventually die. Corals live in zones of relatively stable temperature. As a result, they have evolved to tolerate a narrow range of temperatures.

Corals bleach when they are subjected to some form of stress for a prolonged period of time. These stressors can be either anthropogenic or natural in origin, and a bleaching event may be caused by a combination of these stressors – increased temperature is also a form of stress.

**Temperature** increases -> **zooxanthellae** become **more sensitive to light** -> cant photosynthesize -> coral expels them -> discolouration

Increasing ocean temperatures will cause ocean water to expand and ice sheets to melt, resulting in **rising sea levels**. In turn, this will decrease the habitat available for coral reefs by limiting the light that is able to reach the reefs at their fixed location on the ocean floor.

-temp increase-> ice melts -> water level increases -> **light** penetration decreases-> algae cant photosynthesize

– Co2-> air-> water-> pH->acidification- removes **calcium carbonate**-> even from shells of corals, shell fish (even marine pteropod – sea butterfly )

Pollution, sea-bed trawling, predator outbreaks, invasive species, and overfishing are some of the other pressures that reef ecosystems face. The combination of these pressures weakens the coral, making them more susceptible to disease. As a result, recovery from bleaching events is increasingly difficult and bleaching events often lead to coral mortality.

* **Pharmaceutical** : Medicines for asthma, arthritis, heart disease, and cancer are being developed from organisms that rely on coral reef ecosystems.
* **Fisheries**: Nurseries for a large portion of commercial fish species.
* **Tourism**:
* **Insurance**: reduce the **wave action** of the ocean against the coastline. This reduces the severity and damage from storms, erosion, and flooding. This will cause an increase in insurance pay outs.

## VECTOR BORNE DISEASES

Malaria is the cause of 1 in 5 African childhood deaths.

Malaria -> **Anopheles mosquito** which introduces the malaria **parasite** into the victim where it **matures and multiplies.** This makes malaria **a** [**vector-borne disease**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%205/lesson5.html) **(VBD)**. Both the mosquito and parasite associated with malaria tend to thrive in **warm, humid regions**, especially after large rainfalls leave standing water in which the mosquito can lay eggs.

Mosquitos -> extremely sensitive to changes in temperature and precipitation. So such elevated areas were previously thought to be unaffected by malaria because they **did not have a suitable climate to support the necessary mosquito populations.**

**Anopheles mosquitos require temperatures of greater than 16°C** to complete their life cycles and the **parasites develop more rapidly at temperatures above 20°C.** The activity level of both mosquito and parasite increase when temperatures are above these minimums. This leads to more infected bites. Given the right conditions, certain species of the malarial parasite can be transmitted to **200 people** by the same mosquito.

Prevention:

**Health care**: During times of **civil unrest, medical services often decline because they are dependent on funding from the government or outside sources.** The **quality of healthcare can also decrease after a large disturbance or natural disaster**.

**Malaria prevention**: use **insecticide-treated nets and mosquito repellent sprays**. Treating babies with **sulfadoxinepyrimethamine (SP)** at the time of routine vaccinations has been shown to reduce the frequency of **clinical malaria episodes by 60%**.

**Human immunity**: Human populations in areas where malaria is an endemic disease often have higher percentages of the [**sickle-cell trait**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%205/lesson5.html). This trait increases an individual's resistance to malaria. People who move from low-risk to high-risk areas are often more likely to contract malaria because they have a smaller chance of carrying the sickle-cell trait People are also more prone to disease during times of stress, such as **war or famine, when immunity is decreased.**

**Drug Resistance**: In some areas, malaria has become resistant to **chloroquine**, the cheapest and most commonly used anti-malarial drug.

**Sickel cell trait** - individual has **one sickle gene and one normal adult hemoglobin gene**. Because the sickle gene is recessive, this person does not have sickle-cell disease, a condition caused by two sickle genes which can lead to death or severe illness.

## EXTREME WEATHER

Extreme weather events are a normal part of climate variability. However, as climate changes, extreme weather events may increase in severity or frequency.

As temperature increases, more water molecules gain the necessary energy to enter the gas phase **rate of evaporation increases.**

More water molecules enter the atmosphere as temperature increases. Cooler temperatures are required for the water vapour molecules to condense into water droplets. **Because temperatures are warmer, less water vapour condenses and precipitates out, leaving more water vapour in the atmosphere than before.**

**For hurricanes to form,** [**Sea Surface Temperature**](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%205/lesson5.html) **(SST) must be above 27°C. After this point, the storms gain their energy from the condensation of moist air.**

**ENSO** El Niño-Southern Oscillation - Refers to the **periodic climate pattern** that occurs across the **tropical Pacific Ocean** roughly every **five to seven years**. It is characterized by variations in the **surface temperature** of the tropical Eastern Pacific Ocean - **warming or cooling known as *El Niño*** and ***La Niña*** respectively - and **air surface pressure in the tropical Western Pacific** - the ***Southern Oscillation.***ENSO causes extreme weather (such as floods and droughts) in many regions of the world.

Atlantic: el nino – decreases hurricane activity, la nina the other way around

**Increased rates of evaporation can also produce water shortages, or drought**. Drought is also partly influenced by the accelerated loss of snow caps and glaciers. This melt water provides vital water resources that many human communities depend upon.

climate change is also expected to **produce more flooding**. The higher moisture content in warm air increases the water vapour available to form precipitation. This increases the likelihood of flooding. The risk of flooding is especially high for coastal areas where **rising sea levels also present a problem.** **Although increased heavy rainfall is projected for some regions, annual mean rainfall is expected to remain unchanged or decrease in other areas.**

## BIODIVERSITY

**Thermoconformer** - An organism subject to change in body temperature according to change in the environment.

**Frogs** are thermoconformers. They become more **susceptible to infection when they are exposed to changing temperatures. Chytridiomycosis**, a **highly contagious** and often **lethal disease** caused by **chytrid fungus**, is becoming widespread and threatening frog species around the world.

Scientists project that a rise of **1.5-2.5°C** in **global average temperatures** will lead to the **extinction of 20-30%** of Earth's species. Species that live on **isolated islands, northern latitudes, and at high elevations** are at the highest risk. A rise of **3.5°C** would eliminate the habitat of almost half of the vertebrate species [endemic](http://explainingclimatechange.ca/Climate%20Change/Lessons/Lesson%205/lesson5.html) to **mountain habitats**.

**Boreal forests**, for example, are moving north at a rate of **100-150 km** per degree of temperature increase. All species **dont respond to a shift in climate at the same rate**. This **disrupts many ecosystems** as some species are **forced to migrate** away from components of the ecosystem that they rely on, such as ideal food sources. **Newcomers to an area also put stress on existing populations by competing for limited resources.**

LECTURE 7

## CLIMATE FEEDBACK

**The earth's climate system is directed by feedback loops (also known as feedback cycles). A feedback loop is a circuit-like system in which an initial disturbance acts as an input into the system. This creates a change in some other component of the system, known as an output, which then influences subsequent occurrences of the initial disturbance.**

In a **positive** feedback loop, the output of the system serves to reinforce or amplify the initial disturbance.

In a **negative** feedback loop, the output of the system acts to restrict the effects of the initial disturbance.

Positive feedback – human population – exponential – 20th century – more people producing more people who in turn produce more people. Limiting factor – carrying capacity – population crash.

**Carrying Capacity -** The maximum population of a particular organism that a given environment can support without detrimental effects.

**Populations exhibit natural feedback cycles in which there are both positive and negative influences on the population as a result of the population.**

Many climate feedback loops are in a **delicate balancing act** that is **sensitive to small changes**. If altered, systems such as the **water vapour feedback system or the carbon dioxide thermostat** system, have the potential to significantly change earth's climate.

**forcings** can set feedback loops out of balance and into motion

Non-condensing Greenhouse Gases - Greenhouse gases, such as carbon dioxide, that do not condense and precipitate on earth; opposed to condensing greenhouse gases, such as, water vapour, which readily condenses and precipitates on earth.

## CARBON DIOXIDE THERMOSTAT

* volcanic eruption increases carbon dioxide concentration
* temperature increases with carbon dioxide concentration, allowing more water vapour to be held in the air
* more water vapour leads to more frequent heavy precipitation events
* heavy precipitation events expose rock which can react with carbon dioxide to form carbonate, removing carbon from the atmosphere
* as carbon dioxide concentrations decline, temperature and water vapour concentrations also decrease
* fewer precipitation events slow the rate of weathering

**Carbon sinks : vegetation, ocean – take in almost half of C emissions annualy**

Carbon cycle:

Long term -

* The weathering of rock
* deposition of sediment
* compression of biomass into fossil fuels
* movement of tectonic plates
* activity of volcanoes

**Ocean mixing** – distribution of C compounds in ocean is highly variable. Water in contact with air and having aquatic life have different concentration of C than deeper waters. C: shallow ocean -> deep ocean through ocean conveyor currents. Some C – floor and enters long term carbon cycle through tectonic activity.

**Ocean and atmosphere exchange carbon** – net transport of carbon into ocean. -> reduces pH, acidification, carbonate dissolution, influences shells and mollusks

Human impact – gigatons of C into atmosphere from C fossil fuel reservoirs. Changing natural balance.

**Weathering and sedimentation** – removal of co2 from air and conversion into water soluble compounds. Streams and rivers -> oceans where complex carbon chemistry takes place, some C is deposited on floor.

When tectonic plates slide, carbon slides from ocean floor to earths crust. Co2 is released to ocean. The subducted carbon may reappear later as co2 in volcanic eruptions.

Short term –

* Photosynthesis
* Land reuse
* Cellular use

**Fertilization effect** - Increased rate of plant growth in conditions of higher carbon dioxide concentration. Generally applies to plants with a C3 photosynthetic pathway. – limited by N2 O2 limitations.

The cycling motion of the ocean is driven by **density gradients**. Increased global temperatures are adding large quantities of fresh water to the ocean through melting of glaciers and increasing numbers of heavy precipitation events. Both of these factors affect the density of ocean water and may lead to **stagnation** of the ocean's circulation. **Without the ability to travel to the ocean's depths, surface carbon concentration will increase, slowing the ocean's absorption of carbon**.

C intake : photosynthesis of plankton. When the plankton die, their bodies often sink to the ocean floor C-> floor ( long term cycle ). The amount of carbon they can take is limited by the availability of nitrate, phosphate, and trace elements like iron. Inc iron -> inc phytoplankton

## PERMAFROST AND METHANE CLATHRATE HYDRATES

Carbon cycle – includes processes that occur on a glacial time scale – acts to amplify the effects of climate change through +ve feedback loops. **This helps explain oscillation between glacial and interglacial climate periods.**

**Buffering action of carbon sinks – moderates climate change caused by anthropogenic emissions, at the same time – increasing global average T -> triggers +ve feedback loops of C cycle and begin amplifying climate change.**

**Permafrost** (350-950 tonnes of C can be released )– A layer of soil ( 10’s of cms – 100’s of m’s) – remains frozen year round – Organic material : stored intact here, **kept from decomposing by the frigid temperature.** Found : mammoths.

Permafrost thaws : subsides : creates depressions in which water can pool – here : anaerobic, methane producing bacteria can begin decomposition of stored carbon.

If the seasonally defrosting layers soil is not covered by water, the anaerobic bacteria cant survive, instead C producing bacteria become active in the decay process. -> Both ways : +ve feedback, increasing decomposition of C, amplifying climate change.

Methane clathrate hydrates – within permafrost, also found in shallow ocean seabed and deep ocean. 1m cube of MCH -> 164 m cube of Methane. = 3000 times Methane in atmosphere

MCH – formed in low T, high P

Location of hydrates influences their stability in a changing climate.

**Shallow ocean Clathrates** (unstable in inc T) – destabilized by Sea level rise as warmer ocean, water floods. Ice melts with increasing T, reducing P, destabilizing them.

**Deep ocean Clathrates** (stable to inc T)– pressure increases with increase in sea level rise, so stabilizes. T rises slowly in deep ocean due to large specific heat capacity.

**Methane : global warming potential = 25 times that of CO2 on a 100 year horizon**

## WATER FEEDBACK

Without greenhouse gases : avg temp on earth -> 33 degrees cooler

**Radiative Forcing** - Change in the balance between incoming and outgoing radiation of our climate system due to substances in the atmosphere or changing output of the Sun.

Atmospheric water : clouds, vapour – 35-85 % of radiative forcing depending on geographic location. ( overall largest radiative force ) ; Snow reflects 40-95% of light that hits it, ice reflects 20-45%

Ice, reflective clouds : reflects, increases albedo

Vapour : acts as a greenhouse gas. Inc T -> Inc water vapour -> Inc greenhouse gas (condensing greenhouse gas unlike C). AMPLIFIES ANY CHANGE IN TEMPERATURE. As its abundant.

**Non condensing greenhouse gases** – longer atmospheric lifetimes.

Water vapour amplifies effect of non condensing greenhouse gases.

**If no non condensing greenhouse gases, then water vapour would condense out of the atmosphere. Temp drops by 35 degrees, global ice coverage increases from 4-50%.**

**Cloud cover :** clouds – droplets of water or frozen ice crystals suspended in atmosphere. 2 types of clouds : **cumulus mediocris – reflect sunlight, cirrus – trap infrared radiation from the earth, warm.**

If Inc T -> inc high level, dec low level -> inc T ( +ve feedback )

If Inc T -> inc low level, dec high level -> dec T (-ve feedback )

## MOUNTAIN PINE BEETLE

Mountain pine beetle -> found in North West America – bores through bark of mature pine trees to lay its eggs.

Attack of pine beetle introduces a **blue fungus** in the trees tissues – blocks tree from repelling and killing the beetle with its **sticky sap**. In the process, the fungus also prevents the flow of water and nutrients in the tree, kills it, needles of tree turn red – fall.

Normally beetle attacks **old trees**, removing them from the forest and making room for new growth.

Recently : population skyrocketed in an epidemic that is threatening forests of **British Columbia, Canada**.

**Cold winters –** **kill beetles offspring**, keeping pop in check, but warmer winters of past decade have increased beetle survival rates, increasing range of suitable habitat. **Hot, dry summers stress the pine trees, lowering their defence against the attack.**

Process : Reduces wood, puts C into the ground, acts as a C sink, storing C. Removes future C sequestration potential of a multitude of trees.

After needles drop, sunlight can reach the forest floor and promote new growth which stores C in the process.

Dead trees : less moisture, increases chances of wildfire

Needles fall after years, after that, foster growth on forest floor