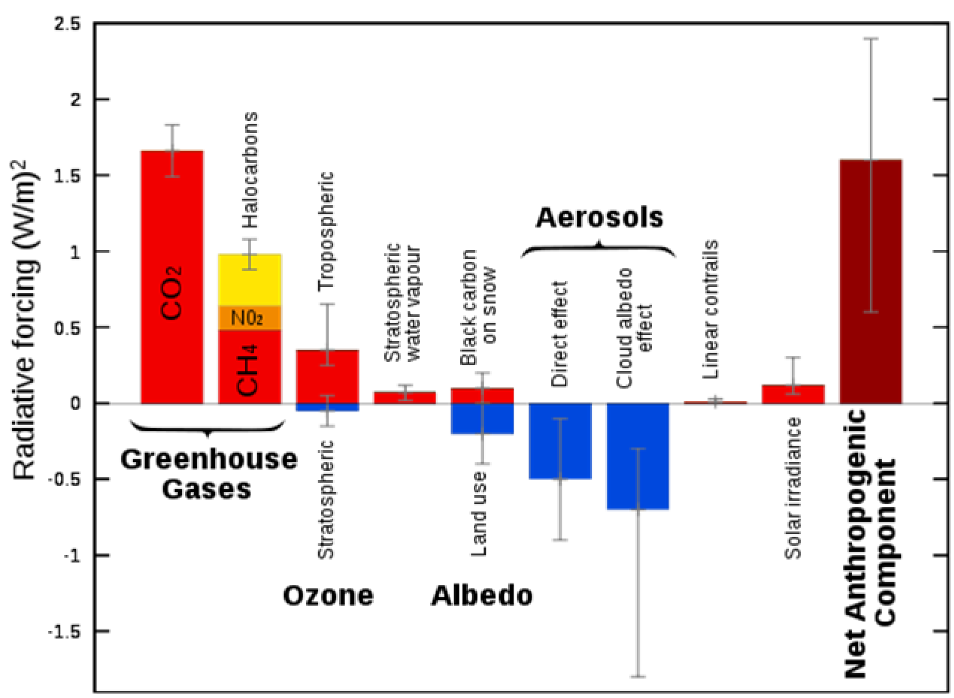
Radiative Forcing

Radiative forcing is a measure of how the energy balance of the Earth-atmosphere system is influenced. The word ‘radiative forcing’ is used because these factors change the balance between incoming solar radiation and outgoing IR radiation within the Earth's atmosphere. The term forcing is used to indicate that Earth's radiative balance is pushed away from its normal state. Radiative forcing is the difference between incoming solar radiation and outgoing terrestrial radiation. measured in watts per meter squared. The earth absorbs power from the Sun and then eventually emits power back into space. The more power the Earth absorbs, the warmer it gets. The warmer the Earth is, the more power it radiates into space. This allows the Earth to sit at some equilibrium temperature. This temperature is set by various Climate forcing factors. Humans have been changing these forcing factors which is leading to changes in the climate system.

When climate forcings result in incoming power being greater than outgoing power, the planet warms. If outgoing energy is greater, the planet cools. Thus, the general expression for radiative forcing is: Eventually this warming or cooling sets a new equilibrium temperature for the planet. The biggest recent change in radiative forcing has been the dramatic increase in greenhouse gases in the atmosphere. where radiative forcing can be a positive or negative value. These positive or negative values can be seen in Figure below.



The process that alters the energy balance of the Earth-atmosphere system (when the radiative forcing value is zero) is known as a radiative forcing mechanism. There are a large number of different types of variations, but they can include external forcings from variations in the Sun or Earth's orbit, or internal forcings such as a change in volcanic activity or in atmospheric composition. However, connecting a cause with some climate change is extremely difficult, especially because the climate system is incredibly interlinked. This connection results in climate feedbacks and changes propagating throughout the climate system.

Before the Industrial Revolution in 1750, the average value for radiative forcing remained essentially stable. Scientists are able to document how the atmosphere has changed since then by calculating current values as if the radiative forcing value were zero in 1750. It becomes clear that the value has increased significantly. In 1950, the value relative to 1750 was determined to be 0.57 W/m2. After only 30 years in 1980, the value had jumped again to 1.25 W/m2. The trend of rapid increasing has continued since then, with 2011 values reporting a radiative forcing value of 2.29 W/m2 relative to 1750. Since 1750, anthropogenic or human-caused climate forcings have been increasing, and have thus been increasing the radiative forcing value.

Year	Radiative Forcing (RF) Relative to 1750 ($W\ m^{-2}$)
1750	0.0
1950	0.57
1980	1.25
2011	2.29

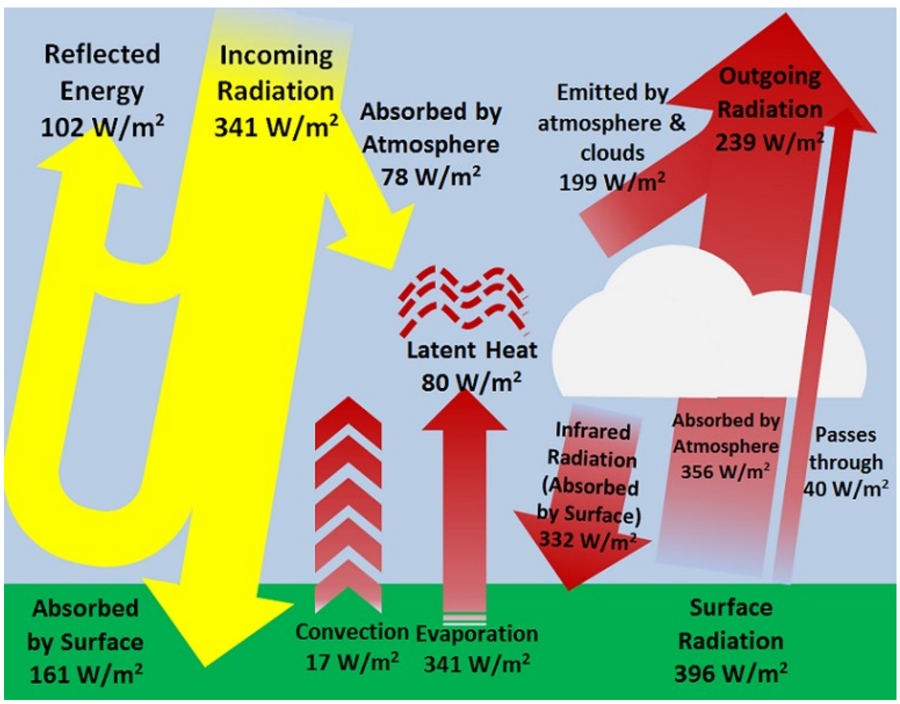
Earth's energy budget

Earth's energy budget accounts for the balance between the energy that Earth receives from the Sun and the energy the Earth radiates back into outer space after having been distributed throughout the five components of Earth's climate system. This system is made up of Earth's water, ice, atmosphere, rocky crust, and all living things. Understanding the Earth's energy budget can help to predict future effects of global warming. Additionally, knowing how Earth's energy budget balances can provide insight into how the energy from the Sun interacts with the atmosphere. For the energy budget to balance, all that needs to occur is:

Energy in=Energy out

Earth's Energy Balance

The two major components that must be investigated to determine if the Earth's energy budget balances is the incoming energy from the Sun and the outgoing infrared radiation from the Earth and its atmosphere.



When the energy budget balances, the temperature on the Earth stays relatively constant, with no overall increase or decrease in average temperature. The energy coming in to the Earth comes from the Sun, and over the surface of the planet this incoming radiation has a rate of transport of 341W/m2.

However, not all of this energy reaches the Earth's atmosphere or surface as some is reflected by clouds or the atmosphere. The energy that does pass through is absorbed by the atmosphere or the surface, and then moves around through convection, evaporation, or in the form of latent heat. Finally, when the energy exits the Earth it can do so by emission from the surface of the Earth, by clouds, or by the atmosphere. Some of the energy that is radiated by the surface of the Earth is absorbed by clouds and greenhouse gases in the atmosphere and then re-emitted downwards, which is how the surface of the Earth is heated and kept at a habitable temperature. This process of heating is known as the greenhouse effect. Overall, the energy that exits the Earth in different forms, when added together is equal to the energy that is absorbed by different parts of the Earth.

Earth's Energy Imbalance

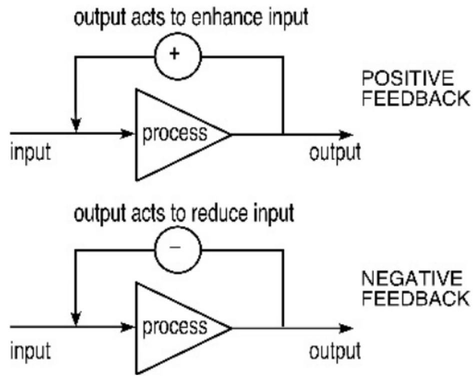
The incoming energy to the Earth and the outgoing energy from the Earth do not actually balance. This imbalance is partially caused by the incoming energy from the Sun which varies with the seasons and changes in the composition of the Earth's atmosphere. Changes in the composition of Earth's atmosphere alters the quantity of energy absorbed and reflected by the atmosphere.

As human activities increase the amount of carbon dioxide in the atmosphere, the energy imbalance continues to grow. Today, the energy imbalance amounts to approximately 0.9Wm2 of energy is coming in, than is leaving the Earth. Compared to flow values in the hundreds of watts per meter squared, this imbalance seems negligible. However, to account for this imbalance, the Earth's temperature will increase in response. As well, since the amounts of carbon dioxide and other greenhouse gases in our atmosphere are increasing, this value is projected to increase at a rate of 0.3W/m2 per decade, contributing even more to increasing temperatures. It is this imbalance in the energy budget that results in increasing temperatures on the Earth, one of the most significant effects of climate change.

CLIMATE FEEDBACK, SENSITIVITY AND EQUILIBRIUM

Climate Feedback

A concept borrowed from electrical engineering. A feedback occurs when a portion of the output from the action of a system is added to the input and subsequently alters the output. The result of such a loop system can either be an amplification of the process or a dampening. These feedbacks are labelled positive and negative respectively. Positive feedbacks enhance a perturbation whereas negative feedbacks oppose a perturbation.



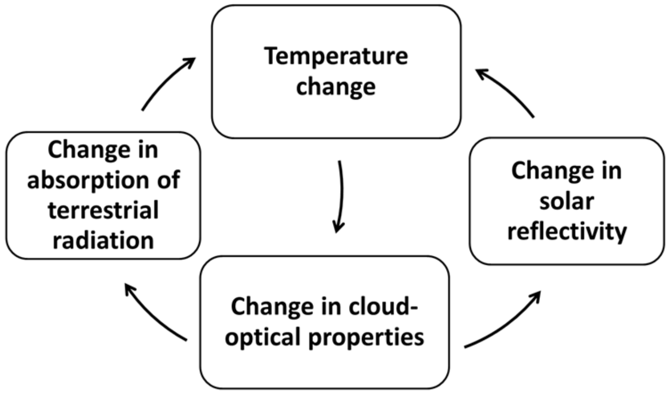
Feedback processes can be classified as positive or negative. In positive feedback a portion of the output is fed back to the input and acts to further stimulate the process. In the case of negative feedback, the portion of the output is subtracted from the input and acts to dampen the process.

Water vapor feedback

Water vapour is also an effective greenhouse gas, as it does absorb longwave radiation and radiates it back to the surface, thus contributing to warming. When compared to other greenhouse gases, water vapour stays in the atmosphere for a much shorter period of time. Water vapour will generally stay in the atmosphere for days (before precipitating out) while other greenhouse gases, such as carbon dioxide or methane, will stay in the atmosphere for a much longer period of time (ranging from years to centuries) thus contributing to warming for an extended period of time.The addition of water vapour to the atmosphere, for the most part, cannot be directly attributed to human generated activities. Increased water vapor content in the atmosphere is referred to as a feedback process. Warmer air is able to hold more moisture. As the climate warms, air temperatures rise, more evaporation from water sources and land occurs, thus increasing the atmospheric moisture content. The increase in water vapour in the atmosphere, because water vapour is an effective greenhouse gas, thus contributes to even more warming: it enhances the greenhouse effect. Water vapour is often discussed and recognized as being an important part of the global warming process. The water vapour feedback process is most likely responsible for a doubling of the greenhouse effect when compared to the addition of carbon dioxide.

Cloud feedbacks

Cloud feedback is the coupling between cloudiness and surface air temperature in which a change in surface air temperature, leads to a change in the temperature and optical properties of clouds, which could then amplify or weaken the surface temperature change. Cloud feedbacks are many and complicated. The feedbacks can be grouped in two: Clouds are good absorbers of terrestrial radiation (radiation from the earth) and reduces the amount of radiation radiated back to space. This has a warming effect. At the same time clouds reflect solar radiation and thereby cooling the earth. State of the art climate models finds the total cloud feedback to be slightly positive.



Albedo feedbacks

The albedo feedback is the coupling between changes in surface reflectivity and surface air temperature in which a change in surface air temperature may lead a change in the surface reflectivity (changes in snow cover, sea ice extent, vegetation) , which could then amplify or weaken the surface temperature change. State of the art climate models finds the albedo feedback to be positive due to the influence of changes in temperatures on snow and sea ice. It should be noted that the strength of the albedo feedback is dependent the strength of the solar radiation reaching the surface. For example the same change in snow cover over a region with strong solar radiation (for example a location with a lot of clear skies, or a location close to equator) would give a stronger feedback than a change in snow cover over a region with less solar radiation.