CLIMAT ACADEMY®

The Scientific Supplement

Chapter One

Radiative Forcing

Summary

Radiative forcing measures the imbalance between energy the Earth receives from the Sun and the energy it emits back into space, compared to pre-industrial conditions. When this balance increases (positive forcing), global temperatures rise; when it decreases, temperatures fall. Human activities are the main driver of current positive radiative forcing, largely due to greenhouse gases such as carbon dioxide and methane. Aerosols and land-use changes can partly offset this effect by reflecting sunlight. Albedo, the reflectivity of surfaces, plays a key role: ice and snow reflect more radiation than water, and melting ice reduces albedo, amplifying warming through a self-reinforcing feedback loop.

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The physical definition of radiative forcing

It is now usual to measure and anticipate global warming in terms of degrees Celsius. However, the GIEC has been using a more precise (but less accessible) physical quantity since its first work: radiative forcing. To understand this radiative forcing, it is necessary to return to the notion of the Earth's radiation balance. The Earth receives a certain amount of energy from solar radiation. 342 $W.m^{-2}$.

In addition, the Earth emits infrared radiation into space, which is partly blocked by the atmosphere: this is the famous greenhouse effect.

The radiation balance can therefore be expressed by the following equation:

(Energy received by the Earth) - (Energy emitted by the Earth) = Radiation balance.

For more than 10,000 years it has been possible to establish that this radiation balance is in equilibrium and that it places the Earth's surface at an average temperature of 15°C.

Having established this, we can now define radiative forcing as the measure of the (energy) imbalance of this radiation balance. More precisely, radiative forcing is the difference in energy received by the Earth and emitted by the Earth if the Earth had remained under the physical and chemical conditions of the pre-industrial era. (1750)

If this radiation balance tends towards an increase, we speak of positive radiative forcing, with a direct consequence of an increase in the average temperature at the Earth's surface.

If this radiation balance tends towards a decrease, then the radiative forcing is negative and the average temperature of the surface of the Earth decreases.

Influential factors on the radiative forcing

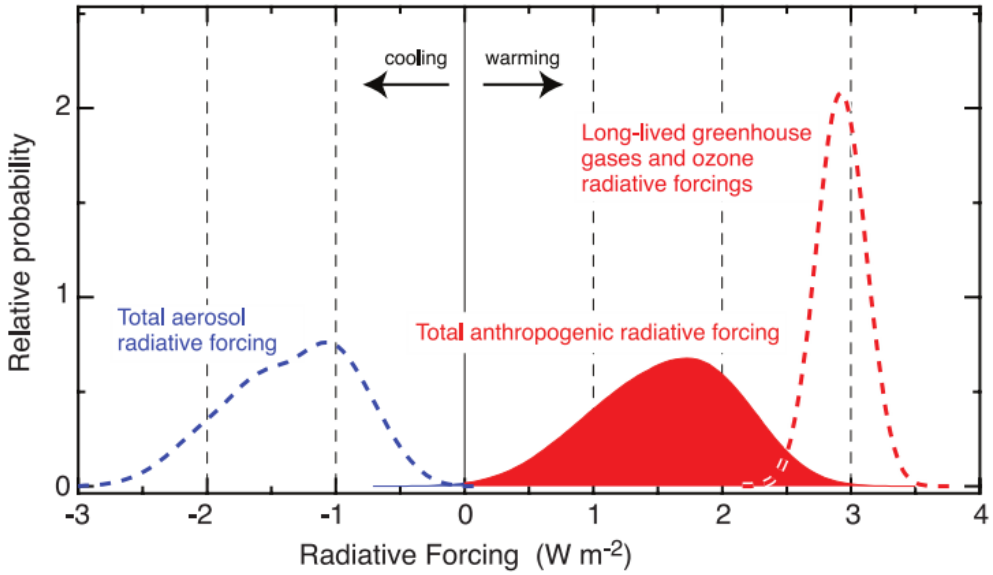
In its 4th Assessment Report[(1)], in 2007, the GIEC established a list of factors capable of affecting the Earth's radiative forcing and demonstrated in an elegant and rigorous way the role of natural and anthropogenic factors in climate change.

The 2 documents below came from it.

The first document graphically summarises the statistical contribution of greenhouse gases, aerosols and anthropogenic actions to radiative forcing. Thus, greenhouse gases contribute to a radiative forcing of +2.9 ±0.3 $W.m^{-2}$., aerosols together result in a median radiative forcing of -1.3 $W.m^{-2.}$
The anthropogenic radiative forcing is therefore between +0.6 and 2.4 $W.m^{-2}$, with a median value of + 1.6 $W.m^{-2}$. In other words, global warming is indeed the result of human activities

[(1)] AR4 Climate Change 2007 : The Physical Science Basis — IPCC. https://www.ipcc.ch/report/ar4/wg1/

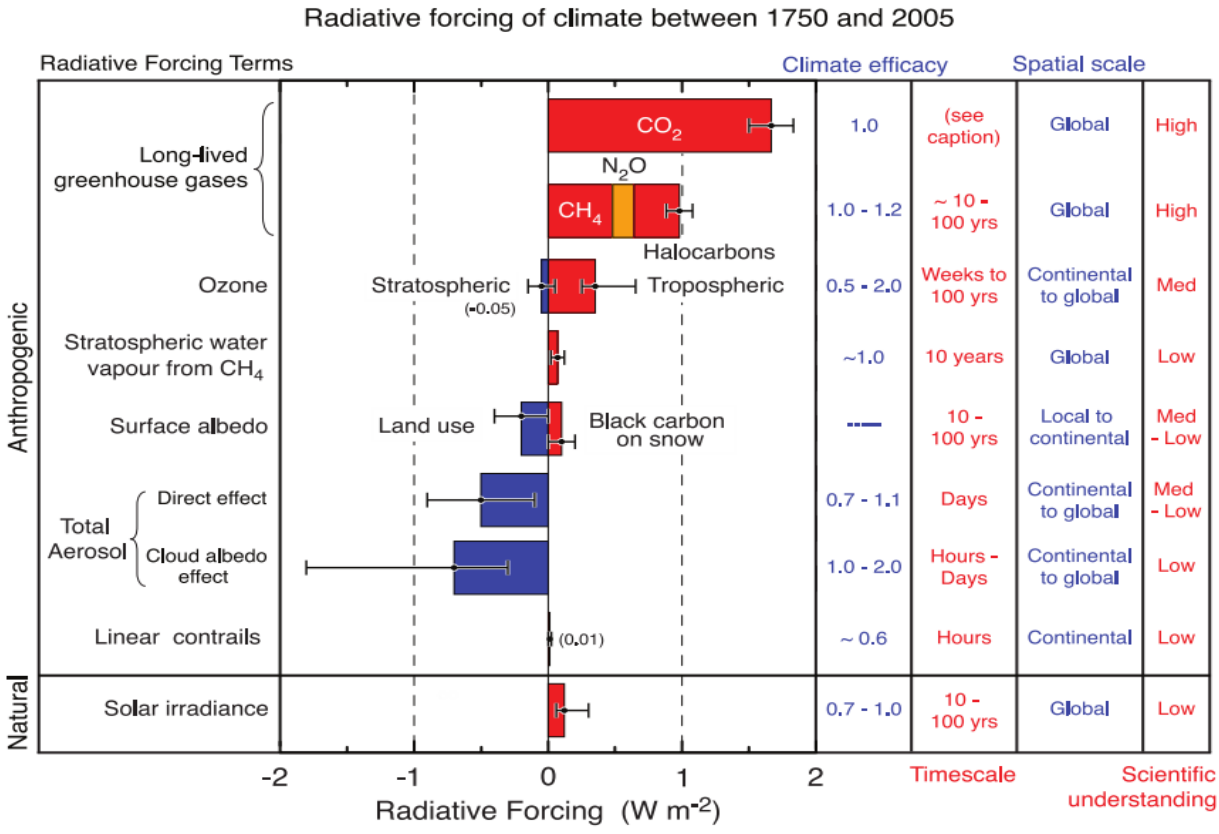
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In the second table, it is easy to see that the positive radiative forcing of greenhouse gases is mainly due to the massive presence of CO_2 and methane.

When it comes to albedo, the overall radiative forcing is negative. This is because human activities have changed the land cover through deforestation and the extension of agricultural crops, which results in increased reflection of solar radiation.
Aerosols are very varied in size, nature, concentration, and origin. They include volcanic dust, soot from combustion, but also sulphur compounds (H_2S).

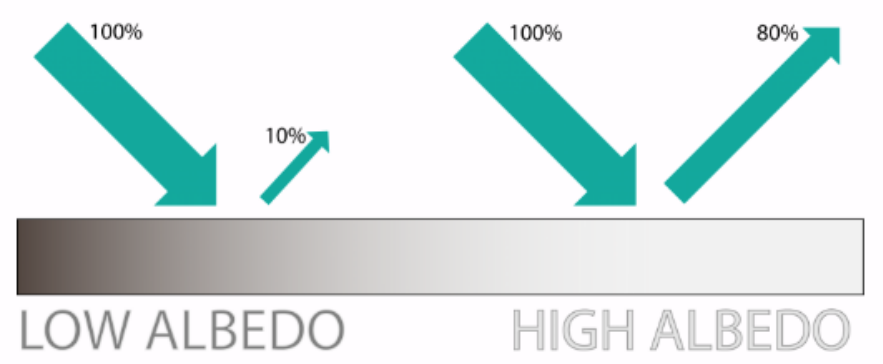
Their action on radiative forcing is also negative. They affect the reflection and absorption of solar and infrared rays, thus reducing the overall radiative forcing.



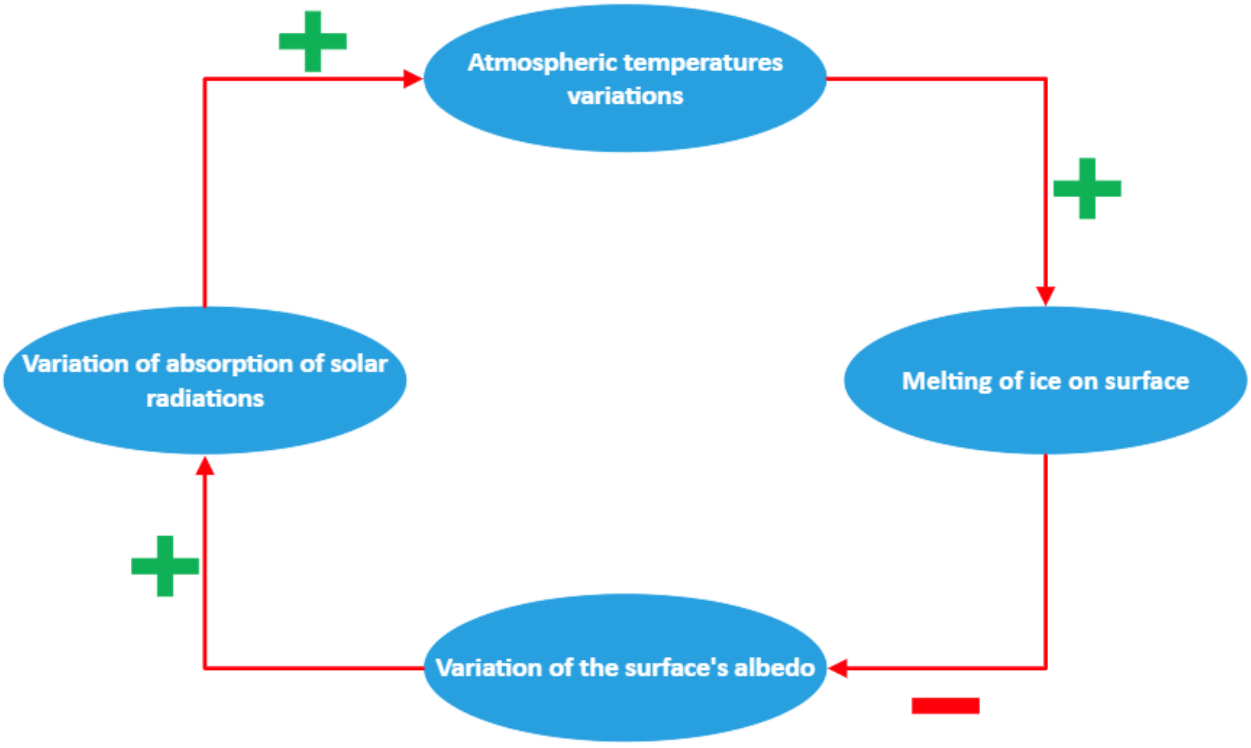
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Albedo, a crucial surface effect

Although the greenhouse effect caused by gases such as CO_2, methane and water vapour is well known, it is important to emphasise the notion of albedo, which corresponds to the ratio between the radiation reflected and received. The albedo varies from 0 for a black body absorbing all the radiation to 1 for a body reflecting all the radiation received. This physical quantity is strongly influenced by the nature of the surface : vegetation in general has a higher albedo than bare ground, such as a desert. Ice and snow, by strongly reflecting solar radiation, have a higher albedo than the oceans. [2]



The snow-and-ice-albedo feedback effect is now well known and helps to understand the implication and amplification of albedo changes in the ice - water system of the poles.
An increase in atmospheric temperatures leads to more ice melting. Because molten water has a lower albedo than ice, solar radiation is absorbed more by water than by ice. The water and the atmosphere warm up, which leads to more ice melting....the vicious circle is thus set in motion.



[2] Velasquez, S. (2021). Why Albedo is important for our melting ice caps. Earth Sciences. https://www.essearth.com/why-albedo-is-important-for-our-melting-ice-caps/

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