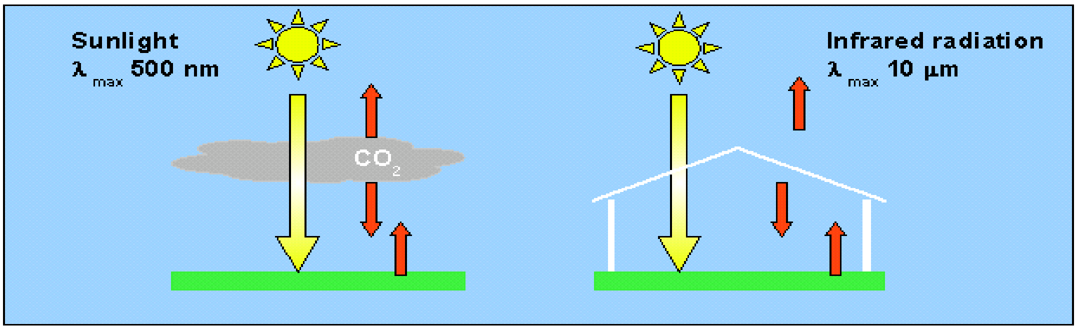
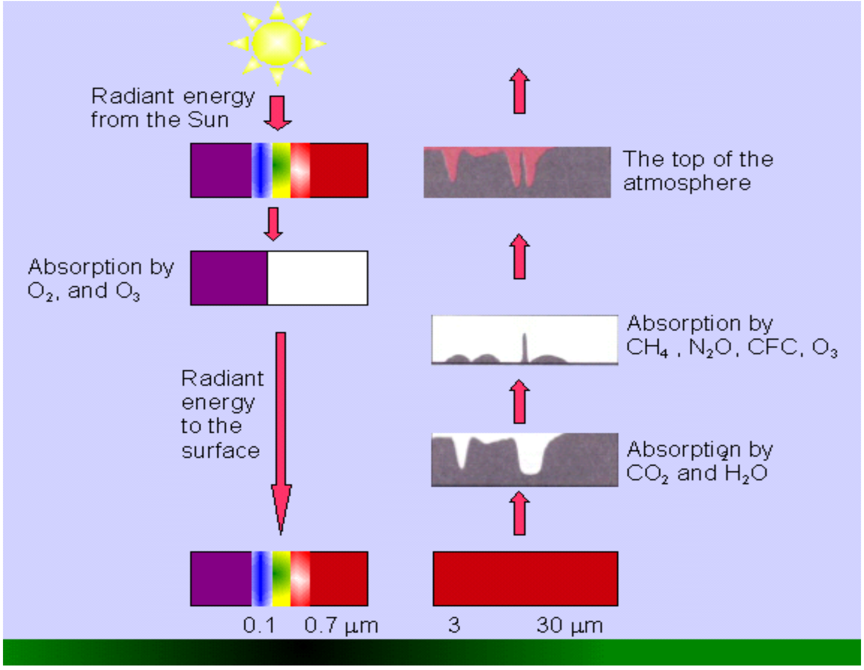
Chapter 3. The Greenhouse effect

The following can be read in an article in New Scientist (**18**, 5 June, 1999): *Most of the glaciers in the Himalayas will vanish within 40 years as a result of global warming*.
In this chapter we will discuss the so-called Greenhouse effect, probably named so by R. W. Wood in 1909 in an article in the Philosophical Magazine **8**, 1909; *Note on theory of the greenhouse*, although J. Fourier had discussed this phenomenon already in 1824 by comparing the atmosphere of the Earth with a glass bowl where the sun light penetrated the glass and the emitted infrared radiation will be kept within the bowl. Svante Arrhenius also discussed this effect at the end of 1800.

3.1 Greenhouse effect

Below is shown a simplified model of the greenhouse effect where the incoming sunlight is heating up the Earth surface, which in turn is emitting infrared radiation upwards. The sunlight that reaches the Earth heats it and the warm surface of the Earth emits radiation upwards, which is partly absorbed by atmospheric gases.





CO_2 and H_2O and other gases absorb the radiation that is emitted from the surface of the Earth at the wavelengths between 3-30 µm. The net result of this reabsorption is that the temperature of the Earth is noticeably higher than it would be in the absence of these greenhouse gases. The total temperature increase due to CO_2 and H_2O is approximately 28^{o}C. The contributions of CO_2 and H_2O to the greenhouse effect are about 22% and 62%, respectively. The remaining greenhouse gases, as O_3, CH_4, N_2O and CFC:s etc, contribute for the remaining 16%.

Assuming an albedo of 0.30 and a solar constant of 1370 W/m^2, the expression

$$(1-a)\frac{S}{4} = \sigma T^4$$

would give an equilibrium temperature of 255 K for the Earth surface, which is far from the observed value.

With the modified expression

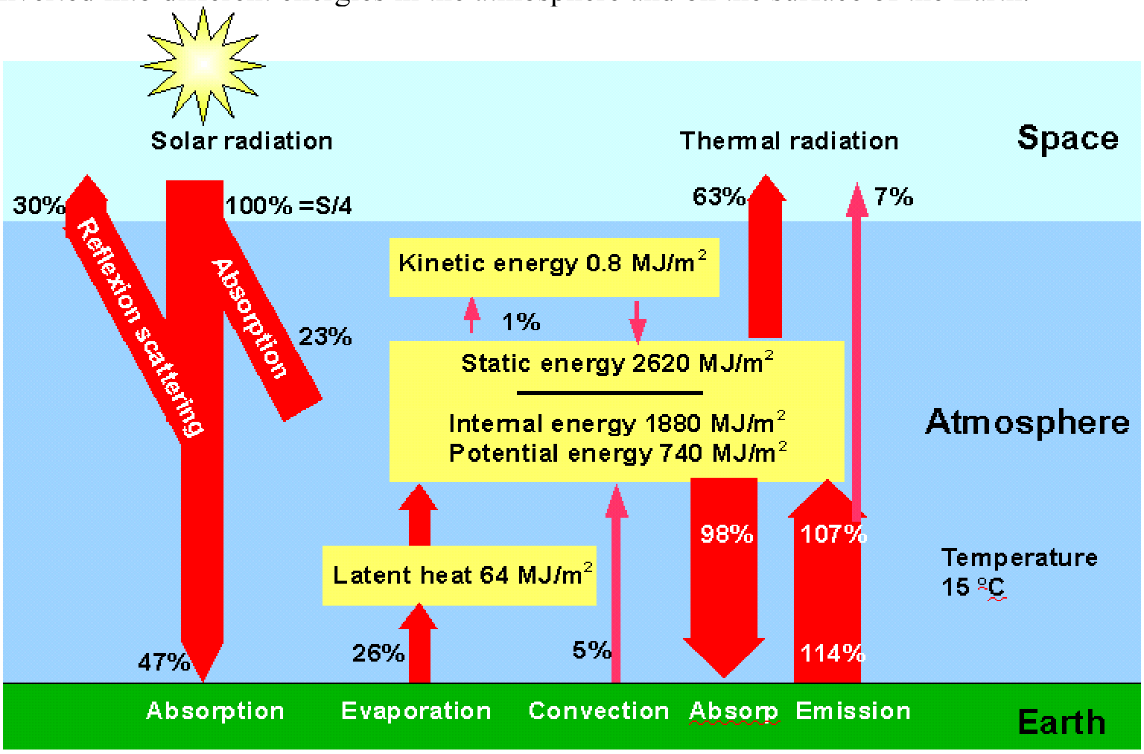
$$(1-a)\frac{S}{4} = f\sigma T^4$$

where $f < 1$ we get, if we put $f = 0.61$, we get the temperature of 288 K, which is the mean temperature of the Earth surface. The factor f reflects the fact that much of the infrared radiation gets trapped by the greenhouse gases on its way out to the space. A part of this trapped radiation is then radiated back to the earth.

The Greenhouse effect is responsible for the life on Earth. Without this sensitive balance of incoming and outgoing radiation the temperature of Earth can vary quite a lot.

3.2 Global energy balance

Below is shown a diagram over the energy balance when incoming solar radiation is converted into different energies in the atmosphere and on the surface of the Earth.



3.3 Anthropogenic Greenhouse effect

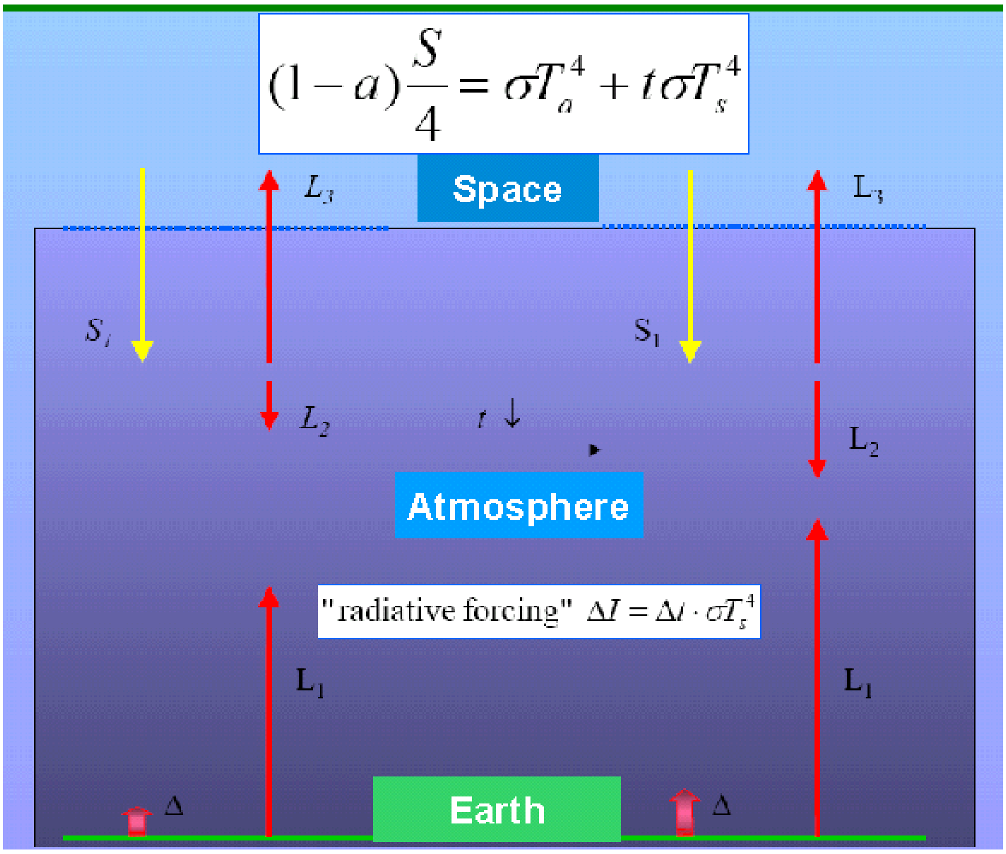
The word Greenhouse effects stands nowadays for the amplified Greenhouse effect that has been caused by the emission of Greenhouse gases, mainly CO_2.

Fossil fuel has been used since the industrial revolution in the 18th century, through coal (C), later through oil and gas.

In the equation

$$(1-a)\frac{S}{4} = f\sigma T^4$$

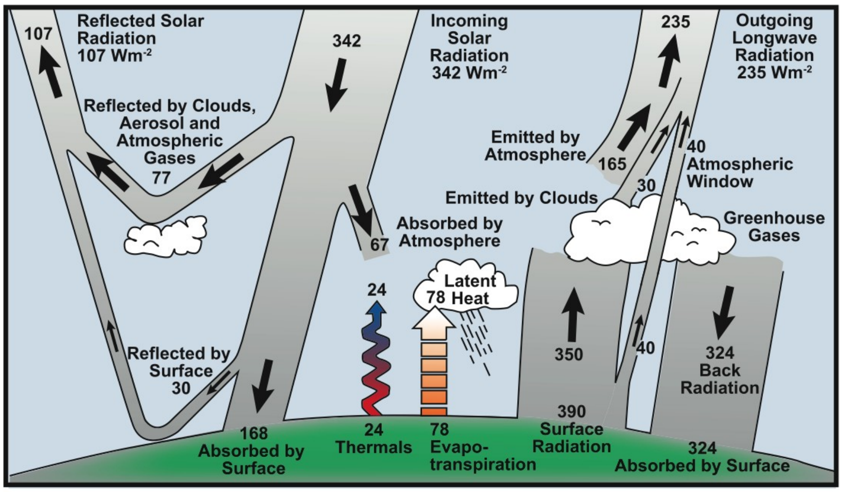
the factor f is decreasing and T is increasing on Earth since a reduction of the outgoing IR-radiation forces an increase of the temperature of the Earth.



The figure above illustrates how we in the expression

$$(1-a)\frac{S}{4} = \sigma T^4$$

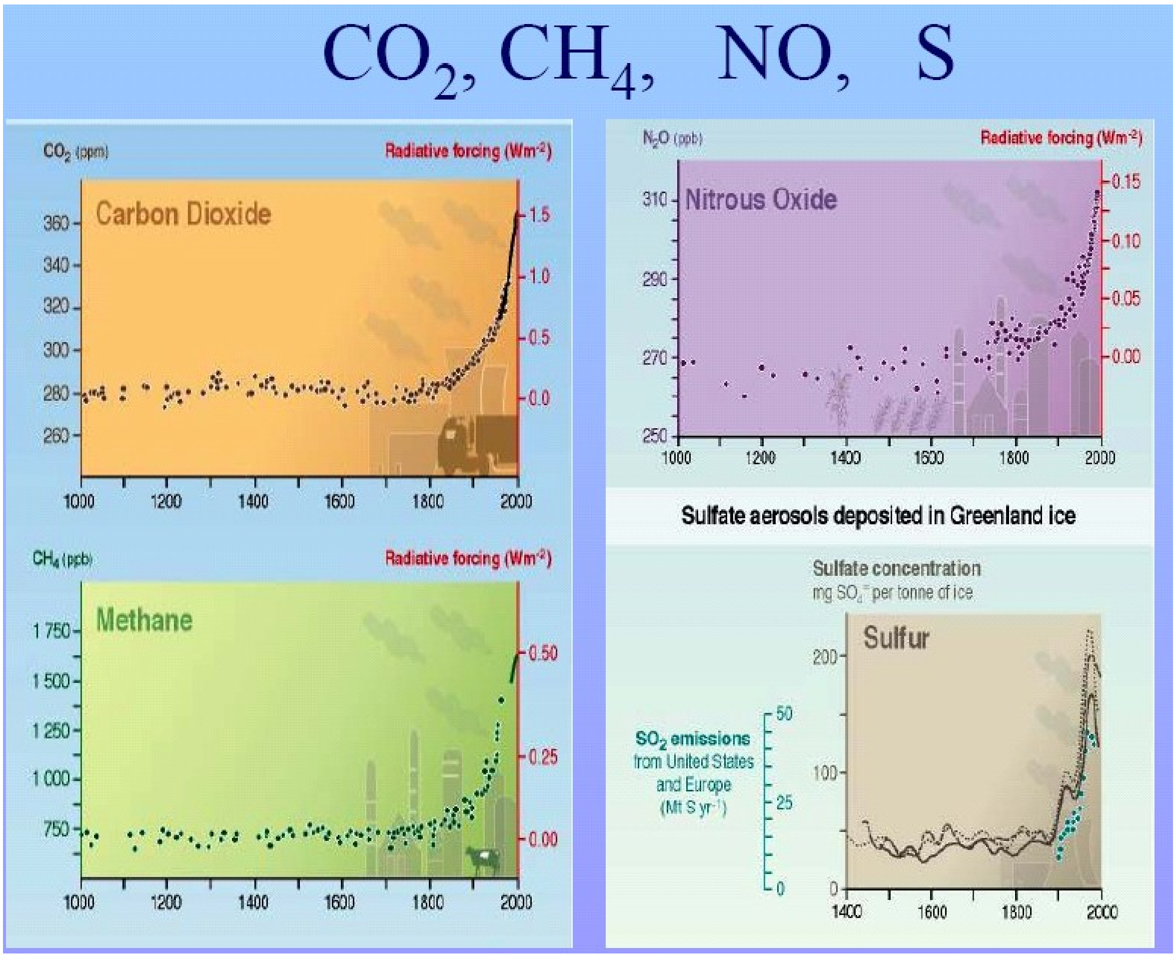
introduce a term we call *radiative forcing*, $\Delta I = \Delta t\ \sigma\ T^4$, where Δt stands for the depth of the atmosphere.



The IPCC-figure above shows how the incoming solar radiation (here 342 W/m^2) is split into parts. Incoming power: 168+324= 492 W/m^2 equals outgoing power 24+78+390= 492 W/m^2.

3.4 The increase in Greenhouse gases

Measurements on species as CO_2, CH_4, NO_2 and S have been performed in the Antarctic ices that can be regarded as a safe where the concentrations over the years are stored. With drilling and techniques to measure the gas contents one has an accurate measurement on the concentrations even in older times. In the figure below the concentrations can be seen:



In all figures one observes a steady increase in concentrations already from the beginning of 1800, after the industrial revolution. The concentrations have increased by at least a factor 2.

3.5 Livestock influences on Greenhouse effect

During a couple of years as well as rather recently, FAO, the UN Food and Agriculture Organization (http://www.fao.org/newsroom/en/news/2006/1000448/) has stated that there are other anthropogenic effects, than those caused by heating and traffic, influencing the Greenhouse effect, namely the role of the livestock sector generally. Many details up to now are not well known, but FAO points in certain directions. Almost all sectors within livestock production affect the atmosphere, as well as our surrounding environment. FAO (http://www.fao.org/AG/AGAInfo/projects/en/lead.html) has discussed several important issues in this field and have presented data of this area, and we will discuss the most important issues here.

Animal	World total million tonnes	CO_2 emission million tonnes
Cattle	500	1900
Pigs	90	600
Sheep, goat etc	50	500
Horses	20	70
Chicken, turkey etc	30	60
Camels	5	20
Total	**700**	**3200**

There is not only carbon dioxide that is emitted in the livestock production, but also N_2O, nitrous oxide. The concentrations of N_2O can be found in the previous chapter. The concentrations have increased from around 280 ppb around year 1900 to ca 300 ppb at year 2000. However, the N_2O molecules are more effective than CO_2 in absorbing heat, some 300 times more effective, and besides, they are very long-lived in the atmosphere. The half-life of N_2O in the atmosphere is just above 110 years. Another gas that is emitted by the livestock production is methane, CH_4, which has increased by nearly 150% since before the industrial revolution. The total emission of this partly anthropogenic carbon source was estimated to end up at 240 Mtonnes annually. In the table below we can see the concentration of Greenhouse gases, both now and in the past.

Gas	Pre-industrial concentration	Atmospheric concentration	Global warming power
CO_2	280ppm	380ppm	1
CH_4	600ppb	1700ppb	20
N_2O	280ppb	320ppb	300

Finally, let us try to summarize the influence on the environment regarding livestock. An estimate of the total anthropogenic emission of Greenhouse gases shows that livestock is responsible for around 20% emission. Here we have compared different activities as i) energy and industry, ii) waste, iii) land use as well as forestry and agriculture. In the last group, livestock's share is more than 50%. If we look at forestry and agriculture, livestock's share is nearly 80%.

Livestock is responsible for almost 10% of the total anthropogenic CO_2 emission, but the use of fossil fuels seems to increase, making the situation even worse on long-term basis. Looking at methane, CH_4, it has for long been know that livestock's role is important, and that livestock is due to almost 40% of all emission worldwide. Still, nitrous oxide, N_2O, is livestock's major emission and reaches around 65% of the total anthropogenic emission. This is also the most powerful of the Greenhouse gases with respect to radiation absorption.

Perhaps will also this figure increase in the years to come? Almost as high numbers can be found in the livestock's emission of ammonia, although the effect of this emission is more local.

3.6 Modelling of Greenhouse gases

Suppose:
The amount of Greenhouse gases C_0 at $t = 0$.
Let the increase be 1 % per year to the amount $2C_0$ at $t = t_2$.

Calculate:
the concentration $C(t)$ and t_2.

Solution:

The change in concentration $dC = 0.01Cdt \Rightarrow dC/dt = 0.01C(t)$

This equation has the exponential solution $C(t) = C_0 e^{0.01t}$

The time when the amount has doubled to $C(t_2) = 2\ C_0$ *is* $t = t_2$:

We get the following equation: $2C_0 = C_0 e^{0.01t2} \Rightarrow ln2 = 0.01t_2$

$t_2 = ln2/0.01 = 100*ln2$ *years* $= 69.3$ *years*

The amount has doubled within 70 years.