Climate change due to CO_2 increase

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The earth surface is heated by solar radiation and is cooled by convection, evaporation of water and emission of longwave radiation (also called infra-red radiation). At thermal equilibrium, the power received by the surface should be balanced by the power lost by the surface. This law, called heat budget law at equilibrium, has been first established by Joseph Fourrier, a French physicist, in 1824. Although many of these heat exchanges were not quantified, he correctly deduced that a change of the solar radiation or of the surface characteristics will impact the earth surface temperature.

If we now consider the earth and its atmosphere as a whole, radiation is the only possible heat exchange between the earth and space. The earth is heated by absorption of solar radiation and cooled by emission of longwave radiation and at equilibrium this two radiative fluxes have the same value. The longwave radiation emitted by the earth to space is much lower than the longwave radiation emitted by the surface, and the difference between these two longwave fluxes is due the "green house effect". Since the end of the 19^{th} century, it has been recognized that water vapour (H_2O) and carbon dioxyde (CO_2) are the two major greenhouse gazes of the atmosphere.

The hypothesis that a change of CO_2 concentration may change the greenhouse effect and therefore the global mean surface temperature was first made by Svante Arrhenius, a Swedish chemist, in 1896. He made a first estimate of the absorption of the longwave radiation by the water vapor and the carbon dioxide of the atmosphere. Using a very simple model, he estimates the impact of a change of the CO_2 concentration on the global mean surface temperature. But these computations contained some important errors.

During the 20^{th} century very strong progress was made in our understanding of the physical laws that describe the emission and absorption of radiation. Since 1970-1980 radiative transfer in the atmosphere is accurately computed and it is possible to estimate how much any change of the H_2O or CO_2 concentration modify the heat budget of the earth. One can for instance obtains that a doubling of the CO_2 concentration increases the radiative budget of the earth by almost 3.7 $W.m^{-2}$, to be compared to the 240 $W.m^{-2}$ of the solar radiation absorbed, on global average, by the earth. If nothing else that the temperature may change (i.e. if the water vapor, the clouds... do not change), the heat imbalance due to a doubling of the CO_2 concentration would lead to a global warming of almost 1.2°C. But this hypothesis is very crude. When the temperature change, the water vapor, the clouds, the snow cover, and many other climate variables are also modified. These changes affect the heat budget and therefore the global mean temperature. They are called feedbacks, and are positive if they amplify the initial temperature change and negative if they damp it.

It appears that there are many strong positive feedbacks in the climate system. To illustrate this, we show in figure1 the mean surface temperature increase due to a doubling of the CO_2 concentration as computed by 12 models that participate to the preparation of the IPCC fourth assessment report that was published in 2007.

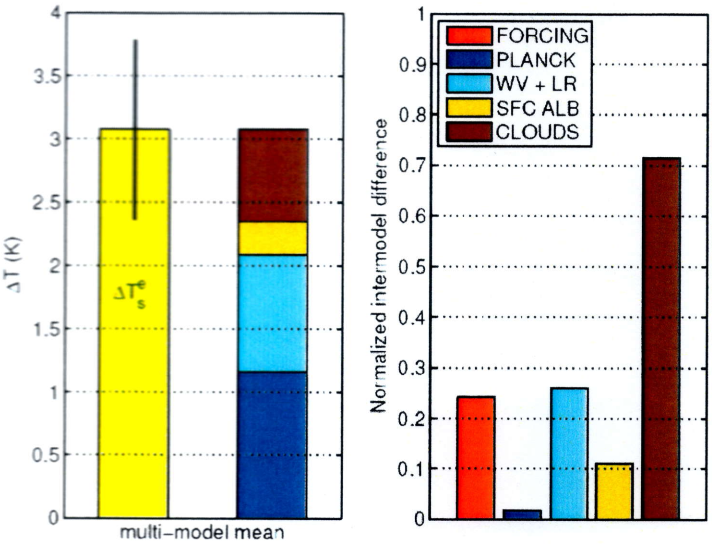

Figure 1: For a CO2 doubling, **(a, left)** multi-model mean ± 1 standard deviation of the equilibrium temperature change (DT^e_s) and contributions to this temperature change associated with the Planck response, combined water vapor and lapse rate (WV+LR) feedback, surface albedo feedback and cloud feedback. **(b, right)** inter-model standard deviation of the temperature change estimates associated with the radiative forcing, the Planck response and the various feedbacks normalized by the inter-model standard deviation of the equilibrium temperature change DT^e_s as reported in (a). (*Dufresne et Bony, 2008)*

On the left of this figure, it is shown that the multi-model global warming is about 3°C, with a standard deviation of 0.7°C. The temperature increase if all but the temperature were constant (the "Planck response") is 1.2°C. The water vapor feedback increase this temperature by 0.9°C. When the temperature increase, the atmosphere may hold more water vapor, and the increase of the water vapor amount increase the greenhouse effect, and therefore the temperature. An other feedback is called the "surface albedo" feedback and increases the temperature by 0.3°C. It is due to a change of the snow and the sea-ice cover. When the temperature increases, the snow and the sea-ice cover is reduced. As they reflect the solar radiation, the reduction of the snow and the sea-ice surface leads to an increase of the absorbed solar radiation, and therefore an increase of the heat absorbed by the surface. The last feedback involves clouds. Clouds reflect solar radiation, which cools the surface, and they absorbed longwave radiation, which enhances the greenhouse effect and heats the surface. How the balance between these two opposite effects change with climate is difficult to assess. It appears that in current climate models the cloud feedback increases the temperature by 0.7°C. This value is a multi-model mean and may be very different from one model to another. On the right of figure 1, one can observed that the cloud feedback is currently the main cause of spread of the temperature increase estimate.