How Much CO2 and the Sun Contribute to Global Warming

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Although in recent years great progress has been achieved in all fields of climate science, explanations of the observed global warming over the last century, in particular the anthropogenic contributions to this warming are still quite contradictorily discussed. So, calculations of the equilibrium climate sensitivity (ECS) as a key parameter and measure for the Earth's temperature increase at doubled CO_2 concentration in the atmosphere diverge by more than a factor of 20 starting at about 0.4°C and ending at more than 8°C. Also the actual assessment report AR5 [1] of the Intergovernmental Panel on Climate Change (IPCC) still specifies this quantity with a relatively wide range of 1.5°C to 4.5°C and classifies the human influence on our climate as extremely likely to be the dominant cause of the observed warming since the mid-20th century.

Since the ECS is one of the most important measures for future climate predictions, it is necessary to understand and to discover the large discrepancies between different accounting schemes applied for this quantity. Therefore, in this contribution we retrace the main steps of the IPCC's preferred accounting system and compare this with our own advanced two-layer climate model [2], which is especially appropriate to calculate the influence of increasing CO_2 concentrations on global warming as well as the impact of solar variations on the climate. It describes the atmosphere and the ground as two layers acting simultaneously as absorbers and Planck radiators, and it includes additional heat transfer between these layers due to convection and evaporation. It also considers short wave (sw) and long wave (lw) scattering processes at the atmosphere and at clouds as well as all common feedback processes like water vapor, lapse rate and albedo feedback, but additionally takes into account temperature dependent sensible and latent heat fluxes as well as a temperature induced and solar induced cloud cover feedback.

Based on extensive line-by-line radiation transfer calculations for the GH-gases water vapor, carbon dioxide, methane and ozone we derive the CO_2 radiative forcing as the main parameter in most climate models - also in the IPCC's accounting scheme - and additionally we get from these calculations the sw and lw absorptivities as well as the back-radiated fraction of the atmospheric emission, which are the key parameters in our model. These calculations were performed under clear sky conditions, at regular cloudiness, full overcast, and for three climate zones with different ground temperatures and humidity. With these parameters integrated in our climate model we simulate the Earth's surface temperature and the lower tropospheric temperature as a function of the CO_2 concentration. The temperature increase at doubled CO_2 concentration then directly gives the CO_2 climate sensitivity.

Such simulations reproduce the basic ECS-value (without feedback processes), as specified by the IPCC, within a few %. Significant differences, however, can be observed with the different feedback effects included. While the lapse rate and albedo influence were adopted from literature, the water vapor feedback is derived from the sw and lw absorptivity calculations performed for three climate zones with different surface temperatures and humidity. These calculations give a positive feedback of not more than 14% [3], whereas the IPCC emanates from an amplification of 100%, which after all is 7x larger than our result.

Since our calculations indicate that with increasing CO_2 concentration the air temperature is less rapidly increasing than the surface temperature, the sensible heat flux at the bound of both layers rises with the concentration. As a consequence more thermal energy is transferred from the surface to the atmosphere. Similarly, with increasing surface temperature also evaporation and precipitation are increasing with the ground temperature. Both these effects contribute to negative feedback and are additionally included in the simulations. While the respective contribution due to sensible heat rapidly declines with increasing cloudiness, the evaporation feedback with an attenuation of 44% is the primary stabilizer of the whole climate system. All the more it is surprising, that the IPCC obviously did not consider this important effect in AR5.

A special situation is found for the influence of clouds on the radiation and energy budget. From global cloud observations within the *International Satellite Cloud Climatology Project* (ISCCP) over a period of 27 years it is deduced that the global mean temperature is increasing with decreasing cloud cover. However, it is not clear, if a lower cloud cover is the consequence of the increasing temperature, or if the cloud cover is influenced and at least to some degree controlled by some other mechanism, particularly solar activities. In the first case a strong amplifying temperature induced cloud feedback (TICF) had to be considered, this for the climate sensitivity as well as for a respective solar sensitivity (surface temperature response to a solar anomaly of 0.1%), whereas in the other case TICF would disappear for both sensitivities and only a solar induced cloud feedback (SICF) had to be included.

A deliberate approach which mechanism really controls the cloud cover, is derived from model simulations, which additionally include the solar effect and compare this with the measured temperature increase over the last century. These simulations show that the observed global warming can best be explained, when a temperature feedback on clouds only has a minor influence (less than 10%). Otherwise the calculated warming would be larger than observed, or TICF would have been overestimated. With a solar anomaly of 0.26% and dominating SICF we deduce a CO_2 climate sensitivity of C_S = 0.7 °C and a solar sensitivity of S_S = 0.17 °C. The increase in the total solar irradiance (TSI) over 100years then contributes to a warming of 0.44 °C (60%) and the 100 ppm increase of CO_2 over this period causes additional 0.30 °C (40%) in good agreement with the measured warming and cloud cover.

Altogether, we see that the positive feedbacks, originating from clouds, water vapor and albedo are even overcompensated by lapse rate and evaporation feedback. Particularly clouds have two stronger opposing effects on the energy balance, which can neutralize each other or can even have an overall attenuating impact on the ECS, dependent on the mechanisms responsible for cloud changes. From these studies we conclude, that all constraints can best be explained by a cloud feedback mechanism, which is dominated by the solar influence, while thermally induced contributions only should have minor influence.

[1] Fifth Assessment Report (AR5): T. F. Stocker, D. Qin, G.-K. Plattner et al., Eds., *Climate Change 2013: The Physical Science Basis*, Cambridge University Press, New York, NY, 2014.

[2] H. Harde, *Advanced two-layer climate model for the assessment of global warming by* CO_2, Open Journal of Atmospheric and Climate Change, vol. 1, no. 3, pp. 1–50, 2014.

[3] H. Harde, *Radiation Transfer Calculations and Assessment of Global Warming by CO_2*, International Journal of Atmospheric Sciences, Volume 2017, Article ID 9251034, pp. 1-30 (2017), https://doi.org/10.1155/2017/9251034