Greenhouse gases and solar radiation have asymmetric effects on climate

According to a new study published by a group of scientists headed by Dr. Hauke Schmidt from the Max Planck Institute for Meteorology, department "The Atmosphere in the Earth System", reducing the solar radiation will not lead to a climate state similar to the one of pre-industrial times but will create a totally new and different climate. Changes in greenhouse gas concentration and solar radiation have asymmetric effects on the climate. In a model intercomparison project which involved Earth system models from four European research institutions, the models showed robust responses in several climate parameters. While in the global mean a pre-industrial temperature level could be reached if the short-wave solar radiation was dimmed, the distribution of precipitation, e.g., differed significantly compared to the past climate.

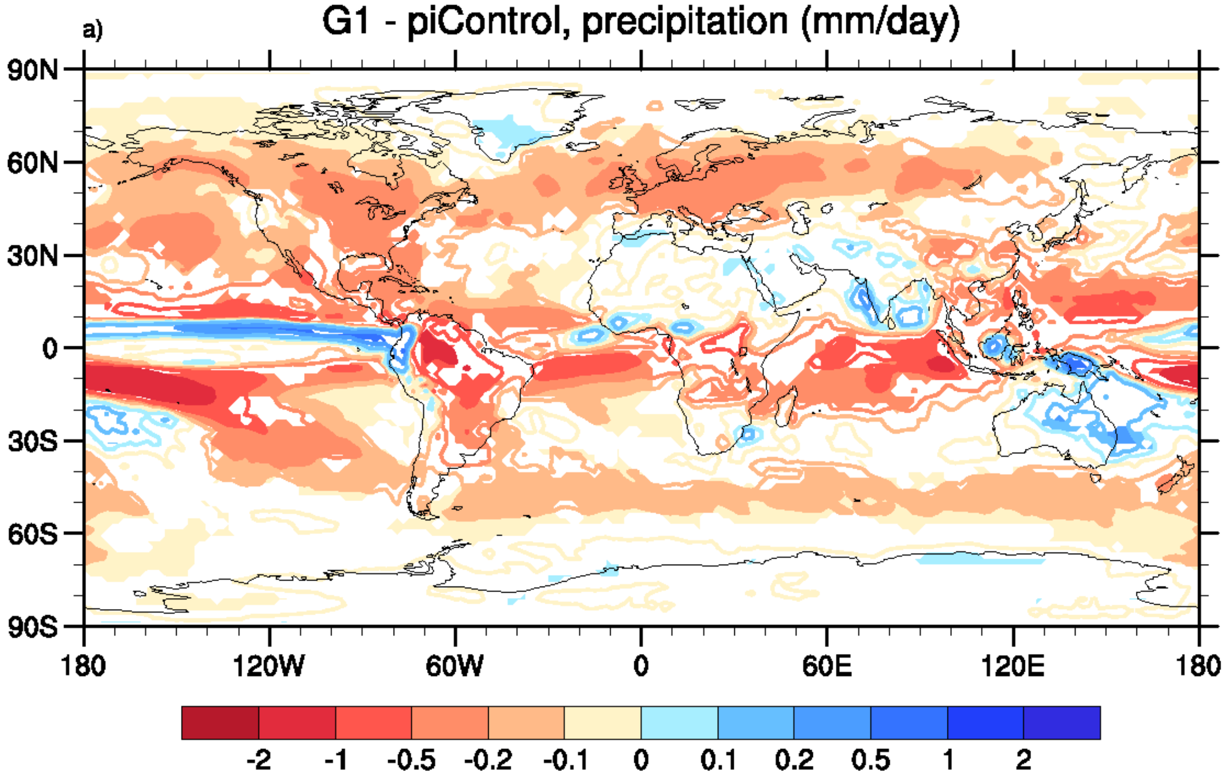

Fig. 1: Differences in precipitation (mm/day) between the simulations G1 (with climate engineering) and the preindustrial control run, averaged over the four ESMs. In regions with filled colour shading all models agree in the sign of the response. The value represented by the contours is given by the upper edge of the respective range in the colour bar, i.e., the zero line is coloured light yellow.

Considering the observed climate change and climate projections for the next century, solutions to limit global warming are being looked for. Simulations carried out by MPI-M's Earth system model called MPI-ESM show that the two-degree target could still be achieved if greenhouse gas emissions were reduced significantly starting from 2020. For the case that this goal may not be accomplished, a variety of engineering methods, referred to as "Geo Engineering" or "Climate Engineering", are suggested to fight global warming. These methods pursue different goals which are either to remove carbon dioxide from the atmosphere or to reflect more short-wave solar radiation back into space. The latter category of approaches is called "Solar Radiation Management".

Can solar radiation management really lead to a significant cooling? Which risks and side effects are to be expected? And most importantly, what kind of climate would result of it? All these questions are of major interest to Max Planck's Hauke Schmidt.

Changes in greenhouse gases and solar radiation have different impacts on the global radiation budget. While greenhouse gases influence the long-wave terrestrial radiation relatively homogeneously on the global scale, dimming the sun, for example by installing reflectors in outer space, effects the short-wave part of the radiation balance. The strongest effect can be seen where solar radiation is intense – thus, all the year round in the tropics and during summer in the higher latitudes. Within the EU project IMPLICC (**Impli**cations and Risks of Engineering Solar Radiation to Limit **C**limate **C**hange) Hauke Schmidt's working group and colleagues from international institutions have now studied how the climate system would react if the greenhouse effect of an increased CO_2 concentration was compensated by a reduction of solar radiation equally strong on the global scale.

Therefor computer simulations carried out by four Earth system models from four European research institutions (from Norway, France, England and Germany) have been compared. All models have run the same scenario with a fourfold increase in the greenhouse gas CO_2 ("global warming") and a reduced solar constant at the same time ("dimming the sun"). This model intercomparison allows predictions in which simulated climate effects can be considered robust – that is when all models show similar results – and which involve uncertainties. G1 of the GeoMIP (Geoengineering Model Intercomparison Project, Kravitz et al. 2011), the scenario which was used is not a realistic one since such a sudden CO_2 increase is not expected to happen. However, a radiative forcing that corresponds to four times the pre-industrial CO_2 concentration cannot be ruled out until the end of the 21st century according to the business as usual scenario RCP8.5 (van Vuuren et al., 2011) if CO_2 emissions are rising continuously. By using such an extreme scenario it is also made sure that the simulated climate signals clearly stand out from natural climate variability.

The models involved react robustly in many respects to this very drastic radiative forcing, i.e. show similar results. The model experiments are set up in a way that the effect caused by the increase in the greenhouse gas concentration on the global radiation budget is being thoroughly equalized through the reduction of the solar radiation – accordingly, the global mean temperature remains at a pre-industrial reference level. Nevertheless, 25 % more "Climate Engineering" than expected is required since less global cloud cover compensates parts of this effect. Also, the temperature is not being held at the reference level all over the world but is generally-speaking slightly higher in the higher latitudes and over continents (up to 1° C) and lower in the tropics and over the oceans.

Significantly stronger effects are expected to arise on the precipitation which decreases in the global mean by about 5 %. If quadrupling CO_2 is not being compensated, precipitation, on the contrary, will increase by 9 %. On the regional scale, changes in precipitation can be stronger after practicing "Climate Engineering" than through a rising greenhouse gas concentration itself. While in the latter case a clear reduction in precipitation, e. g. in the Mediterranean is being simulated, this zone shifts northwards if the solar radiation is being lowered at the same time. Especially over the vast land masses of northern Eurasia as well as over North and South America, a large-scale decrease in precipitation by more than 10 % is being simulated for this case (Fig. 1, see above). Among other things this is based on the lower evaporation rate of the oceans through a reduced solar radiation in the tropics and through less mixing of tropical and mid-latitude air masses caused by a lower meridional temperature gradient. This also reduces the poleward transport of water vapor.

The model intercomparison hence shows that "Climate Engineering" by using solar radiation management methods (here: reducing the solar constant which can be compared to installing reflectors in outer space) can reduce climate change globally but will not recover a historical climate state such as the one of pre-industrial times. It will rather create an entirely new climate. Even if temperatures could be lowered to a pre-industrial level, regional patterns and the global amount of precipitation would change and could not be retrieved.

But the reaction of the climate system is only one aspect that needs to be taken into account when discussing the use of „Climate Engineering" by manipulating the solar irradiation. If it was implemented it would have to be continued further on until a new way was found to remove carbon dioxide from the atmosphere. If the solar radiation management methods were stopped, the climatic change that had been suppressed before would catch up rapidly. Also ocean acidification would not be mitigated through solar radiation management. Moreover, many of the suggested approaches would cause specific side effects: If sulfur was artificially brought into the stratosphere, as observed after huge volcanic eruptions, cooling effects would most likely occur but would also damage the ozone layer. Also, according to a study within the IMPLICC project (Niemeier et al, 2011), much higher amounts of sulfur than estimated from volcanic eruptions would possibly be necessary for a specific cooling target. And apart from scientific viewpoints also political, ethical, legal and economical questions would have to be considered. In summary, it can be stated that "Climate Engineering" cannot be regarded as a strategy to avoid climate change equivalent to reducing greenhouse gas emissions.

Publication:

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Contact:

Dr. Hauke Schmidt
Max Planck Institute for Meteorology
Phone: +49 (0)40 41173 405
Email: hauke.schmidt@zmaw.de