Equilibrium Climate Sensitivity – A Practical Measure for Climate Change and a Grand Scientific Challenge

Earth´s climate sensitivity has been called the holy grail of climate science. No other measure reveals as much about climate change as does the climate sensitivity. It is measured by the change of the global mean surface temperature of the Earth that arises from doubling the atmospheric concentration of carbon dioxide, CO_2.

The Intergovernmental Panel on Climate Change (IPCC) estimated the range of climate sensitivity to likely be between 1.5 and 4.5°C in its Fifth Assessment Report, thus encompassing an uncertainty that has not narrowed since the early assessments of climate sensitivity in the 1970's. The thought-experiment of a CO_2 doubling has of course no counterpart in reality, but provides a single number to describe Earth´s sensitivity to carbon dioxide, as well as other forcings such as methane and aerosol particles that might affect climate. Knowing this number is key to reliable future climate projections.

Dr. Thorsten Mauritsen leads the *Climate Dynamics group* in the department *The Atmosphere in the Earth System* at the Max Planck Institute for Meteorology (MPI-M), led by Prof. Bjorn Stevens. Dr. Mauritsen's group studies how dynamic and moist processes, clouds and convection act to determine Earth´s climate sensitivity, alter its hydrological cycle, and amplify or dampen natural variability such as El Niño.

Climate sensitivity is the combined result of several feedback mechanisms, such as the positive water vapor feedback and ice albedo feedback. Changes in clouds and their interaction with global warming are particularly difficult to assess and contribute more to the uncertainty than does any other single factor. Estimating climate sensitivity based on observations is further challenging, both because climate forcings which are the presumed causes of past climate change and the state of the climate itself are too poorly observed and understood. For instance, the balance of radiant energy at the top of the atmosphere is still difficult to measure with sufficient accuracy to meaningfully close Earth's energy budget.

In the past, Thorsten Mauritsen has shown that climate sensitivity is physically unlikely to be below 1.5°C. To do so he explored the implications of a controversial scientific hypothesis of a negative feedback – an idea dating back to the beginning of the century – that is apparently missing in the models: the iris-effect (Mauritsen and Stevens, 2015). In the tropics, the ratio of variations in infrared radiation emitted to space to surface temperature in observations is stronger than that in climate model simulations, possibly indicating that important feedback processes are missing in the models. The idea is that dry and cloud-free regions expand in a warmer climate, leading to an increased emission of infrared radiation into space. This has been called the iris effect, in analogy to the enlargement of the iris that accompanies the contraction of the pupil in the presence of more light. This iris-effect could imply a negative feedback and thus act to reduce climate sensitivity. Some past estimates of its effect have suggested it could offset all of the other positive feedbacks in the system, resulting in a climate sensitivity as low as 1°C. By incorporating an iris-effect into the MPI-M Earth System Model, Mauritsen and Stevens show that the drier atmosphere caused by an iris-effet leads to fewer clouds, thus offsetting the reduced greenhouse effect of reduced high-clouds. This reduction of high-clouds also enhances hydrological cycle change.

Both a lower-end climate sensitivity around 2°C and an amplified hydrological change could bring models closer to the best estimates from observations. Mauritsen and Stevens suggest that the iris-effect in the tropical convection could be a physically plausible feedback process, if convective precipitation clouds organise into larger but fewer clouds under increasing temperatures.

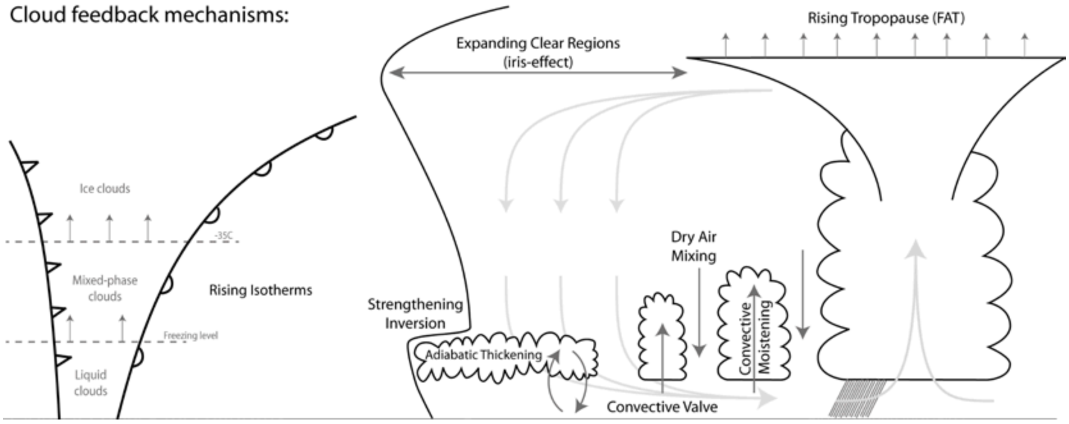

Fig. 1: Depiction of cloud feedback hypotheses. Left: cloud feedback liquid and ice phases in middle and higher latitudes, lower-middle: feedback of low clouds in the tropics, e.g. strength of the inversion, adiabatic thickening, convective valve, mixing dry air into the cloud layer, and upper-right: feedbacks from high tropical convection clouds, fixed anvil temperature (FAT) and iris-effect.

In the future, Mauritsen will focus more on the upper limit of climate sensitivity. A high climate sensitivity implies significant climate change and is therefore of importance for political decisions in avoiding, or adapting to climate change. Even with a lower limit for climate sensitivity at 1.5°C, the politically desired target to remain under a global warming of 2°C cannot be reached without mitigation strategies. However, the risks associated with a high climate sensitivity are more serious, and in certatin regions the consequent warming cannot be handled with adaptation measures alone. For instance, if areas become uninhabitable, the reduction of costs that originate from climate change is no longer relevant; e.g. if low-lying regions or islands are flooded due to rising sea levels, or if temperature and humidity rise so much that they will be fatal for animals and humans.

One may wonder: at which point the uncertainties about climate sensitivity are sufficiently low? For certain purposes the current knowledge of the uncertainty is sufficient, but in most practical cases more accurate information is desirable. Over time, the range of uncertainty will decrease by observing the ongoing warming: the signal of global warming will get stronger against the noise of natural variability. A recent study calculates that it is to be expected that uncertainties can be halved over the course of the next 15 years using this waiting-tactic. But the underlying theory of this study is itself subject to critique, and so it is likely to take longer time than anticipated.

As a natural scientist Mauritsen is driven by a desire to understand how the climate system works. In this regard less uncertainty around climate sensitivity could help, for instance, confirm and reject competing hypotheses on cloud feedbacks and help unravel the role of aerosol particles in driving climate change. The current level of uncertainty leaves too much room for interpretation.

To this end, he wants to employ a holistic approach involving both recent observations, pre-historic climate change indicators (proxies), high-resolution satelite imagery and high-resolution computer simulations. To tie the results together he will develop a hierarchy of climate models that incorporate various scientific hypotheses, such as the iris-effect, which can be tested on the observational data. Mauritsen and many of his scientist colleagues hope that, with such and other complementary efforts, they will reduce the uncertainty in climate sensitivity substantially already within the next five to ten years.

Publication on iris-effect:

Mauritsen, T. and B. Stevens (2015): Missing iris-effect as a possible cause of muted hydrological change and high climate sensitivity in models. *Nature Geoscience*, doi:10.1038/ngeo2414.

Further selected publications on climate sensitivity:

Meraner, K., T. Mauritsen, A. Voigt, 2013: Robust increase in equilibrium climate sensitivity under global warming. Geophys. Res. Lett. 40(22), 5944-5948, doi:10.1002/2013gl058118

Mauritsen, T., Graversen, R. G., Klocke, D., Langen, P. L., Stevens, B., Tomassini, L. 2013, Climate feedback efficiency and synergy. Climate Dynamics, doi:10.1007/s00382-013-1808-7

Contact:

Dr. Thorsten Mauritsen
Max Planck Institute for Meteorology
Phone: +49 40 41173 182
E-mail: thorsten.mauritsen@mpimet.mpg.de