The Strange World of Climate Models
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*When we talk about, and deal politically and socially with the change of climate, it is never the actual climate, but rather models of climate, we base our action and decision on. In this article philosopher of computer simulations, Gabriele Gramelsberger explains how these models work, and she questions the simplicity of these averaged simulations lacking the complex mechanisms taking place between the atmosphere and the ‘anthroposphere’, that we are left with when dealing with climate change.*

Predicting the future is one of mankind’s oldest dreams. Since computers have become tremendously fast, rational predictions based on millions of computations are on the everyday agenda of science. Weather forecasting and climate projections are two prominent candidates in this relatively new contest of telling the future: a new approach, which is based on trusting numbers rather than crystal balls. Unfortunately, these predictions are rarely cheerful, but because we take them more seriously than traditional clairvoyants, they are increasingly dominating our decisions as individuals and as a society.

The ultimate contest for rational climate predictions are the assessment reports by the IPCC Intergovernmental Panel on Climate Change, established by the United Nations in 1988. Since 1990 four assessment reports predicting future scenarios of climate change have been published. In 2007, 23 global climate models from eleven different nations participated in the AR4 Fourth Assessment Report. Australia, Canada, China, France, Germany, Great Britain, Japan, Korea, Norway, Russia, and the United States of America all computed their own climate projections (cf. IPCC AR4 WG1 2007, pp. 597-599). Since the FAR First Assessment Report in 1990 the requirements have become more ambitious. Starting with global atmosphere models and a ‘swamp ocean’, simulations of the AR4 use AOGCM coupled atmosphere-ocean general circulation models, and the ‘next top models’ of the AR5 in 2014 will move toward earth system models. “The continuous evolution of these models over recent decades has been enabled by a considerable increase in computational capacity, with supercomputer speeds increasing by roughly a factor of a million in the three decades from the 1970s to the present. This computational progress has permitted a corresponding increase in model complexity (by including more and more components and processes, in the length of the simulations, and in spatial resolution. The models
used to evaluate future climate changes have therefore evolved over time” (IPCC AR4 WG1 2007, p. 113, 114).

Although “climate scenarios rely upon the use of numerical models” (IPCC AR4 WG1 2007, p. 113) and these models have become superstars of a kind, with an increasingly trendsetting influence on our lifestyle, one should ask: What kind of view of the world do these models create? This view might be less blurry than that of a crystal ball, but it is not as accurate as we usually expect when mathematics are involved.

A look behind the scenes

In contrast to supermodels on the catwalk, climate models get fatter and fatter each season. Each weather and climate model consists of the same dynamic core describing the general circulation of the atmosphere—a set of equations that is rooted in Newton’s laws of motion and has been advanced by mathematicians and scientists like Leonhard Euler, Claude-Louis Navier, George Gabriele Stokes, Vilhelm Bjerknes, and others over the last centuries. Vilhem Bjerknes, in particular, outlined the principles of atmosphere models in his seminal 1904 paper, The Problem of Weather Prediction, Considered from the Viewpoints of Mechanics and Physics. In a the best Laplacian tradition, Bjerknes introduced his paper with the following statement: “If, as any scientifically thinking man believes, the later states of the atmosphere develop from the former according to physical laws, one will agree that the necessary and sufficient conditions for a rational solution of the problem of meteorological prediction are the following: 1. One has to know with sufficient accuracy the state of the atmosphere at a certain time. 2. One has to know with sufficient accuracy the laws according to which a certain state of the atmosphere develops from another.” (Bjerknes 1904: 1) He described atmosphere as an “air mass circulation engine” driven by solar radiation and gravitational forces expressed in local differences of meteorological variables like temperature. Based on seven equations, seven variables are computed which define the state of atmosphere: velocity in three directions, density, air pressure, temperature, and humidity. The dynamic core of any climate model even today follows this deterministic approach of early modern physics.

However, to make a numerical climate model run, Bjerknes’ seven equations have to be transformed into a list of computable procedures which divides the atmosphere into a number of boxes (grid cells) and describes the impact of meteorological effects on fluids—virtual entities used as objects for mechanical and dynamical manipulations and carriers of meteorological properties. These procedures indicate how to compute the flow of fluids between the boxes, the distribution and transformation of energy from one box to the other, the impact of several forces on the dynamics of the fluids,
the transport of water, vapor, aerosols, etc., and the density of the fluids depending on pressure, temperature, and humidity. These procedures express the behavior of an atmosphere model on a global level. A higher resolution leads to a greater number of boxes, allowing it to ‘zoom in’ the space of parameters and solutions as microscopes do visually. Today’s climate models use boxes that represent an average distance of 100 to 60 kilometers in the horizontal and several hundreds of kilometers in the vertical, depending on the number of levels used by the model and the maximum altitude.

The problem is that no process which takes place on a scale smaller than global resolution can be considered in the model. Therefore subscale processes have to be considered in the model explicitly as parametrizations. Each parameterization computes results that are then added to the dynamically computed results. This is one of the reasons why climate models become fatter: the role of parametrization is growing constantly. Typical parametrizations include processes in clouds, which are too small to be resolved in global resolution. Clouds are important agents for weather and climate processes; therefore every climate model includes a cloud file. Overall, a current atmosphere model consists of several hundred files containing several tens of thousands of code lines.

![Development of Climate models, Past, Present and Future](source: IPCC TAR WG1 2001: 48)
Climate models are also growing through combination with other models. Current climate models are AOGCM coupled atmosphere-ocean general circulation models designed to create complete earth systems. The dynamics of the ocean also follows the basic equations which drive the atmosphere. Subscale processes have to be parameterized as well. Today’s oceans are populated with all kind of agents, including fish, plankton, and shrimps.

Strange Worlds

Talking about the atmosphere and ocean, as well as clouds, fishes, and shrimps, conceals the real nature of climate models. Neither do fishes swim in the ocean nor do clouds cover the sky in these virtual worlds. For instance, when ice is melting in clouds we know that it will probably rain. If rain freezes, it will probably snow. In a climate model it also ‘rains’ and ‘snows’ but in this way: $z\text{snmlt} = \text{MIN}(zx\text{sec}*zs\text{fl}(j),z\text{cons}*z\text{tdif})$ instructing the melting of cloud ice ($Q\text{mli}$) as a function of two arguments: (1) available ice/snow ($zx\text{sec}*zs\text{fl}(j)$) and (2) change of temperature ($z\text{cons}*z\text{tdif}$) according to the equation of the mathematical model $Q\text{mli} = \frac{r_l}{\Delta t}$. The code mathematically describes ‘what happens when’, e.g. the temperature exceeds the freezing point. It is not a description for every single snowflake or rain droplet, but for the mean mass in a grid cell. Therefore climate models contain averaged clouds with averaged rain or snow and averaged fish in an averaged ocean—more akin to ‘fish soup’ than to a fish and an ocean.

The real nature of climate models is an algebraic one that describes everything in the language of mathematics, and this world follows its own rules. If we could enter this world we would exist only every twenty minutes according to the simulated size of the time step, and we would face a world with holes as big as Luxembourg according to the spatial resolution. The world of a climate model would be relatively empty and every existing ‘object’ would be distributed in a strange averaged way—including ourselves. Most of the structures in this world would be symmetrical and in a regular geometric shape. If a volcano erupted, ashes and particles would be set free immediately from one time step to the next in one of the grid boxes of the stratosphere, without any volcano or emission of lava.

However, a climate model ‘imitates’ the functionality and processuality of natural processes through coded instructions, in keeping with the idea that everything can—and should—be expressed as numbers. The rain of ashes, the melting of ice, and the flow of water in the ocean consist solely of streams of numbers conducted by the coded instructions of the files of a climate model. It is this idea which enables us to use climate models as forecasting algorithms for any event that we can capture
quantitatively. In the case of meteorological states like temperature or humidity, quantitative detection through measurement and a numerical extrapolation into the future is no problem. In the case of human influence, it is more difficult, however. The ‘anthroposphere’ is no more mathematically accessible than the atmosphere. The remaining problem is: Without the reflective and prognostic insights of the climate models’ decisions, for the ‘anthroposphere’ as well, the future will be veiled in the fog of a crystal ball.

References

IPCC Intergovernmental Panel on Climate Change: Homepage, 2009, URL: http://www.ipcc.ch

