

What is climate science all about?

Philosophical perspectives

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1. Intro

Today, climate science is mainly the science of climate change. Chapter 3 described how the scientific study of climate has shifted from an interest in the description of the geographical diversity of climate to trying to understand climate change. Perhaps surprisingly, it was not observed changes in climate that triggered this shift in interest, but a variety of non-scientific factors such as technological innovations and political interest.

In this chapter we shall analyze what constitutes climate science today. A process that will address questions such as: What do the scientists know about climate change? How was this understanding gained? How confident are the scientists in their results and claims? And, how does climate science feed into politics? In order to answer such questions we must first look at the key tool of climate science – the computer model. As described in chapter 3, climate simulations based on computer models are the core component of studies carried out by the rapidly expanding climate science research community. These climate models represent a large number of processes and can model oceans and water, biological processes, ice and snow, and even soils at the earth's crust.

We shall begin by attempting to define the nature of scientific models in general and how to characterize the computer models that are used in climate science. We shall also discuss how models are constructed and tested, and how they are used. Throughout we aim to address some of the inherently philosophical questions associated with this approach to science including: how computer models relate to the real world, and the role that different kinds of values play in choosing between models.

2. Models and model construction

Models form an important part of science. A model represents a selected part of the world. This representation is not, however, an exact replica of the system that the model represents instead the model represents only certain aspects of the system while ignoring others.

Many representational models are analogue models which are based on certain similarities or analogies between aspects of the represented and the representing systems. For example, the billiard ball model of a gas represents the molecules of a gas as a collection of billiard balls that are randomly moving and hitting each other. However, molecules in a gas and randomly moving billiard balls are far from identical, and while the billiard ball model may successfully represent some aspects of gaseous behaviour, there are many other aspects that it does not represent. Another example is a ball-and-stick model of a molecule. This model is a representation of the molecule in which the spatial structure of the molecule is rendered by the bond angles and the relation between the bond lengths, but there are many other aspects of the molecule that it does not represent.

Other models are abstract and reflect how scientists imagine that different things or processes may work. Many abstract models, such as those used in climate science, are mathematical and provide a numerical representation of specific features of the world, for example selected features of the climate system.

All scientific models are produced by humans, who investigate phenomena, make observations, create abstract descriptions and construct models that can represent the investigated phenomena. But, as noted above, many processes in nature are far too complex to be fully represented in a model or even in a series of combined models so instead a model represents only certain aspects of the system while ignoring others. Thus, when creating a model of a phenomenon those who construct the model select what they want to represent and what they want to ignore. The deliberate focus on single, specific features of these phenomena makes it easier, for example, to establish mathematical relations between these features. In the case of meteorology, in 1903 Vilhelm Bjerknes managed to describe some meteorological phenomena by focusing on the relation of parameters like temperature, wind velocity and pressure in the form of complex mathematical equations. As meteorological phenomena are extremely complex, he was only able to accomplish such a description by being selective – by reducing his interest to the limited number of physical properties outlined above and neglecting many others (such as atmospheric electricity, solar

radiation, chemical processes or the colour of clouds).

This selection process means that there is no single way to construct a model, and therefore no single model for addressing a particular question. However, as we shall see later, this does not mean that models can be constructed arbitrarily, or that all models are equally good for all purposes.

3. Computer models in climate science

Computer models are usually very complex constructions based on many sub-models that model different features. A modern climate model, to take an example, consists of sub-models for meteorology, solar radiation, atmospheric chemistry, carbon exchange processes, oceans and many other phenomena. Thus, climate models build on a multitude of elements from hydrodynamics, aerodynamics, thermodynamics, chemistry etc.

At first sight, it may seem preferable to have a complex computer model that represents many aspects of the climate instead of simpler models. But, when working with complex models, there is a level of uncertainty associated with each process, which when added together increases the uncertainty of the overall model, at the same time as being hard to isolate. This issue of uncertainty in models is worth further discussion. In general there are two major factors that mean a model has a level of uncertainty, 1) limitations of mathematical techniques and 2) limitations of computer capacity.

Lewis Fry Richardson, who attempted to calculate the weather (see the preceding chapter), experienced the mathematical problems involved in solving complex differential equations. Since he could not reach a solution analytically he had to resort to cumbersome numerical solution strategies. Numerical solutions are approximations, however. These solutions do not work in all cases, and they may cause so-called instabilities in simulation runs (which is the production of very strange results due to the approximations). Numerical techniques, therefore, add to the uncertainty of simulation output, even though these uncertainties are usually well understood and can be investigated and minimized.

The limitation of computer power causes more significant problems. The weather models created by von Neumann's group and the first attempt at climate modelling by Norman Phillips (see the preceding chapter) both represented typical examples of model construction for the use on computers with limited power. The mathematical theories upon which these models were based had to be simplified drastically to enable the construction of modules, which could be executed by the computer power available, and which did not have extraordinary long (and expensive) runtimes. The build-

ers of the first weather model intentionally ignored any vertical movement of air, fully aware of the fact that this simplification was far from realistic. Such simplifications in complex computer models are typical of this kind of model construction.

Since there is no clear answer to the question of which processes and modules the model builder should include and on which theories the modules should be based, there is a certain amount of freedom and flexibility in the model construction process. Models, in this sense, are “plastic”. They can be moulded and designed. It is the model builders who decide on the model’s features and choose the forms and extent of simplification, and the level of detail they wish to consider. Their decisions will depend on the problem to be tackled and the questions that need to be solved by the model, and the knowledge and data available.

Usually, a lot of guess-work and trial-and-error is involved in model construction. In climate modelling there was a tendency to keep on increasing the detail of the models until the mid-1990s. Though this tendency continues to the present day, it is now complemented by a second, more recent strategy, which is the use of much smaller models for the treatment of specific problems (so-called EMICs – Earth Models of Intermediate Complexity). Smaller models have several advantages: they need less run time, less input data and they are easier to comprehend. This also means that unavoidable mistakes and programming errors can be found more easily and quickly.

The range of freedom in module design and model construction is one of the reasons why there is not only one accepted model for a certain domain, but usually many models. However, scientists often appreciate a multitude of computer models for single domains, because models and model simulations can then be compared. It has become an important strategy in recent years to perform so-called ensemble-simulations. Ensemble-simulations are simulations of one specific case with identical boundary conditions and input data using many different models.

So what does this mean for uncertainty? It is, perhaps, paradoxical that the uncertainty in climate models becomes apparent because this uncertainty is not visible. Simulation results can usually not be given with any uncertainty margins from which the reliability of the result could be assessed. Computer simulations only produce exact numbers, which may even give the deceptive impression of precision. This is a knotty problem. While climate modellers know about uncertainties, it is difficult for them to assess the level of uncertainty, whether it is 10 percent, 50 percent or 200 percent.

While uncertainty in climate simulation certainly is a significant problem, climate modellers appear to have considerable confidence in what they do.

Investigations by social scientists have shown that scientists get used to uncertainties and the insurmountable limitations of computer model use. They have learned to live in a computer model world, got to know the behaviour of their models after many years of experience and over time developed familiarity and trust. In everyday language in the simulation laboratories scientists talk about clouds, radiation, aerosols and the like referring to computer model clouds, radiation and aerosols. Computer models take on a life of their own. They allow climate scientists to get a feeling for violent storms, pouring rain or heat waves without ever leaving the lab.

Over all, most model builders are aware of the specific problems in computer model building, computer simulation and the uncertainties that are related to these techniques, and they have invented a number of specific practices and procedures to handle many of the problems involved.

4. The art of climate model building I: resolution and parameterization

Climate models can calculate meteorological parameters such as temperature, humidity or precipitation over a long period of time based on relevant conditions and processes in the atmosphere. But, herein lays a fundamental problem. A parameter like temperature can in principle be assigned to virtually every point in the atmosphere and every point in time. This infinity of potential points of measurement has to be reduced to something more manageable. Climate models are therefore based on a grid consisting of grid elements with defined length and breadth. A common size for grid elements in 1990 was a length and width of 500 km, by 2000 it was 250 km and in 2007 the grids had a length and width of 110 km. Since climate models are always based on a grid they, therefore, always have a limited spatial resolution. Similarly, climate models differ in vertical resolution. Very simple models do not distinguish between different heights in the atmosphere, at all, while complex models divide the atmosphere into many layers. The same kind of strategy applies with respect to time. While parameters like temperature change continuously and can be measured for every point in time, computer models can only consider a limited temporal resolution. For simulation runs fixed time steps (e. g. one hour) are defined to calculate the progression of weather or climate.

Computer models never calculate point values; they are always spatially and temporally averaged values. A particular climate simulation means that on a specific predefined grid (for which the model is designed) all climate variables are calculated for every grid element and every time step. All cal-

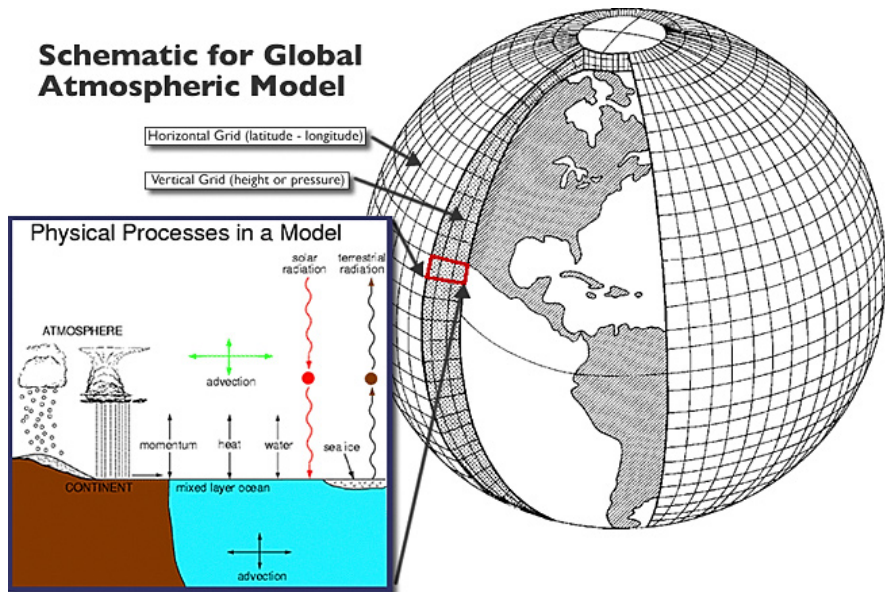


Figure 1: Schematic outline of a climate model. The surface of the Earth is divided into a grid with approximately 110 km between each point and a series of vertical layers. Atmospheric models typically contain 30-40 layers and oceanic models contain 20-30. On the right side the physical processes that are simulated in the model are shown (Source: Wikipedia)

culated climate variables represent spatial averages for the grid element and temporal averages for the length of the time step. Obviously, computer run time increases enormously if the spatial resolution (that is, the number of grid elements) or the temporal resolution is increased. The selection of spatial and temporal resolution usually is a compromise between detail and available computer power and run time.

Limited resolution in climate modelling has significant implications. All processes or phenomena with a smaller spatial extension than the size of a grid element (so-called sub-grid phenomena), cannot be considered explicitly in the model. Instead, the scientists try to consider sub-grid phenomena by using simplifications and generalizations, which are referred to as parameterization. Clouds are a case in point. Clouds play an important part in climate processes, but they are usually much smaller than the size of a grid element and so need to be treated in this simplified and generalized way.

Parameterizations may also be applied for other phenomena, which can for different reasons not explicitly be considered in the climate model, e. g. because of the lack of computer power. Since both the amount of available computer power and our knowledge of the various phenomena may change

over the time, some phenomena that were first parametrized may later become explicitly modelled. The oceans and aerosols are relevant examples. In the 1980s, oceans were usually not considered explicitly in climate models. The effect of oceans could be parameterized, for example by assuming a certain uptake of carbon dioxide by the oceans. Ten years later, however, ocean models had been developed and were included in climate models.

Over all parameterizations add a great deal of uncertainty to models and are constantly a matter of debate. Clearly, parameterizations do not reflect real physical processes, but a much simplified and generalized description. There is no generally agreed upon method for creating good parameterizations, in fact there is not even agreement on what makes a good parameterization. Some parameterizations appear to work well for specific applications, but fail in other applications. Scientists, therefore, strive to reduce the number of parameterizations by explicitly modelling the respective phenomena.

5. The art of climate model building II: testing the models

Single parameterizations and modules are tested before they are integrated into the model. Ideally the calculated data from the model can be tested against measured data, but this is not always possible if, for example, measured data does not exist for your model or the existing measured data is incomplete. Therefore, scientists sometimes test submodules and parameterizations with the help of other, more detailed models. Then if the calculated data of a sub-model do not match measured data or are not consistent with calculated data from existing and tested models, modules may be changed and adapted. Simplification schemes may be revised, parameterizations adjusted or single parameters tuned, until model tests bring better results. Parameter tuning is a common practice in model building. As many uncertain assumptions flow into model construction, tuning provides a strategy for improving model performance by trial and error. Ideally, tuning and testing are limited to the process of model construction and stop once model construction is complete. But in many instances model development is an ongoing process, which benefits from knowledge gained through use and simulation experience, so a clear separation of model construction and model use is often not possible.

In several cases it has been found, for example, that less complex models with more simplifications and neglected effects have given better results than complex models, which may not have been what the model developers

would have predicted. The problem of model assessment also makes it difficult for the model developer to decide how best to improve her/his model. Identifying the source of errors within a model is difficult and consequently it is hard to say which part of a model should be improved first. Many model developers start by ensuring that their models reflect the most up-to-date scientific understanding. Including a recently understood effect is generally considered a good way to raise confidence in a model, even though an improved performance may be impossible to prove

Climate model construction is thus a complicated process which involves a large diversity of data, experimental outcomes, theories, models, parameterizations, assumptions, simplifications and technical tricks as well as repeated processes of fitting, testing and tuning. Climate models, in this sense, can be compared with complex technical machines like airplanes, for which many different parts are needed and often have to be optimized according to trial and error testing. As in complex machines, the different modules must be designed so as to fit well together in a comprehensive computer model.

6. Uses of climate models and features of climate simulation

Above we described the main challenges involved in constructing climate models. We shall now look at the challenges that are involved in the climate researchers' use of climate models. Some of these challenges are primarily related to the collection and interpretation of data, while others are related to the different kinds of predictions that can be made from the models.

When a climate model has been constructed, it is not a simple and straightforward task to run simulations. The model cannot simply be switched on like a machine. Climate models need an enormous amount of input data, which first have to be provided. Meteorological data sets, data on solar radiation, data on the composition of the atmosphere, data on carbon cycles, data on ocean processes and many more data have to be collected and prepared for a simulation. These data are needed for every single grid cell and every single time-step (e. g. every hour) for the whole period of calculation. Here a fundamental problem arises. A full set of input data is usually not available. Data, therefore, are produced from many different sources and through a variety of routines. Input data may comprise measured data sets, calculated data, interpolated data, extrapolated data, estimated data and invented data. These data sets also comprise predictions, e. g. of future greenhouse gas emissions. In many projects (e.g. in the framework of simulations produced for the Intergovernmental Panel

on Climate Change (IPCC)) these predictive data are predefined and based on standardized socio-economic scenarios.

Simulation runs do not only require large sets of data, they also produce very large sets of data. Never before in the history of science have such large amounts of data been created within such short periods of time as with computer modelling. While in traditional experimentation data production usually is cumbersome, expensive and slow, computer models can very quickly produce gigabytes of data. Masses of data have to be managed, checked, condensed, represented and interpreted, which is not a trivial task. Many routines and tools have been developed to handle these floods of data and wring out information from them. While computer modelling is usually more visible to the outside world than the processing and management of data, data management in many cases requires a much larger amount of work.

7. Prediction, experimentation and control

Once the data requirements have been met and the problems of data processing and management overcome, climate models can prove to be enormously versatile tools which are widely applicable. The most visible application of a climate model is for prognostic purposes as a forecast tool. If a model manages to simulate past climates in such a way that many of the predictions come close to what we can measure, scientists feel encouraged to use it for climate predictions. As most climate models come to very similar conclusions with regard to climate warming these predictions, or at least their general tendency, are almost universally accepted, today. So, while it is still regarded an open question as to whether the average temperatures in the 21st century will increase by 2 or 5°C, or even more, the idea that it is very likely that there will be increasing temperatures is not seriously questioned anymore. It is interesting to note that this almost universal agreement has been accomplished with the help of computer models and would otherwise probably not have been achieved.

Computer modelling is not, however, only a tool for making predictions of this sort. A second application, which is at least as important, is the use of models to predict hypothetical developments. In such cases the model is used to calculate what will happen, given specific conditions. A computer climate model, for example, can be developed to provide answers to questions like the following: What happens if we reduce carbon dioxide emissions by 50 percent? What happens if ice melting occurs twice as fast in future decades? Or what would be the impact on climate, if deforesta-

tion in the tropics accelerates? Also unrealistic assumptions can be tested for scientific reasons or just for the sake of curiosity, such as: What would happen in an atmosphere without clouds? Or what impact would it have, if huge sails in outer space shielded the earth from certain kinds of solar radiation?

In this way climate models provide the opportunity to perform virtual experiments, where the researchers vary some variables to see how that affects other variables. This form of experimentation is generally called “numerical experimentation”, to distinguish it from experiments in which we study aspects of the world by interacting with it. Scientists in many fields have embraced enthusiastically the use of computer models for virtual experiments, because it enlarges the reach for “experimental” investigation enormously. Computer “experiments” are mainly performed in fields where scientists do not have the option to make traditional experiments, either because it is impossible (such as investigating what will happen to the world economy given dramatic changes in interest rates), too expensive (such as making real tests of nuclear fusion) or because it is ethically problematical (such as making epidemiologic experiments by circulating certain bacteria), or a mixture of these reasons (such as testing an intervention like spreading aerosols in the atmosphere to lower temperatures in the Earth’s climate system which at this time would be practically impossible, very expensive, and ethically problematic since it could have very severe and unwanted effects). It has to be kept in mind that computer “experiments” are a form of playing with theories— and thus are a theoretical and not an empirical exercise. In fields, which are investigated by computer simulation, concepts like “experiment” and “theory” have to some extent lost their original meanings.

Finally, a third application of computer models is as a mutual control for other computer models. As described in the section “The art of climate model building II”, scientists test submodules and parameterizations with the help of other, more detailed models. In this mode of application the output of computer simulations is compared with data obtained from other models in order to answer questions like the following: Are the emission estimates that have been put into the simulation realistic? Is this new parameterization good enough? Is the spatial resolution chosen for a certain model application appropriate? Usually, new models or new modules are tested extensively with the help of other well-known and accepted models that serve as control devices. In some cases, computer models may also be used to control the quality of empirical data and answer questions like: Can these historical climate data obtained from unreliable historical sources be correct?

Most scientists agree that computer models and computer simulations such as those used in climate modelling have enhanced scientific knowledge considerably. In fact computer simulation appears to have become a fundamental scientific methodology in its own right, similar to theoretical reasoning and real-world experimentation. Climate models, for example, can neither be considered as empirical nor theoretical constructions, instead they represent hybrid entities that involve both theoretical (e.g. laws of atmospheric physics) and empirical data (measured data), and use elements of both experimentation and theory building. For this reason, some scholars have pronounced computer simulation as a “third way in science”. Although their opponents argue that hybrid forms of scientific practice have always been common, noting that even empirical data, like measurements, are not pure empirical entities since theory is applied during their interpretation. But, even if not all scientists see computer simulation as the “third way”, most agree that computer models and computer simulation represent a new, powerful and increasingly influential scientific strategy.

8. Models and the real world

So far we have spoken about how the predictions of a model correspond with measurements without going deeper into the philosophical question of how models relate to the real world. An important issue when dealing with models is how well the model fits the world, that is, whether the predictions made by the model are similar – within a certain degree of accuracy – to the data that can be obtained by studying those parts of the world that the model is assumed to represent. If the observational data are far from the predicted results, then we know that something is wrong with our model. However, we may not know exactly what is wrong with our model, only that something is wrong. On the other hand, if the observational data are close to the predicted results, we may be tempted to think that the model truly represents the world. However, there may be other models that provide equally good predictions. We may not be familiar with such competing models, but still they may be possible. These other models may provide equally good predictions, and therefore there would be no empirical way to choose between them. Instead, we may make a choice based on values such as simplicity, coherence with other parts of science, or internal consistency.

Some of these values many scientists consider fundamental. Most scientists expect their models to be consistent, and inconsistencies will count

heavily against accepting a model. Likewise, new models are expected to be coherent with known theories from other areas of science. Climate models have to be based on physical laws and are not allowed to contradict such laws. A case in point is mass balance. If atmospheric gases flow into a certain grid element and are subject to chemical transformation and deposition processes, the total amount of the mass of chemical compounds must not change at different points in time. Mass simply does not get lost.

In choosing between models we may also be influenced by social, political or ethical values. We may choose a model, for example, because it focuses on aspects of the world that we are especially interested in, it is more economical to use, or it produces results quickly. One model, for instance, may provide good data on oceanic transport and possible changes in the direction of ocean currents such as the Gulf Stream, while another is better at providing information about atmospheric phenomena and relations between green house gasses and temperature changes.

9. Comparing prediction and observation: validation

The most important part of the model assessment process is “validation”. The term “validation” simply refers to the process used to see whether the model models what it is supposed to model. A climate model, for example, firstly has to be able to simulate past climates for which measured data exist. A climate model that is able to simulate the differences in climate observed during different seasons or in different geographical regions is considered more valid than a model that is not able to reproduce such observations. All modern climate models pass such validation tests, but there are large differences as to how well a model reproduces observational data. All models do so in many cases of comparison. But all models also fail in other cases, sometimes even miserably. A good model should be successful in most cases of comparison and only fail in a few instances. But even successful validation tests do not allow the conclusion that the model is correct and will provide correct results in the future.

Validation projects suffer from many problems. Firstly, validation is limited by a general lack of measured data. While climate models can quickly process a large amount of data, the measurement of comparable data is much more expensive and takes much more time. For that reason, the amount of measured data usually is much smaller than the amount of calculated data. As a consequence, validation opportunities are limited from the outset. Secondly, data bases of measured data are not equally good for all parameters involved in climate modelling. While good data

bases may exist for temperature over the surface of the earth, much less measured data are available for the concentration, type and size of aerosols in higher layers of the atmosphere. Thirdly, measured data are usually measurements at a specific point. Simulated data, in contrast, represent a whole grid element, which even in the best models has a size of a tenth of a kilometer. In that sense, measured and simulated data are not comparable, at all. Scientists have to assume that point measurements (or the average of several point measurements) may be regarded as representative of the whole grid element, in which the measurements were taken. And finally, predictions for future periods of time can of course not be validated. Based on a large amount of experience with computer models, scientists have to assess whether such predictions can be considered reliable. If future conditions of the atmosphere, upon which the simulations have been based, are similar to past conditions, confidence in the model predictions may be warranted. More problematic are simulation cases, in which the atmosphere or other systems of the earth like the oceans, the biosphere etc. enter a new state, e.g. noticeably higher greenhouse gas concentrations than in the 20th century, or higher ocean temperatures than experienced previously.

Major sources of uncertainty in climate model predictions are the so-called secondary effects. Such effects are caused by climate change, but also may have an impact on future climate development, which is unknown. Examples of such secondary effects are increasing cloud formation (which would cause a negative feedback due to increased reflection of solar radiation, that is a slowing of climate warming) or the melting of arctic ice (which would cause a positive feedback due to decreased albedo, that is an acceleration of climate warming). Climate scientists, however, do not have any measured data for states of the atmosphere with increased cloud formation or with decreased arctic ice volumes. For that reason, it is not possible to tell, whether current climate models are able to provide realistic predictions of such future states and their impact on climate warming.

In spite of the manifold problems of climate model validation there is agreement among climate modellers that climate models can be – and have to be – validated and applied as useful tools. In order to increase the confidence in model simulations, several additional practices have become important, such as sensitivity studies, model comparisons and ensemble predictions. Sensitivity studies serve to provide information on the sensitivity of the climate model with regard to a specific parameter. In sensitivity studies a particular parameter is varied over a certain range of values and for all these variations simulation results are calculated. If the simulation

results do not differ very much in spite of parameter variation, the model is considered a little sensitive with regard to that parameter. Such information is extremely valuable, because a parameter included in the simulation might be very uncertain or even not known at all. Such a situation is not so problematic, if the model is not very sensitive with regard to that parameter. In the opposite case, however, if the model reacts sensitively to parameter variation, simulation results have to be considered as very uncertain and unreliable.

The use of ensemble simulations is one approach that is gaining credibility as a means of increasing the reliability of climate models. Since the 1990s, a growing number of projects have set out with the goal of performing climate simulations with many models which use standardized conditions and data sets, such as those defined by IPCC working groups. Such model comparisons originally were devised to compare the behaviour of different models and provide insights into the reasons why models behaved differently. In recent years, the use of several models for climate simulations has also become a standardized practice to increase the reliability of simulations. This practice is called ensemble simulation. The rationale behind it is the belief, that averaged simulation results from many, very different models would be more reliable, and the probability of gross errors smaller.

10. Climate models and politics

A special feature of climate science is that this form of science has become closely linked with politics. There is a panel of scientists under the auspices of the United Nations, the Intergovernmental Panel on Climate Change (IPCC) that has been given the role of assessing “the scientific basis of risk of human-induced climate change”.

The testing of models and model results are a priority of the relevant IPCC working groups. Here, the consensus of a large number of the most prestigious scientists provides the basis for confidence in models and simulation results. On the other hand, the need for these IPCC working groups and their standardized procedures reflects the fact that comprehensive and effective scientific criteria to assess and rank models are not yet available.

In addition to politically driven initiatives there are also a whole host of individual scientists and research institutions which are trying to develop and present their ideas and findings in open competition with other scientists and research institutions. In this instance, the scientists rely on

getting their papers published in esteemed international journals as a way to get their ideas into the public domain. To get a paper into such a journal a scientist or – more typically – a group of scientists will submit their written summary of ideas and findings, known as a manuscript, to a specific journal. The editor of the journal then sends the paper to one or more eminent scientists who are familiar with the field that the manuscript addresses. These experts, or referees, then provide an anonymous assessment of the paper and recommend whether the manuscript should be accepted, should be accepted but only if certain revisions are made, or should be rejected.

This process of so-called peer review is the backbone of science. The aim of the system is to ensure that only papers which in the eyes of eminent scientists are up to the highest standards will be published. So, in this system, it should not be possible to have your ideas or results published just because you are an influential person or because your ideas or results fit into what is considered politically desirable.

A consequence of this system is that often conflicting and competing ideas and hypotheses will get published side by side. For example within climate science some scientists have managed to publish papers which argue that climate change is not mainly the effect of human activities but rather the effect of naturally occurring fluctuations, e.g. in the sun. At the same time other scientists, and the majority of them, have presented results that they take to indicate that climate change is mainly the effect of human activities.

Such disagreement and openings for discussion are considered good for the process of science by, among others, academics interested in the philosophy of science who generally believe that science and scientists should not be aiming for consensus. Robert Merton, a British sociologist of science, is one proponent of this way of thinking. According to Merton the essence of science is to be objective. Scientists should not band together and aim for consensus. Quite to the contrary, they should constantly aim to put each other's results under critical scrutiny. In his opinion, science can only make progress towards an objective truth through constant and organised scepticism.

However, this situation is not very convenient in a political context, where politicians seem to need unanimous advice from the scientific community rather than conflicting pieces of advice that are likely to be taken up and used by other political parties with different political agendas. An example of this kind of use of science is the selective highlighting of scientific publications which argue that climate change is not mainly man-made by those groups

and political parties that have a vested interest in the economy being driven by the unhindered consumption of coal and oil.

It was against this background that the IPCC was established in 1988. The IPCC was set up by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), which both come under the United Nations. This new organization built on earlier international collaborations set up to gather and share meteorological data, but its establishment also reflected a growing political awareness of the potential negative effect of human activities on the climate.

The role of the IPCC is to assess the scientific information relevant to understanding the risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. Review is an essential part of the IPCC process. Since the IPCC is an intergovernmental body review of IPCC document involves both peer review by experts and review by governments.

Since its establishment the IPCC has published four main reports, the first in 1990 and the fourth in 2007. The main parts of these reports are reviews made by prominent scientists in various branches of climate research. And these reviews are again carefully scrutinized through peer review processes very much like the peer review processes used by scientific journals.

To write a report is a huge undertaking involving a lot of scientists. The 2007 IPCC Fourth Assessment Report, for example, involved people from over 130 countries making contributions over a period of 6 years. These people included more than 2500 scientific expert reviewers, more than 800 contributing authors, and more than 450 lead authors. Besides all the individual reviews an IPCC main report also contains a summary report, called Summary for Policymakers. This summary undergoes review by participating governments in addition to scientific review, and it is this summary that usually gets all the media attention.

But even though the IPCC uses some of the procedures followed by non-associated climate scientists, there are some features that are specific to the IPCC. Firstly, scientists are selected to participate; and there is no way that a scientist with views opposing the mainstream is going to be able to make a contribution to the report. Secondly, the main aim is to achieve some form of consensus – a feature which clearly serves to modify the norm of organized scepticism. Thirdly and finally even though it is said in the remit of IPCC that the panel should be neutral with respect to policy there is a clear link to policy, not least via the role governments play in reviewing the report. The political role of the IPCC is also underlined by the fact that the organization's panel shared the 2007 Nobel Peace Prize

with former vice-president of the USA, Al Gore. This prize is given for actions that make a positive political difference in relation to creation of peace in the world.

It is, therefore, not surprising that there have been controversies surrounding the IPCC. One example is that in January 2005 the prominent climate scientist Christopher Landsea resigned from his work with the organization, saying that he viewed the process “as both being motivated by pre-conceived agendas and being scientifically unsound”. He made his decision following the highly publicized claims of one of the leaders of the IPCC that global warming was contributing to recent hurricane activity. Other critics have argued in the opposite direction, claiming that the IPCC reports tend to underestimate dangers, understate risks, and report only the “lowest common denominator” findings. According to these critics the IPCC actually serves to legitimate governments withholding necessary action in the light of alleged scientific uncertainty.

Some puritans would like to have an iron curtain between science and society. However, in reality science and politics have to interact. It is the role of science to give advice in many politically sensitive areas besides climate science. For example, when it comes to the safety of products, including the food we eat, it is the role of scientists working for governments to do risk assessments which are then used by regulators and ultimately politicians to make decisions about what to allow and what not to allow.

Many scientists involved in assessing risks will claim that they are not mingling with politics at all – they are just presenting the facts and then leaving it to regulators and politicians to decide what to do. However this view does not really stand up to closer scrutiny. Firstly, often it is the role of scientists, as is the case in climate science, to identify what things we ought to be worried about, and this, if anything is, is a value-laden decision. Secondly, scientists are partly being selected because they are considered “reasonable” and work in committees which aim at consensus rather than organised scepticism.

The only solution to the problem seems to be transparency, a value that is also written into the remit of the IPCC. Climate scientists should be open about the uncertainties and limitations relating to their scientific efforts, they should allow different voices to be heard, and when they engage in work for organizations like the IPCC, they should be open about their political role.

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