

Climate change, science and debate

Important note: this is an unofficial, rough translation, and discrepancies will exist between this translation and the official text in Dutch.



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Foreword

Climate change is one of the most important global issues. Positioned at the crossroads of society, economy and science, and in light of great public interest. This problem raises many concerns and questions.

In the past year, climate change has been the subject of a very intense debate, both inside and outside of science – a debate that was easily polarized and politicized. The world is then conveniently divided into "alarmists" and "skeptics", who, on ideological grounds, do or do not 'believe' in climate change.

In addition, the published e-mails from some climate scientists and the discovery of some errors in the final report of the UN climate panel IPCC - for many the most important source for an overview of the global knowledge about climate change - led to further public confusion and outcry. Climate scientists looked with dismay at how the debate became clouded, and how sometimes little notice was taken of the boundaries between politics, media and science. In the public debate, it appeared that opinions were not always based on purely scientific foundations.

In many ways this fierce debate reflects the importance that everyone attaches to the issue of climate change. Climate change not only threatens a fragile world, the actions involved in mitigation require tremendous efforts of our society and economy, which will be also significantly affected. A vigorous debate on such an important issue is complimentary to anyone. But, as U.S. Senator Daniel Patrick Moynihan said, everyone is entitled to their opinion, but not his own facts.

The complexity of the climate change issue will make it a nearly impossible task to distinguish facts from opinions, for anyone who remotely follows the debate. Let alone make a clear assessment of how climate change really works. The nature of science itself contributes to this confusion, as a researcher is, by nature, —his own critic. An increase of scientific knowledge would therefore not automatically lead to increased certainty. This fact requires a lot from those who seek to make policy based on knowledge.

Over the past year, the academy has participated in the climate change discussion in two ways. The academy was closely involved in the review of the working procedures of the IPCC by the InterAcademy Council and has supervised the research that the PBL (Netherlands Environmental Assessment Agency, part of the Dutch Government) has carried out on the scientific basis of the most important conclusions of the IPCC regarding the possible regional impacts of climate change.

However, the involvement of the Academy does not stop there. As an independent voice of science, the Academy sees a role for itself to provide guidance for the lay public, public servant and politician to enable them to form an opinion on climate change. With this brochure the Academy, as an honest broker of knowledge, provides the most reliable a picture as possible of the current situation on climate change. What do we know and how sure are we? Where are the real controversies, and why are they there? The content of this brochure is not new, but the emphases and the author are. In creating this brochure, the Academy requested the input from dozens of scientists from across the breadth of climate science, inside and outside its own ranks. I would like to thank them for the enthusiasm and the care with which they approached this project.

This brochure systematically presents the physical sciences' 'hard' facts about climate change, and highlights the controversies and uncertainties inherent to climate research and that you encounter in the media. It starts with an explanation of how science works and what to expect from it, who are allowed to participate in the scientific debate and under what conditions. In the final chapter you will find seven summary statements on climate change - issues on which science agrees.

The research is continuing and this brochure is certainly not to be regarded as the final word on climate change and the human influence on it. But hopefully it can contribute to the debate on climate change and everything that relates to it, to a level that this important issue deserves.

Robbert Dijkgraaf
President KNAW

1. Background

The public debate on the Earth's climate change and human influence thereon is characterized by ambiguities. Scientific facts, wild speculations and factual uncertainties in this debate are often used together, so that a perhaps dangerous, but in any case extremely murky mix has been achieved. For the average citizen, but also for policymakers and politicians it is becoming increasingly difficult to get a clear picture of what arguments are valid, or outdated, or misleading or simply ad hoc. Let alone to obtain insight in the vested interests that hide behind the arguments.

At the same time the climate debate, more than any previous debate, makes publicly clear that there are limits to science, there are areas where science has sensible things to say and where science should remain silent. For those for whom science is dear –are all too well aware of its limitations and that scientific arguments in a debate do not always have to be decisive. If only because the science is often better in indicating uncertainty and risks, than it can offer certainty and inevitable decisions.¹

With this brochure, the Academy tries especially to clarify the climate debate and the role of science in it. The academy doesn't see it as its task to provide the redeeming or final word. She doesn't want to position itself above, but in between the parties, as a kind of honest broker who wants to understand the statements and views of all participants as well as possible, to present these in a comprehensible form. Hopefully that will bring the parties closer together, but if that fails, then at least to the outsider it will give a better understanding of the issues on which the parties disagree. This brochure is therefore aimed at the outsider - from politicians to interested layman-. Since the role and position of science is at stake, it is good to give the necessary attention to science and the scientific method.

The first part of this brochure therefore does not deal with climate, but with science. In the course of its long history, science has developed some fairly strict rules in which the game is played. These rules are, of course, not set in stone, but who in the twenty-first century will depart from it, must have some quite strong arguments to do so.

The rules of the scientific debate are different than those of the political debate. Not all scientists feel at home in political debate, just as many politicians feel uncomfortable in scientific debate. Much would be won, if the rules of science would be better known. Not only in the climate change debate, but also in other debates in which scientific knowledge play a role – such as biodiversity, nanotechnology, and vaccination programs.

The immediate reason for this report is, of course, the controversy that arose after the publication of the latest report of the IPCC, the Intergovernmental Panel on Climate Change.

There is controversy about the accuracy or thoroughness of some of the claims of the IPCC, the scientific basis for it, and how the findings, especially in the summaries for policymakers, are shown. There was also discussion about whether all author teams have shown all available information, or that findings were ignored that did not suit the theorie presented. All these matters have now been investigated by the InterAcademy Council (of which the Academy is a prominent member and president of the Academy is co-chair). The main issues was the question whether there are errors that affect the final conclusions of the IPCC, and whether the procedures used by the IPCC have been rigorously and sufficiently strict applied.

Scientific debates have always involved controversies over the value and importance of particular classes of evidence, and this can be expected to continue. Moreover, all scientific knowledge always contains some level of uncertainty, and any action based on scientific evidence inevitably involves an assessment of risk and a process of risk management. Finally, given the dependence of major facets of IPCC assessments on vast data collections and complex models whose parameters are especially difficult to assess independently, risk assessments are especially challenging. However, as the resulting controversies gained some momentum, they tended to expand beyond the IPCC assessments and raise issues

¹ See also the Academy's publication: Uncertainty and Climate Change (2008)

ranging from the proper role of science (and scientists) in policy making to the dangers of group think or consensus building as a general proposition.'

[Harold T. Shapiro, chairman of the IAC review committee, in his foreword to the IAC rapport "Climate change assessments. Review of the processes and procedures of the IPCC)

Next, the brochure examines the climate science itself. The composition of the atmosphere has changed dramatically in the last century, and virtually no scientist denies that this is largely a result of human activity. But the discussion starts with the following obvious question:

Has this change a noticeable effect on other components of the climate system, and how serious are these effects? Another important facet of the climate debate is the great role models play in science, and the brochure will take a closer look at these. Few people will doubt the physical scientific model in which a ball is thrown up will also come down again. But such certainty is quite unusual in climate science - especially when working on the frontiers of scientific knowledge. These researchers must take into account wide margins, with uncertainties, incomplete data, and sometimes there are fundamental limits to the accuracy of predictions. Researchers are familiar with those uncertainties, but political decisions often are looking for more certainty than science can offer.

The last part of the brochure offers some recommendations for both the research and political agendas. As the commission (which wrote this brochure) did not consider it sufficient to provide only a 'distant' description of the science scene without expressing any further opinion. The commission also provides a brief account of the process behind the brochure.

In 1988, the IPCC was set up because the United Nations had a need of information about the causes and effects of climate change, and about the possibilities to match policies with those effects. In 2007, the fourth report was published, consisting of three parts - the first one on the scientific knowledge about climate change, the second about the effects of those changes on nature and society, and the third on ways to mitigate climate change as far as possible. The reports present extensively the state of the knowledge. In so-called 'technical summaries' scientists summarise their conclusions. In the 'summary for policy makers', in consultation with the policy makers, the findings are considered that could be important for policy making. The IPCC Bureau does not carry out research themselves, it provides summaries of existing knowledge.

A committee of representatives from participating countries (currently 192) decides on in which areas there is need for an overview of the current state of knowledge, and which procedures should be followed when making this overview. The participating countries, but also the office of the IPCC and international organizations, can propose authors and reviewers. Through a multi-stage editing process, in which all comments and criticism and how they have been made are kept and published, the IPCC tries to get a coherent report.

Due to the fact that there is a very large number of publications - who sometimes contradict each other, or who leave margins of uncertainty - the objective is to come to a balanced representation of the state of knowledge, including among others the level of certainty and the white spots in that knowledge. It focuses on a description of the facts and the uncertainties surrounding them, and refrain from expressing an opinion on the seriousness of the findings that will be handed over to the policy makers.

2. The scientific method

Major driving forces behind the science are creativity and criticism, especially public criticism. Those scientists who keep the results for themselves, or those who will not show exactly how the research has been carried out, lack the most important step in science: the presentation of the results to colleagues. For this purpose we have scientific journals. Scientists who believe to have found something interesting, will not rest until the results are published in a scientific journal.

It is not easy to get an article published in a reputable journal. There is always a rigorous peer review before an article gets published. If the editors find the proposed article interesting enough, it is usually sent anonymous and confidential to a number of other researchers who work in the same area. These reviewers will analyse the report mercilessly, will sometimes require additional experiments or additional information, and try to detect false arguments and calculations. It is expressly intended that such a review is highly critical, because only articles having past this first filter will also count as 'science'. Researchers who are critical of a scientific article but who do not publish their criticism in a scientific journal, are not highly regarded - at least, they are treated by other scientists with suspicion (or worse).

Peer review is a good system, but it is obviously not foolproof. Even in the best magazines an article slips through the cracks and that actually should have been dismissed or at least thoroughly corrected. And conversely, even in less highly regarded journals, and even outside the 'official' paths, there is excellent research. Research that in principle is carried out in accordance with the rules of science, but for various reasons is not published in a scientific journal, is called "gray literature". This applies, for example to government reports or studies that cover such a small area that there is little interest, but also annual reports of the World Bank and the thorough reports of the United Nations. The gold standard in science is a published article in a scientific journal, anything published outside a scientific journal is called 'gray'. Even if gray literature is excellent research, if it would count as science, it will still need to be subjected to peer review.

Of course there is conflict, competition and idealism in science, but ultimately science is always intended to improve understanding and awareness, in other words its objective is to find 'truth'.

Tension areas

Many scientists, and with them traditionally and specifically the Academy, see an active role for science in society. Science can and must, they say, be involved in policy - the science can provide knowledge to support different policy options, study the consequences of actions and put them in perspective, so that scientific knowledge is incorporated into social and political issues.

But scientific research also may inadvertently end up in social tension areas. For example when scientific results are selectively used to support political positions or to achieve social goals. Or scientific doubt is used to support political arguments and to postpone policies.

This applies of course to the climate change debate. Forty years ago, climate research was one of the quietest corners of science, now it stands in the center of attention.

If science wants to serve policy, and society as a whole, then it must perform four important tasks.

- Science can give early signs of future problems, as a sort of early warning system - which would be good if there is also an early listening system.
- Science can identify certainties and uncertainties in our knowledge. In the climate change debate there is currently much emphasis on these uncertainties, perhaps because in the previous period they have received little emphasis, but one should not lose sight that there are many certainties in climate science.
- Most often, science has resources to establish the consequences of policy choices and as a result to prepare forecasting and scenarios in order to understand the consequences of intervention or waiting.

- Finally science, in the eyes of the committee, can play a role in keeping the discussion 'clean'. Not every discussion can be resolved by scientific knowledge, but every discussion can be brought to a higher level using scientific insights.

The Academy is, by its very nature, a strong advocate of scientific research and rational criticism. She is not blind to the problems of peer review, the race that science often is, and the growing influence of commercial and 'non-scientific' interests in the research, but it is at the same time convinced that science is an important contribution to the solving the problems of our time. Even with all these deficits, it is still better to solve problems using scientific understanding, than without scientific insight. And that certainly applies to the climate change debate.

What is climate?

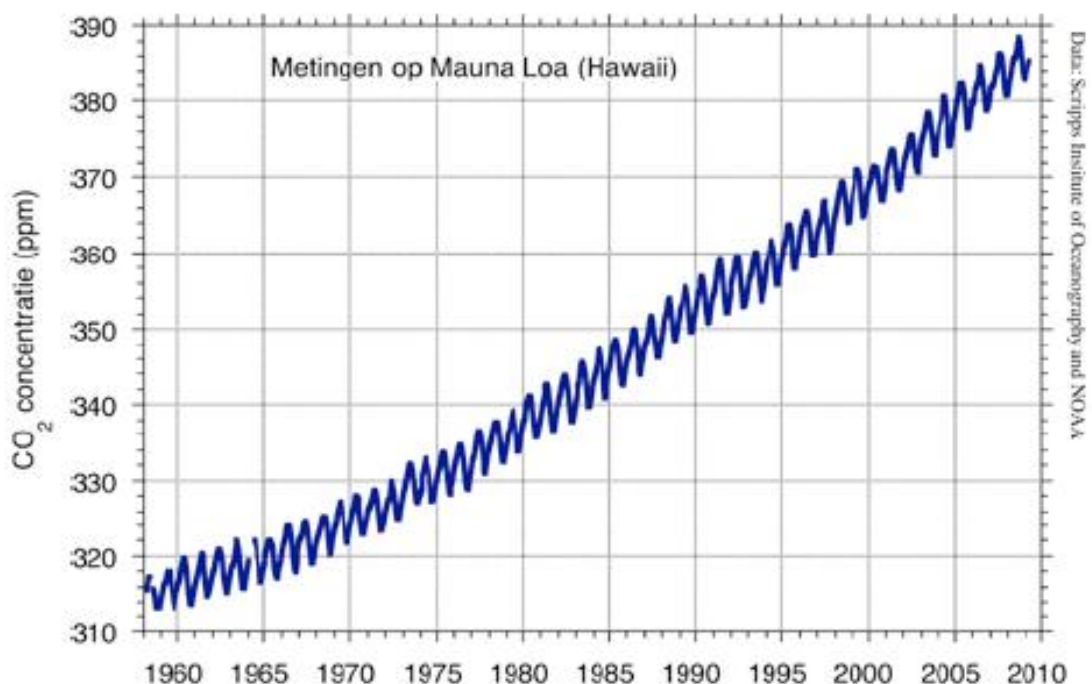
We use the term 'weather' to describe the state of the atmosphere at a given moment. If we describe the 'climate' we look at the characteristics of the weather over a long period at a certain place or a region. The climate of a place or region is not only determined by averaging (eg temperature or sunshine) but also by deviations from the mean (extremes) and the probability of these deviations.

(source: www.klimaatportaal.nl)

3. Climate change

Increase of greenhouse gases in atmosphere

The composition of the atmosphere changes continuously, in the course of hundreds, thousands and millions of years. Since the last ice age that change has never been as fast as in the past century, and a substantial part of that change has certainly been caused by human activity. The increasing use of fossil fuels like coal and oil - together with massive deforestation – has over the past 150 years led to a buildup of carbon dioxide in the atmosphere. Also the concentrations of methane and nitrous oxide has increased in recent centuries.



Carbon dioxide measurements at Mauna Loa (Hawaii)

In 1960 it was found that in the clear sky above Hawaii included 317 molecules of carbon dioxide per million air molecules. In 2008, this concentration increased to 386 parts per million, and this figure is now increasing with about 2 per year. Looking back in time, including an examination of air bubbles in ancient ice in Antarctica, show that around 1750, before the Industrial Revolution, the concentration was about 280 parts per million.

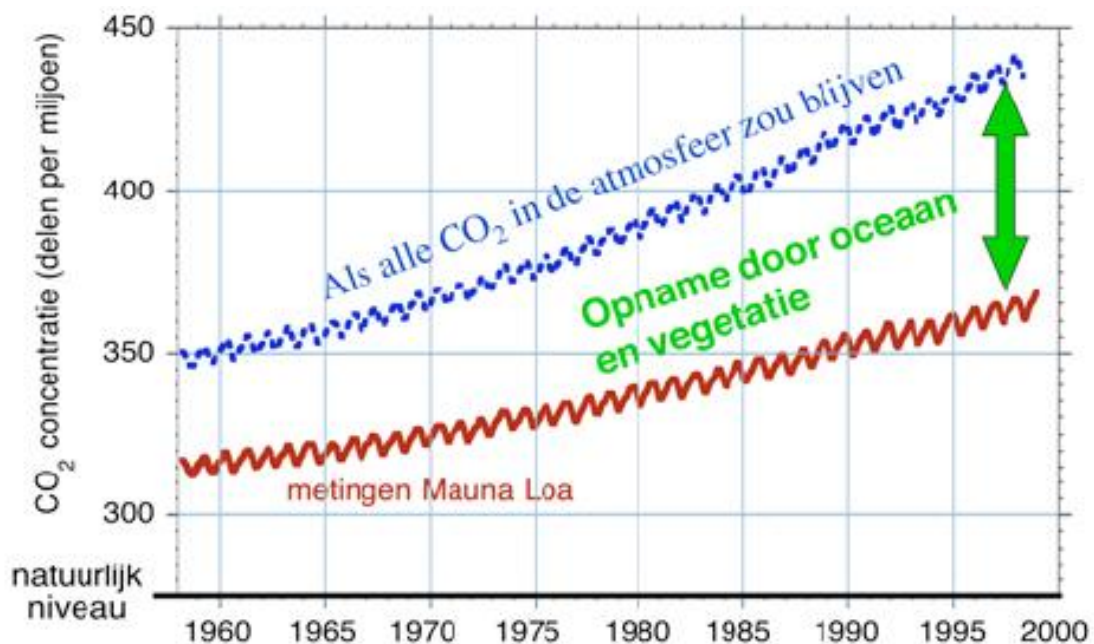
This increase is certainly due to human activities. The burning of fossil fuels brings carbon dioxide in the atmosphere, while methane and nitrous oxide are primarily due to the changes and expansion of agriculture and livestock and increased traffic. These different sources can be detected in the atmosphere by using specific properties of carbon, oxygen and nitrogen that cause these sources. Thus, the carbon dioxide from fossil fuels can be clearly identified.

That mankind is capable of changing composition of the atmosphere, is also evident from the history of the "ozone hole". The unexpected decrease in ozone above the Antarctic was discovered in 1985. The cause appeared to be the use of chlorofluorocarbons in aerosol sprays and cooling systems. Since the Montreal Convention in 1989, CFC's were replaced by other substances, and their concentration in the atmosphere slowly reduced after that.

Additional uptake of carbon dioxide by sea and land.

The total amount of used fossil fuels in the world is relatively easy to calculate and as a result how much carbon dioxide ended up in the atmosphere. In 2000, this emitted carbon dioxide would have led to a concentration of about 440 parts per million. In reality, 369 parts per million were measured. This means that some of the extra carbon dioxide is absorbed by different ecosystems. The oceans play the largest role in this absorption, and the natural landscape with its vegetation can also store carbon into the soil and as peat. Plants grow better if more carbon dioxide is in the air, and with more vegetation, more carbon dioxide is captured and stored. Soils under grasslands show - more so than soils under forests- to absorb a lot of carbon dioxide. Together, oceans and vegetation appear to store about half of the extra carbon dioxide.

The absorption of carbon dioxide in seawater could also be a new risk. It is a fact that water is more acidic by absorption of carbon dioxide - carbon dioxide plus water gives carbon acid. This also happens in the oceans. At least part of the problem is transferred from air to sea. Concerns about the acidification in recent years has grown, about the exact impact is still much uncertainty



CO₂ in the atmosphere rises only half as fast as expected.

Temperatures

While in the last century the concentration of carbon dioxide in the atmosphere increased, the average temperature on earth also increased. A relationship appears obvious, especially since carbon dioxide, like methane and nitrous oxide, is a 'greenhouse' gas.

The earth is being warmed by the sun, while the greenhouse gasses hinder the cooling of the earth. There is a balance between the long-term warming and cooling. But as the level of greenhouse gases in the atmosphere increases, the temperature at which this balance is achieved, is higher.

Over the past century, the temperature at the surface of the earth increased between 0.6 and 0.9 degrees Centigrade. That's an average: while the warming in the polar regions was quite strong, warming in the tropics was far less pronounced. Nowhere on earth it actually got any cooler over the last one hundred years. The average temperature of all stations on the earth together (the "global mean temperature") has increased by about 0.2 degrees centigrade every ten years since 1980.

The next question is, how much will the earth heat up as for example the amount of carbon dioxide in the atmosphere has doubled, compared to before the industrial revolution?

The search for the answer to that question is, in a nutshell, the scientific climate debate. The IPCC draws the following conclusion: a doubling of the amount of carbon dioxide leads to a warming that is

likely between 1.7 and 4.4 degrees centigrade. These margins are a measure of uncertainty. The research tries to underpin better margins and preferably to reduce them, but it is questionable whether the latter is possible in to a level that we would appreciate.

In the climate debate speculation on the lower and upper limits play a major role. There are climate researchers who have reason to believe that the climate is less sensitive and that the increase in temperature, a doubling of carbon dioxide content will be at most 1 degree, and there are researchers who believe that the estimate of the IPCC is far too low. A few believe that the increase of carbon dioxide will not lead to any warming. There's really no one who believes that increase (in carbon dioxide) will lead to cooling.

The warming of the earth is also led to other effects. Some examples: The sea level in the past century, partly due to climate change, increased with about 17 centimeter. Since 1978, the total surface of sea ice in the Arctic declined by three percent per decade, and living areas of various species of organisms changed.

Cause and effect

It is obvious to make a causal link between the amount of carbon dioxide in the atmosphere and the temperature increases, and in physics there is much to say for this. But we are not able, strictly speaking, to prove such a causal relationship.

Both phenomena could for example be a result from an unknown underlying cause. Moreover, in the past, the earth sometimes heated up by other causes causing more carbon dioxide in the air. This happened for example after the ice ages, when changes in ocean circulation released carbon dioxide in the atmosphere from the deep ocean. This carbon dioxide contributed to extra warming. We also know of situations in the very distant past such as in the Cretaceous Period (about 120 million years ago), when there was a much warmer world, coupled with a very high carbon dioxide content in the atmosphere.

But the main obstacle is still, that the climate is a very complex system with an almost inextricable tangle of influences, opposing forces and self-reinforcing factors.

Besides greenhouse gases such as carbon dioxide, methane and water vapor, also oceans, icecaps, the biosphere - all life on our planet – have an important influence on the climate. Ice caps are white and reflect sunlight for example, but if they melt, less sunlight is reflected back. Opposed to global warming, there are also cooling effects. Tiny particles (aerosols) will lead to additional cloud formation, which can reflect the sunlight.

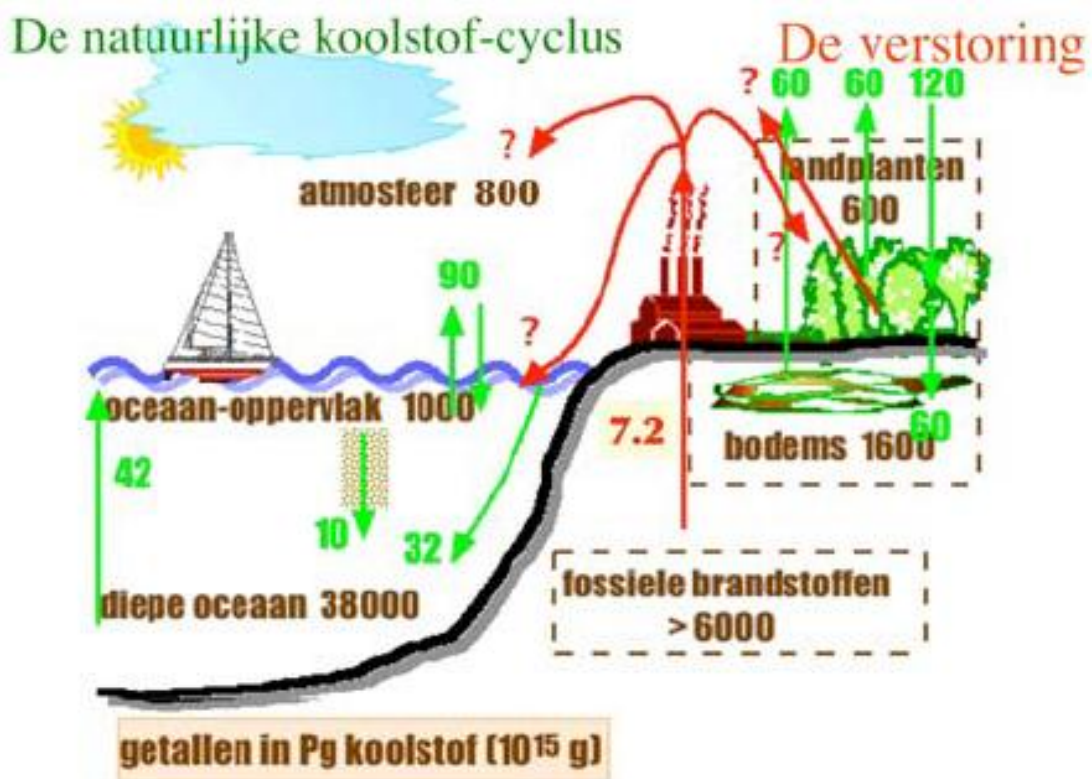
The scientific way to tackle these things is either by the construction of models, or a through a more accurate reconstruction of climate changes in the past, and of the mechanisms that have played a role, and where possible to mimic and investigate the natural phenomena under controlled conditions in a laboratory. The scientific climate debate is not only about the interpretation of the data, but also about the usefulness of models in order to find the link between increased greenhouse gases and warming of the earth. Are the data interpreted correctly and the are the models not too simple? Or too complicated? What else can fit in the model and what unexpected development would undermine the climate projections ?

Because results of climate models play an important role in the climate debate, it is important to give an idea of such a model, what these models calculate and what the limitations are.

4 Climate models

In almost every science there is an important role for models. Models are there to be able to better explore and explain phenomena, and using this understanding to make predictions were possible, to both the social and the natural sciences.

In climate science models are indispensable. With the additional problem of course, that the Earth's climate is unique. There are not a lot of Earths where we can see how the different processes take place.



The natural carbon cycle: the annual exchange (in green) between carbon reservoirs (in brown) and the disturbance by humans (in red).

There is no second earth where we, in order to practice, can keep certain processes constant and change other, and then see what happens - although in laboratory experiments we can simulate processes and examine them. Climate change in the past may under favorable circumstances, be used as a "natural experiment". We have to do with our scientific knowledge, our understanding of the past, and with model calculations on supercomputers that simulate Earth's climate as well as possible.

As many influences as possible are quantified as good as possible, and incorporated into a computer model. This will then be used to experiment: one influence is made stronger, the other weaker, until the model matches the available observations reasonable enough. If one factor appears essential for the agreement between model and observations, it is said that the change can be attributed to that factor. Not the 'cause' is sought, but the decisive factor that influences the chosen model. Hence, climate researchers not only emphasize models but also 'quantifiable' effects.

Climate models have their limitations, but they are getting better. In the first climate model, from 1990, for example, ocean currents were not included, while in 2005 these currents could be calculated in detail, worldwide. The next generation of climate models, expected in 2014, there is focus on a better representation of biological processes such as vegetation, agriculture and biological activity in the oceans.

It is not known how much the concentration of greenhouse gases will increase until the year 2100, but there are a number of scenarios. With these scenarios, 'projections' - they are explicitly not predictions – can be made of possible impacts (temperature, precipitation) of changes in the concentrations of greenhouse gases (and also of external influences such as volcanic eruptions). Making a prediction is difficult, to explore possible effects is very well possible. But although the models are getting more accurate, there will always be imperfections and limits to the accuracy of projections. The observations and calculation methods are incomplete, our theory is limited, and the computers are too slow for what we really want to calculate. Minor changes may also have serious consequences, causing some aspects of the climate to remain fundamentally unpredictable - even if we would know much more. Greater understanding of processes does not always lead to greater predictive power.

It remains conceivable that all the models built to date, provide results that will be far different from the actual of the year 2100. But they are based on the best knowledge we have now, and they explain important developments in the climate of the last century. The projections made by these models, indicate that in 2100, if we follow the scenario of an increasing use of fossil fuels, the world average temperature will be between 1.1 and 6.4 degrees higher than in 1990. That may not seem like much, but it should be noted that a temperature increase of several degrees, depending on the location on Earth, could have very drastic consequences!

Politicians seem to believe that these limits will become more accurate as the research progresses, but, again, not necessarily. It may be that further research into new uncertainties arise, making the uncertainty ranges are even wider. Who waits until science provides one hundred percent certainty, disregards the capricious nature of the unique climate in which chaotic behavior and positive feedback can occur.

4. Controversies and uncertainties

Some influences included in climate models are virtually undisputed and unchallenged, many others are being disputed. Not so much about whether a certain influence in the model should be, but on how large the effect is, how it interacts with other effects, and how sensitive the results are for small and large changes in initial conditions. And of course on how well the observations then correspond to the model and vice versa.

Temperatures then and now

If the Romans already had begun to accurately track the temperature, the climate debate would perhaps be simpler. Also if there was a thermometer on every square kilometer on earth, it would also make a big difference. As things stand, there are still many holes in the "Temperature Files".

Over the past fifty years, the global average temperature has risen, and we frequently hear that once again records have been broken. The extremes of the "natural variability", that can be achieved even without accumulation of carbon dioxide, are not yet well known. If we limit ourselves to the recent past (since only this period is relevant for the foreseeable future) then in the thirteenth, seventeenth and nineteenth centuries there have been periods that were relatively cool and there have been also relatively warmer periods. Around 1935, it may have been somewhat warmer than the computer models indicate. The IPCC does suggest, not incorrectly, that it is always about probabilities: once in several years, through a combination of natural conditions, such as a period of low volcanic eruptions with a strong El Niño and casual high solar activity, the temperature could increase suddenly.

Even critics of the IPCC recognise this uncertainty, but they think because of this argument that the theory of warming by the increase in greenhouse gases is undermined. If the IPCC is so uncertain about the temperatures of the past, how can it say it is now much warmer than before? However the objection raised by critics that it was once much warmer than today, is then also called into question. Perhaps the temperature data from around 1935, or of the thirteenth century, are not entirely reliable. And even if it was much warmer during the Middle Ages than it is now, climate researchers say further it means only that the changes in climate are greater than we thought, not that the physics of the greenhouse effect is undermined.

Data of measurement instruments such as the thermometer are only available for the last two centuries, and then only a small part of our earth. If we want to know the climate before the last two centuries, we can use "indirect measurements" - proxies in jargon. For example, tree-line shifts are determined on the basis of tree pollen in sediment, which constitutes a measure of temperature. A less precise but more appealing proxy is the date of the start of the wine harvest in France, which provides information on summer temperatures. In Greenland and Antarctic, snow stored in the icecaps, provides a measure of temperature by the properties of the oxygen. Every proxy must be "calibrated" with other direct and indirect measurements. This is a source of uncertainty, which should not be forgotten in the presentation and discussion of proxy measurement series.

Modern temperature measurements are also sometimes under fire. When researchers measured temperatures at high altitudes in the atmosphere, they saw to their surprise that they were not in line with the expectations. If it warms in the lower parts of the atmosphere, it must be cooler in the upper atmosphere, the stratosphere. Satellite measurements showed the opposite: either the theory was not correct, or the measurements were not correct. The latter proved to be the case. When the data was studied better and some errors were taken out in the processing, the expected effect appeared to exist. Not quite - the temperature trends in the tropics are still not fully explained - but most uncertainties are eliminated: it is actually cooler in stratosphere.

Thermometers

Something similar applies to the placement of the thermometers on earth. It sounds simple, but there are all kinds of hooks and eyes that climate scientists only gradually, in person or on the advice of critics, have acknowledged.

A well-known 'hook' is the "urban heat effect"; thermometers are traditionally placed in and around cities, but cities are getting bigger, produce more heat, and thus drives the temperature up. This distorts the measurements. Meanwhile, this effect is adjusted in the observations, and the magnitude of this effect also appears to be small.

A similar effect which needs to be taken into account is that the thermometers are increasingly situated at airports – also a huge 'heat island'. Also the quality of the stations sometimes are to be desired, they do not all meet the highest meteorological requirements. Climate scientists have agreed to this criticism, and it is one of the factors that make uncertainties get occasionally bigger as a result of scientific research, rather than smaller.

Finally, not everyone is convinced that the irregular distribution of the thermometers on earth can be completely corrected. In recent decades, many stations are dismantled, primarily in the far north of Canada and Siberia. But even as the earlier measurements are removed, the heating effect remains. There has been no study that leads to a cooling or even a nearly constant temperature over the last fifty years.

Volcanism

With the eruption of volcanoes, much gas and ashes are thrown into the atmosphere. These affect the climate in many complex ways, and moreover, the composition of the gas and ash eruption is unpredictable. It is certain that volcanic eruptions, such as Pinatubo in 1991 and Tambora in 1815, led to strong and sometimes disastrous cooling - the year 1816 is known as the "year without summer": the average global temperatures fell at least with 0,4 degrees Centigrade and maybe even 0.7 degrees.

This allows a greenhouse gas effect to be hidden, both in the present as well as the past. But geologists have no reason to think that there is any system in the volcanic activity in this period of time. After a volcanic eruption it takes a couple of years, not decades, for all ashes to have fallen back to earth, and the effect on global temperature has gone.

Oceans, water vapor and clouds

The biggest gap in knowledge are most likely the effects of ocean currents, water vapor and clouds. When the earth warms, the warmer atmosphere contains more water vapor. Water vapor is itself a greenhouse gas, that would in turn strengthen the warming. But clouds formed out of water vapor can block the sunlight. But there are also types of clouds that can enhance the greenhouse effect.

Also, soot and other greenhouse gases like methane and nitrous oxide have subtle effects, also in interaction with carbon dioxide, which impacts are not well known. These uncertainties largely define the debate about the 'climate sensitivity'. If in a climate model the role of water vapor as a greenhouse gas dominates, the net greenhouse effect is much greater than when water vapor is mainly assigned a role in cloud formation. There are critics of the IPCC who believe that water vapor can explain most of the warming, but there are also critics who believe that the IPCC underestimate the dangers of increasing water vapor in the atmosphere. Further research will have to provide clarity here.

This also applies to the aforementioned role of oceans. It is known that the oceans can absorb around thirty percent of the extra carbon dioxide from the atmosphere, but there are indications that in the coming decades this will be less - as warming of the oceans will put carbon dioxide into the atmosphere - making that the ocean absorb less carbon dioxide, on a net basis. Incidentally, it is unclear what the consequences of this absorption are for life in the oceans, concerns about this has increased. Much of this research is still in its infancy.

Ice and glaciers

The figures from the IPCC show that glaciers are shrinking worldwide. It is not clear how great the human influence is (via the greenhouse effect) and how much can be attributed to natural variation (the glaciers shrink and grow, always subject to e.g. changes in precipitation). It is remarkable that the recent retreat of the glaciers already started before the carbon dioxide in the atmosphere increased. A complicating factor with the ice sheets is the long response time. The Antarctic ice sheet for example is still responding to the transition from the last ice age to the present interglacial, which happened about 10,000 years ago. The ice sheet is moving constantly so that an exact diagnosis is impossible. This makes assessing the future behavior of the ice sheet very difficult.

Again, only good measurements and good modeling will offer understanding. It is certain that the behavior of ice - both sea and land ice – is hard to understand.

The IPCC drew unwanted attention to the glaciers by a curious error in its final reports on the effects of climate change in 2007: instead of writing that all glaciers in the Himalayas would have disappeared in 2350, it said '2035'. This error was overlooked by researchers and editors but they also did not deny that it was a mistake, and the IPCC was unable to calm down the publicity storm. This led to a critical report on the IPCC at the request of the United Nations which drafted by the Inter Academy Council. It was recommended among other things, that the governance structure of the panel should be thoroughly changed, and procedures should be tightened and work should be as transparent as possible. There was no criticism on the summary conclusions of the IPCC reports.

The sun

The heat radiation from the sun varies in a cycle of about eleven years, and this affects the Earth's temperatures. There are also longer periods of varying activity, which astronomers can not quite explain. The shorter cycle is also not as well understood as the experts would appreciate.

This uncertainty, plus the observation that the sun might be part of the explanation of past climate changes, makes the sun one of the favorite weapons of critics of the man-enhanced greenhouse effect. Because the sun and the variations in solar activity are not well understood, some people attribute a more important effects to these- the role of greenhouse gases is correspondingly smaller.

According to some researchers it is even possible that the solar activity reduces to such an extent, that the earth's temperature will fall. But even if the influence of the sun is not yet completely analysed - all possible feedback mechanisms are still not understood - in climate models that take into account the sun, its influence appears to be small. There is speculation about other ways the sun could play significant role, but to date no convincing mechanism has emerged.

And again, the influence of the sun makes things more complicated, but does not undermine the potential consequences of the enhanced green house effect.

The role of humans

In the recent period, the world population shows a spectacular growth. At the beginning of our era, it is estimated that some 300 million people inhabited the earth. We reached the first billion around 1800 and we grew to seven billion people in 2011. This rapidly growing population has an increasing influence on the state of 'Planet Earth' and is in turn sensitive to climate change. Think for example of the greatly increased population concentrations in areas sensitive for increases of the sea level.

Mankind also has more influence on the climate than only the greenhouse gas emissions. Changes in land use is an important factor. And interventions that we do for various reasons, may turn out differently. For example, measures that make the air cleaner, may lead to global warming (with cleaner air, less cooling by dust particles), while the planting of forests and improved management of grasslands may reduce global warming.

It should be remembered that policy choices not only have climate aspects, but also political, economic, social and psychological aspects. The third working group of the IPCC has analysed these interactions in much more detail, here we indicate just a few. For example the government can decide to store carbon dioxide deep underground, but the recent past shows that they cannot ignore the social consequences of such a measure. Tax on emissions of carbon dioxide and energy also have expected but also unexpected undesirable consequences. Measures to reduce car use, can intervene on privacy. Choices of energy sources and advanced ecological farming can have far-reaching consequences - on climate, but also for example on economic development. This forms especially for countries in the Third World an opportunity, but often a serious dilemma.

Finally

Climate research, and especially research into climate changes, has only recently been well established. The natural variations can be large, the number of observations is often limited. This makes it difficult to separate random fluctuations from real trends - let alone explain this. "The time series are too short", say climate scientists. From the beginning they have noted the uncertainties. The IPCC has chosen to express the margins of error - often based on expert judgments, using only the

words: likely, very likely, unlikely, In practice, media and politicians ignore these terms or understanding, which in turn was grist to the mill of critics.

Meanwhile, not all objections raised by critics are still as relevant, the "urban heat" effect has long been corrected, but it is still considered by some as a serious undermining (of the understanding climate change). Similarly, the role of the sun, although uncertain, is for now judged to be small. So perhaps until new insights, there is no reason to doubt the reliability of all projections for the near future just because of unexplained variations in solar radiation.

And of course we must not forget there are indeed facts that we can not ignore, such as the rapidly rising levels of atmospheric carbon dioxide and, globally rising average temperatures.

It is of great importance to present the research results as clearly as possible together with the corresponding (un) safety margins, and continue to provide space for various scientific theories regarding the interpretation of measurements. This is an important task for the IPCC.

At different times, in different countries and at different groups of people will make different conclusions, even if the facts are beyond question, - the one is more risk-averse than the other, one group has more or different interests at stake than the other. The climate debate is therefore, in addition to a scientific debate, a genuine political debate. That should be it: the politicians should for themselves review the uncertainties, and take their own decisions. Science can investigate and supply risks, opportunities and boundaries; the politicians decide to wait, slightly adjust or to intervene forcefully.

6. Some recommendations for policy and research

In recent years much progress has been made, but the understanding of the climate system seems to be a very difficult problem for science. Making climate change projections for the next century is an even greater challenge. As indicated in previous chapters, many factors are still insufficiently understood. The way they interact, strengthen and weaken each other even less. Bringing together all those factors and interactions in models requires great efforts. It is even more difficult to find an easy answer to the question of which policies quickly and effectively diminish climate change or adapt to it.

Climate change poses major and minor risks, and it is difficult to deal with these risks - if only because sometimes there is even no agreement on the seriousness of those risks. Any human intervention, and any technological development, has incalculable consequences, but also non-intervention and non-innovation has consequences.

The Royal Dutch Academy of Sciences is convinced that there is no longer any reason, the impact of increased concentration of carbon dioxide and other greenhouse gases in the atmosphere to be trivialized or neglected. Certainly, the matter is complex, but so far observed changes are so obvious, and the possible consequences can be so large that there is every reason to take these observations seriously.

It would certainly be not a wise policy to act as if there is no problem, as though the problem itself would disappear, or if a solution will be found by incidence.

It is already better to opt for a 'no regrets policy': a policy that if the wrong results are achieved can be reversed without much effort and that can be justified on the basis of benefits outside the scope of climate change. Even if the climate change would be less than expected, it would be wise, in the context of other considerations such as concerns about future energy supply and a sustainable development, to take account of climate change as expected in the IPCC reports.

But the Academy considers such a "no regrets policy" very minimal. Not only because, in effect, the discussion moves to the question of what measures would belong to that policy, but also because the policies are reduced to a regional and national problem, while an international, concerted effort is needed.

There are still relatively simple enough policy options available to slow global warming and reduce its effects. It is beyond the scope of this brochure to include an extensive list any benefits at all drawbacks to consider, but noted may be continuing research aimed at promoting the use of non-fossil fuels and materials, increasing efficiency in energy, developing cleaner production, expanding the market for greenhouse gas emission and reception of carbon dioxide in particular by increasing the amount of vegetation on earth.

Moreover, and this is often overlooked, climate change is not only determined by technological problems which only technological solutions can solve. There is already extensive reflection and discussion about social change - in consumption, production resources, production processes, management and policy. It is therefore good that the social sciences increasingly become involved in discussions about climate change, and that within the Academy there is a growing interest in a broad approach across disciplines.

The IPCC will have to make efforts, particularly by improving communications, regain trust from government and the public. The IPCC promised to consider the advice of the InterAcademy Council on the working procedures of the IPCC in the upcoming fifth report may. For the rest, the IPCC is aware that the choices and the process need to be more transparent and less opinionated. It is good that outsiders and critics are given a possibility to give a contribution to the debate.

Much is already known about the climate of the past and present, but still a lot of research is needed from scientists of all relevant disciplines. The climate debate not only makes clear that science is at the heart of society and is it better to learn how to handle this. It also makes clear that there are numerous major and minor gaps in our knowledge. Both science and society need to learn to cope with this.

For decision-making in society, it is very important that a good and widely shared view consists of risks and uncertainties, and their margins. In this area, the role of the media is also very important.

The tone of the climate debate has hardened in recent years, but at the moment seems to get a bit milder. 'Sceptics', 'neutral' and 'alarmists' inside and outside of science are getting back into discussion, and the discussion is back to the assumptions, analysis, diagnosis and conclusions. The

Academy welcomes that, of course, and can only hope that the required level of the discussions can be conducted based on scientific data and rational arguments.

7. Summary statements

a. Mankind is changing the composition of the atmosphere rapidly and dramatically. The increased concentration of carbon dioxide and other greenhouse gases can not be trivialized.

b. About half of the extra carbon dioxide produced by humans remains in the atmosphere. The rest is absorbed by the oceans and land vegetation / soil surface.

c. The absorption of carbon dioxide in the oceans will lead to acidification of the water. Deforestation and urbanization will lead to a reduced absorption of carbon dioxide by the soil.

d. In the last fifty years there has been a rise in global mean temperature. The period 2001-2010 was the warmest decade since systematic measurements began around 1850.

e. The current climate models explain climate change in the 20th century to a large extent. According to these models, the observed increase in average global temperature is not properly explainable without the effect of the additional man-made greenhouse gases.

f. If we follow the scenario of the consumption of ever more fossil fuels, the models indicate that the average temperature on earth in the year 2100 will be between 1.1 and 6.4 degrees higher than in 1990.

g. Minor changes can have major consequences for the climate. This property is, certainly for a system like the climate, a compelling reason to prevent abrupt large (on the time scale of decades) changes (eg a huge increase in carbon dioxide) as much as possible.

Accountability

In early 2010, the Academy, in light of the sometimes fierce, partly polarized debate, decided to make a brochure to indicate the state of the science around climate change and what we may or may not expect. For this purpose, an ad hoc committee was formed, consisting of Academy members Henk Dijkstra, Louise Fresco, Henry Hooghiemstra, Hans Opschoor and Rudy Rabbinge, the latter serving as chairperson.

This committee has organised a discussion meeting in which the issue of climate change has been presented and discussed from various perspectives, with a certain emphasis on controversial issues as emerged in the public debate. The results of the discussion meetings and other information formed the necessary input for the brochure. The design concept of this is discussed in a special meeting for Academy members.

A draft of the brochure has been subject to a review procedure, organised by the academy's board. The feedback are processed by the committee, after which the Academy's Board has adopted the text for publication.

The committee has been supported by academy's staff members Linda Groen, Irene Kuiper and Jaap van Houten.. Science writer Hans van Maanen has edited the text of the brochure.

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