

Climate Change – Facts and uncertainties¹

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1. Temperature in the 20th century

Good morning ladies and gentlemen. I often start my lectures with these well-known graphs to illustrate a number of points.

What you see here is the evolution of the annual mean temperature in de Bilt and the anomaly in the annual and global mean temperature in the past century, on the same scale.

First of all you can see that there is a lot of interannual and decadal variability. Secondly, you see that this is much larger in a particular location like the Bilt, than in the global mean, as you would expect for an average. Thirdly, there is a clear emerging trend in the mean global temperature, and, in fact, also in the De Bilt series.

As you can see 1998 was a record high in the global mean temperature, and some believe that this is an indication that the temperature will be dropping from now on. But this argument does not convince me, because one extreme forms no proof. In fact, as you can see for yourself, there have been many local extremes in the past century, which did not announce a persistent cooling.

Of course, no one knows what will happen, but I expect – note that I say *expect*, not *predict* - that the upward trend will continue. Why do I expect this? Well, to understand this let's first have a look at the climate system.

2. The Climate System

This system receives energy from the sun. Part of the solar radiation is reflected, the rest is radiated as long wave radiation. The radiative balance is complicated by atmospheric water vapour and other trace gases, clouds, heat transport, albedo variations and other factors.

Latitudinal variations in insolation and the rotation of the Earth lead to complex turbulent geophysical flows, which induce important transports of mass and heat. In this way excess heat in the tropics is transported poleward where it is radiated back into the universe. By their nature these flows are highly variable.

Variability occurs on all time scales and with varying spatial patterns. At high temporal frequency we have intra- and interannual variability, with strong peaks on diurnal and annual timescales. At the

¹ Text of a lecture presented at the KNGMG Conference Climate Change: facts, uncertainties, myths. KIT, Amsterdam, 20 November 2008. Slides are available [here](#).

other end of the spectrum, on geological time scales, there are also many significant variations. Sometimes, it is possible to associate physical mechanisms with variability on particular temporal and spatial scales. An example is the North Atlantic Oscillation. This is an important mode of variability affecting the climate of Europe. Its magnitude is characterized by the pressure difference between Iceland and the Azores, and you can see here how this NAO index varies on decadal timescales. The North Atlantic is one example of a variability pattern. Another well-known example is El Niño.

To understand the full variability we have to study the full climate system. Here it is. This is a complex system consisting not only of the atmosphere, the ocean and the land surface, but also involving biogeochemical feedbacks and external forcings. Examples of external factors driving climatic variations are solar variability, major volcanic eruptions and variations in the orbital parameters of the earth. In recent years the human influence is a factor of growing importance through changes in atmospheric composition and through changes in the land surface.

The scientific study of the climate system starts from observations. And these are then analysed with the help of the laws of physics. In general, climate variations are the result of many competing mechanisms. In such situations the quantification of processes, transports, interactions and feedbacks is essential. Numerical models are essential tools for this. So let me first say something about the observations, and then about the models.

3. Climate Observations

There are very many valuable observations. (But never enough!) It is useful to distinguish between the natural archive and instrumental observations.

Tree rings, corals, ice cores, oceanic sediments, etc provide information about variations on the longer time scales. This is extremely interesting and challenging and it provides important perspectives for judgement of recent variations.

Later today, other speakers will discuss aspects of the longer-term perspective. Therefore, and because of the limited time I have, will focus in this lecture on the past century, where we do have a wealth of instrumental observations.

Here you see a diagram illustrating the Global Observing System of the World Weather Watch of the World Meteorological Organization. It was originally set up for the purpose of weather prediction, but it has been extremely useful for climate research and in the past few decades much effort has gone into its extension into a Global Climate Observing System.

Note that there are different types of observations: surface observations, on land and sea (from ships and moored and drifting buoys), upper-air observations by balloons and aircraft, and satellite observations. It is absolutely impossible to give a proper discussion of this system in 5 minutes. In fact there are major conferences just on this topic alone. For now, I selected a next few slides to give you a flavour of what we have.

Here you see the network of surface stations, which send in 3-hourly reports which then are quality controlled by designated centres. The next slide shows the networks of upper/air radiosonde stations. A third slide shows shipping lanes from which observations have become available. Note the broad coverage as well as the data gaps.

I have selected two datasets to illustrate the kind of observational data we have, but you should remember that there are very many additional datasets.

The first example I have chosen is the well-known Mauna Loa series of atmospheric CO₂ concentrations. You see a steady increase from 320 ppm in 1960 to 380 ppm in 2007.

The second example is from the so-called CMAP dataset. This dataset provides global gridded precipitation data based on gauge measurements, satellite data and reanalysis data. Shown here is the annual mean precipitation, as observed. Don't try to understand the detail, but the gross features are as expected: heavy rainfall in the tropics, droughts in the deserts and plenty of rain in midlatitude.

These are only two examples. As I said there is a wealth of observations and these are readily available the global research community in different data centres.

This is all a can say about observations. If you are interest in more I recommended that you attend one of the international conferences on this subject. For example, next year there will be a one-week conference in Venice, focussing on the ocean component of the Global Climate Observation System.

4. Climate Models

Climate models are essentially based on weather prediction models, i.e. general circulation models of the atmosphere. The skill of these models has improved significantly over the last few decades. But of course, the climate system is more than the atmosphere. Therefore, many groups in the world have extended atmospheric models into climate models by coupling additional components. Here you see how this was done at the Hadley Centre. They began in 1985 by coupling a land surface module, then an ocean and sea ice model etc until more recently the model was extended to include atmospheric chemistry and an active carbon cycle.

The most recent IPCC report discusses in detail more than 20 independent climate models. These have all been validated and intercompared in a concerted effort. Model results have been made available in a public database, and every interested person can retrieve these data and analyse them. For these details I refer to <http://www-pcmdi.llnl.gov>. Currently, there are more than 1000 diagnostic projects, many of which have published results in the peer reviewed literature.

I will show two examples.

The first example is a comparison: the top figure gives the observational dataset; the bottom figure shows the mean precipitation as computed by the models. Shown is the multimodel average. I leave it to you to judge.

A second example is a simulation of the global mean temperature in the 20th century. Time is along the X-axis; annual mean globally averaged temperature along the Y-axis. Here the models used realistic forcings based on observations of solar variability, volcanic dust load, aerosols and Greenhouse gas concentrations. The black curve represents the observations, individual models are plotted in yellow; the multimodal mean is given red. I think the agreement is impressive, both in the simulated trend and in the magnitude of the interannual and decadal variability.

Let me summarize: Climate is always changing. Numerical studies have provided insight into the relative importance of different mechanisms of climate variability, both natural (chaos, sun, ocean, orbital variations, volcanic dust . . .) and anthropogenic (Greenhouse gases, aerosols, land surface change . . .). So how does one study the human influence? Hans von Storch will treat this in detail, but since this is such an essential point I will also discuss it briefly here.

5. Attribution

Look here: the top graph is the one we have seen before. The models are forced with ALL forcings, both natural and anthropogenic, and there is good agreement. The bottom graph is similar, but in these simulations only natural forcings were used, and as you can see there is no agreement.

So, one can understand the observations if one includes the human influence, and one cannot understand the observations if one does not include the human influence. It is exactly this, - and no more than that - what is meant, if one says that the observed increase of the global temperature is attributed to human influence.

Obviously, these findings depend on the quality of the observations and the skill of the models, neither being perfect, and one should remember that it is always possible that the discovery of a new (so far unknown) mechanism might change the picture.

Personally, I believe that climate science will never provide absolute certainty. In a way it is like weather prediction. We know that there are limits to predictability, but we also know that the weather forecast is immensely useful and has improved considerably over the last few decades.

Maybe a little anecdote may help clarify my point. In the 1990s I was involved with an international research programme CLIVAR, which stands for Climate Variability and Predictability. The objectives of this programme were to UNDERSTAND and PREDICT climate TO THE EXTENT POSSIBLE. I attended many meetings of the international scientific steering committee, so I had a chance to discuss the objectives with a number of world leading experts. Amazingly, I got very different reactions. Some argued as follows: it will be very hard to make climate predictions, but we may be able to get some understanding. Others felt just the other way around: it so complex that we will never be able to understand everything, but we may be able to simulate the climate with computer models, and this may give some predictability. Personally, I believe that there are limits both to understanding and predictability. The challenge of our climate research is to explore and to shift these limits, very much as has been done in weather prediction.

6. Uncertainties

Summarizing: there are different sources of uncertainty. In brief: 1. The system is complex and unique; 2. Observations come with errors bars; 3. Models have imperfections, and therefore nothing is certain and there is always a certain amount of uncertainty. The question then is how you quantify and communicate this uncertainty. Well, this is quite a challenge.

IPCC has made an impressive effort, which resulted in statements of the following type

- Most warming over the past 50 years is *very likely* due to anthropogenic GHG increases. Part of the variation can be accounted for by natural causes.

Another example is from our national Platform on the Communication of Climate Change PCCC

- ΔT in 2100 (relative to 1990) is *likely* to lie between 1.1 en 6.4 °C

While these examples speak for themselves, I would like to make two comments:

- The first is that these qualifications are poorly understood and very often omitted in the media and the public debate.
- The second remark is that the confidence and likelihood terminology of IPCC has a quantitative basis, but the actual assignment of value often involves some kind (subjective) expert judgement and should be seen as best estimates which may be subject to revision if new information comes available. People who appreciate this point seem to be very rare.

7. Robust findings and uncertainties

After this long introduction, I have now reached the stage where I can indicate what I believe are facts, or more accurately robust findings, and uncertainties. I have based this on the IPCC assessment, in particular on chapter 6 of the Synthesis Report, a summary of which is contained in my abstract. Here I can only give you the main points by giving what now is a summary of a summary of a summary.

Let's first look at the climate system itself. Robust are

- The observed temperature increase, the observed increase of CO₂ concentrations, the human influence and the expected future rise of mean temperature.

Key uncertainties are

- The magnitude of expected change, trends in extremes, regional change, feedbacks, the role of aerosols, the behaviour of the Greenland ice sheet and its implications for sea level, etc.

IPCC also reported on possible consequences and possible measures. Here the following findings are labelled as robust

- Climate change will impact on human society and the biosphere
- Reduction of vulnerability requires more adaptation - but there are limits to adaptability
- Mitigation is possible

In addition there are many important uncertainties, concerning

- Costs of unmitigated climate change, adaptation, mitigation
- Best possible development path (energy innovation speed, adaptive capacity, governance, . .)

This completes my short introduction to facts and uncertainties in climate change. I would like to emphasize that it is a summary of 3000 pages, and I can only make a recommendation that you consult

the extended summary in my abstract and preferably the full report for detail and more precise formulations.

I wonder how many of you have read the IPCC reports. It seems that most of the criticism on IPCC refers to the Summaries for Policymakers and media presentations of individuals, while friend and foe praise the main report. This summer I had the privilege of speaking with a number of critical scientists running experiments in search of a mechanism linking solar variability to climate variation. To my satisfaction they were very positive about the chapter on solar variability in the IPCC report.

8. Actors

Before I make a few concluding remarks I would like to make a comment on the climate debate itself. Personally, I find it very helpful to distinguish different actors, as indicated in what I call my taxonomy of actors in the climate debate.

Here it is. There are two dimensions. The vertical axis labels the amount of policy involvement. I distinguish three types of scientist: just curious, those who want to be policy relevant without being policy prescriptive, and people who try to influence policy. This latter group makes directive policy statements involving the words ‘must’ or ‘must not’. In this group, political values, and attitudes with respect to risk play an important role, explicitly, or, often, more implicitly. On the other axis I have people with an open mind in the middle, those who forget about uncertainties on the left, and those who emphasize them on the right. Believers and non believers, if you wish.

This yields nine categories; I leave it to your own imagination to fill the squares with names. Where would you place yourself? And your neighbours? Allow me to just give a few generic names: first of all we have the pure scientists, some more sceptical than others; then we have what I call honest brokers (after the book of Roger Pielke jr on this subject), and finally we have sceptics and alarmists.

I admit this is an oversimplification, but I find it useful to have this in mind when following the climate debate.

9. Concluding remarks

I would like to end with a few concluding remarks.

1. Climate science will never provide absolute certainty
2. A description of our current understanding is rather complex (*see Annex to the abstract*)
3. This complex message is often deformed in the media and in the public debate.
Both the scientific and the public debate would gain from a better awareness of this complexity.
4. Values play an important role in decision making
I discussed this only briefly. Important values are the relative weight you give to here and there, now and later and man and biosphere, but also the attitude with respect to risk.
5. Last but not least: Science should proceed as usual, that is through the collection of observations, their quantitative analysis with the help of the laws of nature, the publication of results in the scientific literature, and through discussion of new results, as in today’s conference.