Climate Change 2013: The Physical Science Basis

Thomas Stocker

Thank you very much. Good evening ladies and gentlemen. It's a great pleasure to be here in Ireland, specifically in Dublin. And I am absolutely excited to see at….what is a sunny day out there, where you could sit with a beer, that you sit here in this lecture hall and listen to some important facts that I would like to bring closer to you in the next 40 minutes.

As was said already, I will draw all the material from the scientific assessment that was carried out at the duty of the governments of the world, given to us in 2008, lined up as the Fifth Assessment Report. We have completed that report in September 2013 in Working Group I. Working Group II and III dealing with adaptation and mitigation respectively have delivered their reports just a couple of weeks ago.

I am also giving this presentation on behalf of the 259 scientists who have showed a tremendous motivation and dedication to our report and our duty over the past three and a half years. And it should be said that that work was extended to us free of charge and in a voluntary manner. Of course, these colleagues were paid through their institutions, but no extra pay was involved in this tremendous work. It has taken hours and many days of free time and leisure to dedicate to this report. The report itself consists of over a million words. It prints on 1,535 pages, consists of 14 chapters and an atlas. And it's true, this is a thick piece of work, 4.2kg that book weighs printed at Cambridge University Press. And of course it's important to condense this message down to a size where policy-makers or the interested public would actually read the messages. And we have done so by compiling a summary for policy-makers which consists of just 14,000 words. But that's still a brochure of 27 pages. And again if you ask very busy policy-makers to read quite some heavy scientific stuff that extends over 27 pages this is a challenge. And in fact it was the criticism that we received most for the past assessment reports that still the summary for policy-makers was a document that was written in technical terms and hard to digest.

That is why for the first time we added an additional step of condensation by creating 19 headline statements, which summarise, in a very compact manner, the entire material of our scientific assessment. And they print on less than two pages. So I daresay now there is no excuse anymore not to have time to read our messages nor not being able to understand them, because these messages are simple, quotable and comprehensive. And I will show you a few examples of these statements.

What has been published in September 2013 was the fifth of a series of reports, the first of which was published in 1990 in preparation of the Rio Conference on Sustainability in 1992, providing at that time the policy-makers with the scientific assessment of what we know about man-made climate change. Four more reports have been published after five or six years and are in sequence. And this is now the fifth one.

Our report is based on three major pillars. The first one on observations, measurements of changes in the climate system, meticulously documented and published in the scientific literature, carried out by many institutions comprising millions of data points around the world, from all the components in the climate system. The second pillar concerns the understanding. Can we say something reasonable about the causes in a quantitative, scientific manner? Do we understand all the changes that we are seeing and measuring? And finally, using the same scientific method, to estimate the various possible futures of climate change.

This is the first figure in the summary for policy-makers, one out of ten figures. It shows the global mean temperature increase since 1850, as is measured by millions of stations around the globe. We have averaged these global averages in chunks of ten years, just to focus on the most coarse signal across these 160 years. And what you can see is, indeed, natural variability. There are decades that are colder than previous decades.

But if you take a look from the distance, you see very clearly that the world has warmed over the course of the past 100 years. The warming indeed can be quantified at about 0.8-0.9 degrees since the beginning of the 20th century. And in fact this is one of the headline statements that you see here projected: "Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850."

Because this is a headline statement in the summary for policy-makers it carries quite some weight. Because this is not only a statement that the scientists have created, but it's also a statement that all governments of the world have agreed to and accepted as part of this summary for policy-makers.

The second sentence that we conclude out of a critical assessment of all paleo-climatic information, in other words tree rings, ice cores and many other paleo-climatic archives that permit us to reconstruct the temperatures over a longer period than what is available from direct thermometer measurements, we conclude that in the northern hemisphere, 1983-2012, was likely the warmest 30 year period of the last 1,400 years. And the scientists make this statement with medium confidence. I show this headline statement because it indicates the careful use of language of the IPCC, in that we provide information regarding uncertainty. You see two words here typeset in italic print, the likely and the medium confidence. Part of the calibrated uncertainty language that IPCC has been adopting…adopted for the three working groups in this cycle.

We now take a look at the surface, the distribution in the different regions of the warming, measured over the past 112 years. And the message here is quite clear. You see red colours in many parts, in most parts actually of the world. But you also see white spaces. These are the locations where the scientists have assessed that the information based on thermometer readings is not sufficient in quality or coverage, and therefore we have decided to keep these areas white.

The largest area is in the southern ocean and in Antarctica, where we don't have information covering the last 112 years. But you see also quite clearly that the warming is present almost everywhere, in a significant manner. And you also recognise enhanced warming, the purple colours over the continents. This has led to another very short and concise headline statement, warming of the climate system is unequivocal.

And indeed this is a repetition of a short sentence that was already present in the fourth assessment report published in 2007. Seven years ago the scientists have come to the same conclusion when it concerns the warming. And that was an important point for us to make in this most recent assessment, that there is a historical thread in our scientific endeavour and some messages simply don't change with the accumulating evidence.

Now this is a figure that is less well known in the public. But I am very pleased to show it, because it's a synthesis of extremely important measurements that have become available in the past seven years by scientists and scientific institutions who have invested millions of dollars, swiss francs and euros to measure the temperature of the top two kilometres of the world ocean using automated roving vessels that measure temperature, salinity and pressure.

Based on these measurements we can now calculate the change of the energy content of the climate system. And you see here that this energy content has increased over the past 40 years. The lighter blue area shows the increase of the energy content of the top 700 metres of the world ocean. The darker wedge shows the increase of the energy content of the layers between 700m and 2km of the ocean.

The deeper ocean is unfortunately not accessible in a global coverage. You see three more wedges here on this …small slivers…a white one, a brown one and a dark red one. The white one is the increase of energy due to the melting of ice sheets and glaciers. A tiny amount of energy in comparison with the increase of energy in the ocean. The increase of temperature of the soil on the continents is shown in the light brown colour. And the smallest sliver is the energy increase of the atmosphere.

And if you now take this physical based look on global change, an energy based look, you could argue the most fundamental way how to look at climate change, this change is very obvious. The ocean is recording and storing that information for us, the ocean water can, due to its heat capacity, take up a lot of heat, and that can be measured very precisely, looking at temperature.

And isn't it paradoxical? We are always fixated on measuring the temperatures at the surface of the earth, admittedly an important parameter. But in terms of energy it's simply not relevant as you see in this graph. The accumulation of energy in the climate system amounts to 70m twh over the past 40 years. And this is a huge number, and I will just give you one other number. It's 500 times more than the world's energy consumption in one year. This accumulation is caused by the increase of greenhouse gas concentrations in the atmosphere.

And here I show a figure that has been measured at our institute, asking Antarctic ice cores as to the concentration of carbon dioxide over the past 800,000 years. This is a record that you see demonstrates that carbon dioxide naturally varies in the climate system. This is not a constant quantity.

Over the past 800,000 years it has varied within very clear bounds. But in the past 250 years we have gone out of these bounds. The concentration in the year 2013 was actually 30% higher than any concentration that the climate system has experienced in the past 800,000 years.

And in fact we can make that other headline statement that says that “These levels of carbon dioxide have been unprecedented in that time period.” Now the reason why this increase has happened is the burning of fossil fuel by man, plus deforestation and to a minor extent the production of cement.

You see here the emission figures reported in a billion tonnes of carbon per year since 1980. And with the exception of the financial crisis that you see as a little blip, very much resilience in terms of emissions of fossil fuel. You see that every year almost we write record emissions worldwide. 2013: 9.9bn tonnes of carbon that were emitted during 2013.

And it’s nice to go back for a moment and to ask a question. How much has this increase been since the world has declared we have a problem? Now when was that? 1992 was the Rio Summit. And that is arguably my time point where I say the world has declared climate change is a problem that we need to address. And in fact the UN Framework Convention on Climate Change was created at that conference. And since then the emissions have increased by 61%. And they are today rising at a constant rate of 1.8% every year.

Now let’s address the second pillar of our report - the understanding. It’s not enough just to observe the changes in the ocean, in the atmosphere, in the frozen world on this planet regarding vegetation and many other parameters. But we want to understand the physical causes of the changes that we are measuring.

Now we cannot go back as an experimental physicist would naturally do when they want to understand processes. We would go back to the beginning of the 20th century and re-do the experiment but we would just stop the emissions of fossil fuels and see what happens with the temperature. That would be really a telling experiment. But we can do almost as good as that by using comprehensive climate models and carry out that experiment on the computer.

And you see these climate models here compared to observations. The observations you see as black curves on this graph. The red curve shows the most recent model simulations carried out by 25 centres around the world. Incidentally these scientists all compete against one another, who has the better model etc. But we find ourselves within this assessment to compare openly all these model simulations. They are plotted here as the red curve. And you see that the red curve follows quite nicely the observations.

Now you should know that these models have been forced by the information of a changing atmospheric condition in terms of greenhouse gases. So the information that carbon dioxide has increased, has been used by these model simulations, as well as the fact that some volcanic eruptions have happened in the past 150 years. That is also information that these models have available. As you see for example in these blips that occur here frequently in the record and in the model simulations. Now because this is quite good agreement that we find between the models and the observations we say, rather cautiously, models reproduce observed continental-scale surface temperature patterns and trends over many decades.

Now wait a minute. Haven't we read in the media that the past 15 years have seen very little warming and that some of these models or perhaps even all of the models cannot simulate that? I want to address this question. You see here that time period at issue. First of all it's a very short time period compared to the 150 years that I have shown. But you do see some deviation on a decade timescale between the observations globally averaged and the simulations given in red.

So let's now go back and enlarge that section here. It's important to note that this section usually starts in 1998 and it just so happens that 1998 saw one of the largest el nino of the 20th century, a time period where naturally the temperatures around the world are a little bit higher than normal, because of the very warm ocean in the tropical pacific.

So it matters where you start looking at deviations of models between…and observations when you look at only 10 years of record. But the important question is are models generally unable to simulate pauses of ten or 15 years? This is a question that has been recently addressed. Unfortunately no longer available for our assessment, because it's a publication and a piece of research that has been published after our cut-off period. But it is based on simulations that were available for our assessment. And I show you here this time period in observations. And we just pick one model simulation to see how that individual simulation would actually compare to the one realisation that we have observed.

And you see there is trends of 15 years, in fact this particular model simulation has a very steep trend, indicated in red, that doesn't compare well with the observations. Interestingly followed by a very flat trend and then again by a very flat trend after a step. So there are various characteristics here of interannual to decadal variability that these models can simulate. It just is a question of when does that particular variability start? That is a fundamental question. So we take another of these many simulations and you see here that is one that is picked to agree in the first 15 years regarding the trend…very close to the observed, but then followed by a trend that is significantly steeper, followed again, indicated in purple, by a flatter trend. The lesson here is that it's actually quite important which of an individual realisation of many models you pick and compare it to the one realisation of nature that we have available. And in fact the scientists have gone at really great lengths and depths to address the question of causal relationship between drivers, greenhouse gases, but also drivers that cool the earth such as aerosols, tiny dust particles in the atmosphere, to quantify how much of the observed warming is actually due to mankind.

And this is summarised quite nicely in this graph. You see the observed warming in the past 60 years as the black bar, anywhere between 0.6^{o}C and 0.7^{o}C. You see the warming that we expect from the greenhouse gases only in the green bar. It's actually more than we have observed. But fortunately there are also drivers that cool the earth. These aerosols, these soot particles which are ejected by volcanoes, occasionally in a natural manner, but also our part of the emissions of greenhouse gases due to combustion of fossil fuels. We always produce some soot along with that. And you see that in the yellow bar which brings some cooling over the past 60 years. Now put the green and the yellow bar together you receive…you obtain the brown bar. And the brown bar explains very nicely the warming that we have observed. Whereas the solar variations and the internal variability as you see here in the last two bars which are hardly visible because their contribution to the temperature is almost nil. That plus many other evidences tells us that "it is extremely likely that human influence has been the dominant cause of the observed warming since the mid 20th century." This again is a headline statement.

But the science would not be complete if we focus only on temperature. More interesting are other effects that we see in the climate system. So here we have the cause. Here we have effects, and they range throughout all components of the climate system. We see warming in the atmosphere, uptake of energy and heat of the world ocean, we see soil warming around the world. We see changing statistics of extreme warm events and heavy precipitation. We see an intensified water cycle. We measure retreating sea ice in summer in the arctic. We see melting glaciers around the world. And we can now measure through satellite soundings the shrinking and mass loss of Greenland as well as Antarctica.

But the most integrative change around the globe is the rise of sea level caused by the thermal expansion of water and by the discharge of water from sea ice and glaciers into the world ocean. All these observations actually suggest very clearly that there is a quantitative relationship between the increase of carbon dioxide, caused by the fossil fuel combustion and by deforestation and the effects that we see. So convincing that actually the scientists created this other short headline statement which says, human influence on the climate system is clear. And I mentioned it is a headline statement, which means that the delegates of the countries that approved our summary for policy-makers have also approved that very sentence.

Let's now turn to the last pillar of the three that I would like explain to you this evening. And that is using the same models with which we have tried to understand the causal relationship between the increase of carbon dioxide, the increase of aerosol load in the atmosphere and the physical changes in the climate system, we take these models and now explore the different futures.

If you look at different futures we are all used very well to the following approach. Whenever we think about our personal future we actually think in scenarios. What if tomorrow I would earn twice as much as I earn today? This is a scenario…unfortunately quite unrealistic. There are many many other scenarios you make when you want to estimate the future. And the same happens with the climate models. We have to make assumptions about the future.

So we talk in scenarios. For simplicity we show you here two scenarios, a red scenario which means business as usual, emissions will grow further. And a blue scenario which is an aggressive mitigation scenario, a scenario that assumes that by the middle of the 21st century the emissions have been reduced substantially by about 85% and they will reduce further throughout the second half of the 21st century.

Now the outcome in terms of global mean temperature is very different for the two scenarios, with the business as usual scenario showing a 4 degree warming by the end of the 21st century, whereas the warming is contained and limited to about 1 degree by the end of the 21st century with the mitigation scenario. Now, in fact, it's clear that continued emissions will cause further warming and changes in all components of the climate system. Now nobody lives in a global mean temperature.

We want to know how that plays out in the different regions. And that is depicted here for the high emissions scenario, the business as usual at the end of the 21st century, enhanced warming over the continents, and in particular over the high latitudes of the northern hemisphere - warmings on the order of 7 degrees or more. One result out of these climate models that strikes me personally is the fact that along with the temperature any other climate variable will change - the most important probably those variables that are associated with the water cycle - because they indicate changes to our life support system – the water.

And you see here projections of precipitation changes by the end of the 21st century, with intensive blue colours indicating an increase in precipitation, particularly in the tropical areas and in the high latitudes of the northern hemisphere. The brown colours indicate reductions in precipitation on the order of 20%-30%. And you identify very clearly that these reductions of precipitation all occur in the already dry latitudes, in the dry sub-tropics. And that means that situations regarding water shortness and drought risk will exacerbate in the course of this century. In fact we say the contrast in precipitation between wet and dry regions and between wet and dry seasons will increase.

And it's absolutely important for those people who produce food, for example, to know that not only the amount of precipitation will change, but also the timing, when precipitation will fall, is likely to change. But of course there is a very strong regional signal to these changes, which needs to be explored.

Now a first step regarding these regional signals has been taken in Working Group I this time around by creating an atlas of global and regional climate projections. And I will just show you one of 37 regions that have been analysed on the basis of these global climate model simulations for the two scenarios here. The complete atlas is accessible both in printed form but also in digital form through the internet.

You see here the temperature changes in Europe by the end of the 21st century. We also give time series for people who are interested in the temporal, the transient changes. But more importantly we do the same thing also for precipitation. And you see your country here along with my country for the low emissions scenario on the left column, we are in an area where you see the hatching pattern of precipitation, which means that we will have a hard time for that scenario to distinguish between changes due to climate change in precipitation and the natural variations we are anyways used to.

This is less of a case in the right column, the high emissions scenario, where you see that the high latitudes of Europe will experience increases in precipitation which are beyond what we are used to with regards to natural variability. Now here you see this extremely complex climate system, consisting of atmosphere, ocean, cryosphere, vegetation, carbon cycle. And sometimes you wonder why are the scientists so confident to talk about temperature changes, about other changes in the climate system in the light of its complexity.

Now what really helps us are some fundamental balances that come out of the physical science, the balance of energy I have mentioned, but also the balance of matter, substance, the balance of momentum and a few others. And it turns out that we also look at a balance of the carbon cycle which permits us to make another extremely policy relevant observation.

It is the observation that the true and most important determinant of warming in the 21st century is the totality of all emissions since industrialisation, since 1750. If you take all these emissions and investigate the warming that will happen in the 21st century you realise that these quantities are almost approximately linearly related. More emissions in total, more warming in the 21st century. In fact we can quantify that, 1,000 billion tonnes of carbon will cause a warming of 0.8°-2.5° Celsius in the course of the 21st century.

Now if there is this tight relationship between all the carbon emissions and the temperature increase in the 21st century this also means that if the policy-makers or society decide on limiting the warming at a certain temperature, for example at 2 degrees, that implies immediately that there is a finite…a fixed amount of carbon to be emitted while being consistent with that target.

Any climate target therefore implies a limited carbon budget. And we can actually depict that rather nicely. This is the last figure out of the summary for policy-makers in which you see a straight line, different trajectories with different colours, but they all lie on top of one another indicating that the four scenarios that we are calculating, they all march through the 21st century along that same trajectory. And as you increase the cumulative total carbon here depicted on the horizontal axis you are increasing the warming.

So for a policy-maker who wants to limit the warming at 2 degrees Celsius they would go into this graph at 2 degrees, go over to the right where the models sit and then read off how much carbon is compatible with that specific target. For a 2 degree target it's 790 billion tonnes of carbon. And this leads us to a small calculation – 790 billion tonnes of carbon. By the end of 2013 we have emitted 535 of these 790 billion which leaves us with 255 billion tonnes of carbon to be emitted while still being compatible with the two degree target. And it's no rocket science to put that into a context.

I have given you the number already before, about 10 billion tonnes of carbon are emitted currently every year, which means that in 25 years at the current emission levels we will have exhausted the budget that is allocated to be consistent with the two degree target. In other words a limitation of climate change at two degrees requires us to act fast. In fact this is the way how physical scientists rather factually communicate the urgency of the problem. And that is also why the policy-makers and the delegates of the countries have accepted this final headline statement, which says "Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions." And because it's a headline statement firmly embedded in our summary for policy-makers this is not only an affirmation by the scientists, but it actually is an affirmation by all governments of the world.

Now we speak in scenarios, as I have tried to convince you the two degree world looks like this. We will experience warming, warming beyond what we have experienced already in the 20th century. We will experience changes in precipitation. But this world, the business as usual world looks rather different. It's a world which is warmer by 4.5^{o} Celsius, with areas in the tropics in particular that have not experienced these temperatures in millions of years, which means that the ecosystems haven't experienced those temperatures either. There is quite a challenge in terms of adaptation. You also see the precipitation in this figure - I have explained that before. By putting these two worlds next to one another in the summary for policy-makers implicitly we give a message to the policy-makers and the public, the message that today we have a choice, because these are two scenarios. And that is actually the final message that I want to convey to you.

Today we have a choice. And if you would like to learn more about this assessment, access all the material that I have mentioned in passing, accessing summaries in all six UN languages, fact sheets, etc. then please visit this website. And with that I thank you very much for your attention. Thank you very much.