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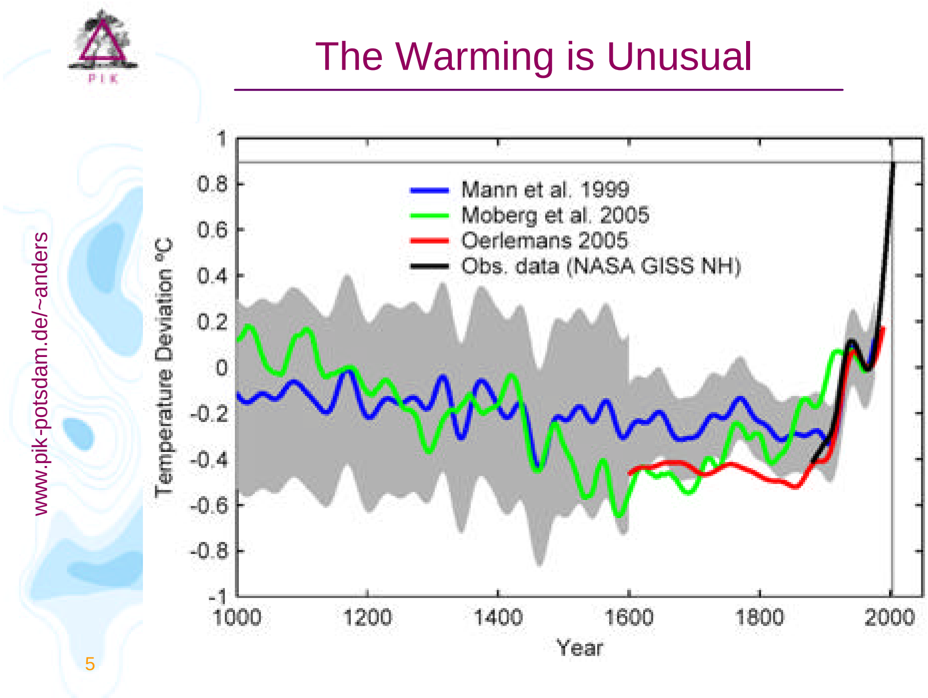
Points for discussion:
The state of global climate; to what extent is energy consumption responsible for global warming? What is irreversible, what can be inhibited? Climate impacts.

I was asked to talk about climate change and I will try to give you some scientific bases and the resulting risks that we might be facing in a warmer world.

CO_2 concentration is rising rapidly in the atmosphere. If you look at the evolution of the carbon dioxide concentration in the atmosphere given in parts per million (ppm) for the last 10,000 years, you see that CO_2 concentration has not been above 280 ppm for most of this period. Only since the industrial revolution about 200 years ago we observe a sharp increase in carbon dioxide concentration. We know from isotopic records that this is mainly fossil carbon, i.e. carbon that was digged up from ground in one way or another and that oxidized to become CO_2.

It is known for at least 110 years that CO_2 is a greenhouse gas. Arrhenius, a Scandinavian researcher, calculated the so called "climate sensitivity", which is the amount of global warming in response to a double of CO_2 from 280 ppm to 560 ppm. He calculated with pen and paper a warming of about 4°-6° Celsius. We have a lot of different techniques now that are used to obtain this important quantity. Half of them are based on measurements in one way or another, paleoclimatic data and direct observation. The other half is based on model simulations. The number that you might want to remember is that a doubling of CO_2 in the long term could lead to about three, plus or minus one, degrees of global warming.

Now, taking these two pieces of informations together, the increase in CO_2 should have led to some increase in global mean temperature, and this is indeed the case. If you look at the time evolution of global mean temperature, this is here given as the deviation from the year 1990, you see some increase of about 0.8 degrees in the past 100 years. This is now only the last forty years, you see the dots of the measurements, and there is some running means on top of it as the black curve. NASA has announced the year 2005 to be the warmest year on record, i.e. the warmest year in the last 140 years since we have enough thermometer measurement to obtain the global mean temperature directly. What is also shown here is the grey shading, and these are the projections that were given in the last UN-report of the Intergovernmental Panel on Climatic Change (IPCC) in 2001. These are projections which include all the different models that took part in the comparison.



If you look at the projections that were given in the last UN-report of the Intergovernmental Panel on Climatic Change (IPCC) in 2001 and various other climate change models, you find that the warming that we have observed so far is, if anything, at the upper level of these projections, i.e. we have seen a stronger warming than projected. This warming is indeed unusual. A time evolution of the northern hemisphere temperature was developed for the last 1,000 years. Since for this we cannot rely on direct measurements, we have to do reconstructions. You might have heard about the Michael-Mann-Curve; also named "hockey stick" curve because it has a hockey stick shape. Together with its general uncertainty this curve has been under attack from a lot of directions, from political directions and also from scientific ones, but it has to my understanding survived all these attacks with small corrections. Indeed it has been confirmed in the meantime by completely different analyses which are based on different proxy data, e.g. the Moberg-Curve that gives the reconstruction based on sediment data or the curve by Oerlmann et al 2005 that was based on the retreat of mountain glaciers. Both curves confirm that there is, of course, variability in the northern hemisphere temperature for the last 1,000 years and that there is, of course, an even larger uncertainty in this curve, but neither of them can explain the sharp increase in temperature that NASA has observed in the last 140 years.

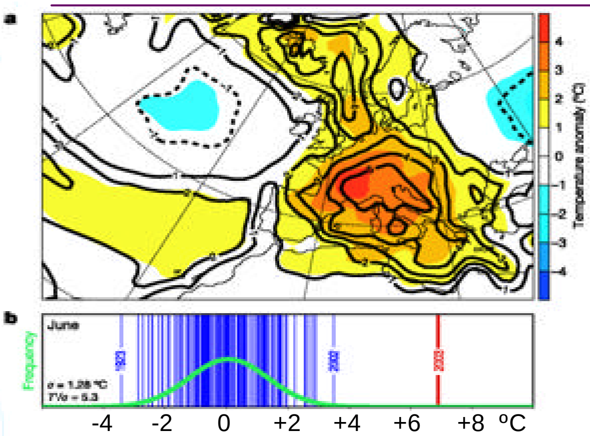
This has some implications, I cannot really go into detail here but if you look at satellite pictures of the sea ice extend in the Arctic from 1997 and from 2005, you observe a strong decrease in Arctic sea ice cover. Most model projections actually predict a more or less complete vanishing of this sea ice in this century. The reason why models seem to agree on this point – no matter on what the scenario is – is in part because we have already committed ourselves to a certain degree of warming which we would even get if we froze the CO_2-concentrations in the atmosphere at present level of about 380 ppm. That is due to the fact that our planet, our climate system is at present in an imbalance because of the sharp increase in carbon dioxide induced by anthropogenic emissions. We put an extra forcing onto the system, and this has led to the fact that the ocean has taken up a lot of heat. Now, if we freeze

CO_2-concentration to the present level we would get an additional warming – additional to the 0.8 degrees that we have seen – of about 0.6 degrees even without increasing CO_2 any further.

At this point of the talk, I am leaving the area of known facts. So far, I believe that I have addressed the first two points of your list, Dr. Linn. Now, I am going to talk about risks and I think no climate scientist at the moment can say with certainty that any of these risks that I am going to address now, are really going to happen in the future. What I am going to do is: I am going to try and give you some physical reasons why we believe that these are possibilities for the future.

First of all, let us talk about the quite obvious possibility of an increase of heat waves. We have more energy in the climate system because we have a warmer system, and this might lead to an increase of extreme events.

Risks: Heat Waves



Europe, Summer 2003

Schär et al. 2004

Chance 1:10 000 000

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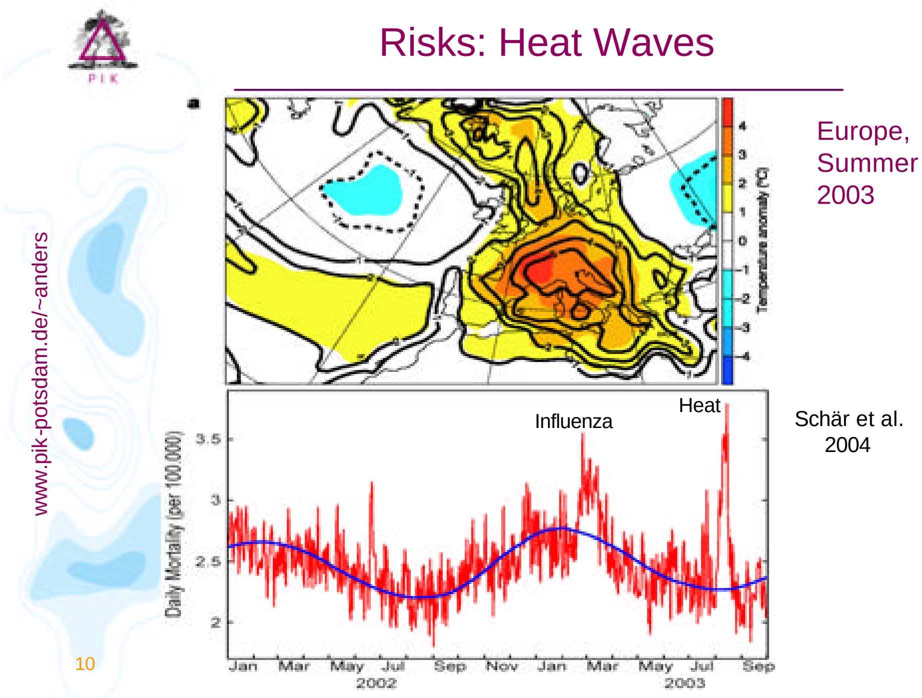
You might remember the European summer of 2003 which resulted in a very strong warming anomaly over Europe, you see this in this upper panel here. But let us concentrate on the lower one, I hope you can read it. What is given here is the mean June temperature for different years; each blue line gives you a different year. Shown is the deviation from the long term mean. On the left hand side here, this is 1923, on the right this is 2002. Combining these numbers yields a nice Gaussian distribution - the green curve plotted on top of it. The year 2003 is all the way up here, outside of the fifth standard deviation of this Gaussian distribution. This means more or less that the chance of this event to occur when you do not take global warming into account is 1:10,000,000. This is a very rare event.

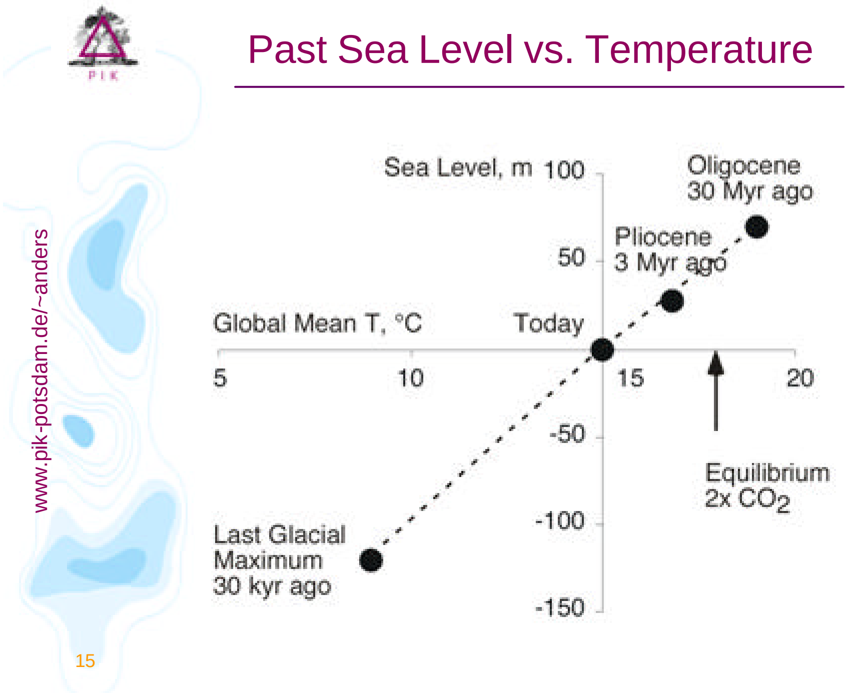


This, of course, had consequences. One effect that I want to mention is the daily mortality rate which you see here per 100,000 inhabitants for Europe. The seasonal cycle tells us people tend to die more in winter than in summer. But there are deviations from the natural seasonal cycle. This one deviation is the influenza in winter 2003. The other one was this heat wave that I just discussed in summer 2003.

Another risk concerns ice sheets. We have two major ice sheets on Earth, one is on Greenland, the other one on Antarctica. They have very different dynamics but what they have in common is the reason why we care about them. The water that is stored in Greenland alone amounts to about seven meters of global sea level rise if it would all melt and pour into the ocean. Antarctica adds up another 50 to 60 meter of global sea level rise. We do not understand the dynamics of these ice sheets very well. We know that they are very different in Greenland and in Antarctica. In Greenland, e.g., we have melting regions that are increasing with time. In 1992, for example, a strong volcanic eruption led to low global temperatures and little melting on Greenland. In 2005 we had much larger melting regions. This is how it works on Greenland. Snow is falling in the center, and then ice is floating to the sides and is melting when it gets into lower regions where it is also warmer. The Greenland ice sheet is up to 4000m high. During the last two or three years there have been a lot of studies on the dynamics of these ice sheets. What we understand now is that we do not take these dynamical effects into account properly in our ice sheet simulations. It seems that all these dynamical effects indicate in a direction that the melting would rather be faster than slower which has led, e.g., Jim Hansen, the head of the NASA Goddard Institute, in 2005 to the statement that “ice sheet responds time rather of the order of centuries than millennia”.

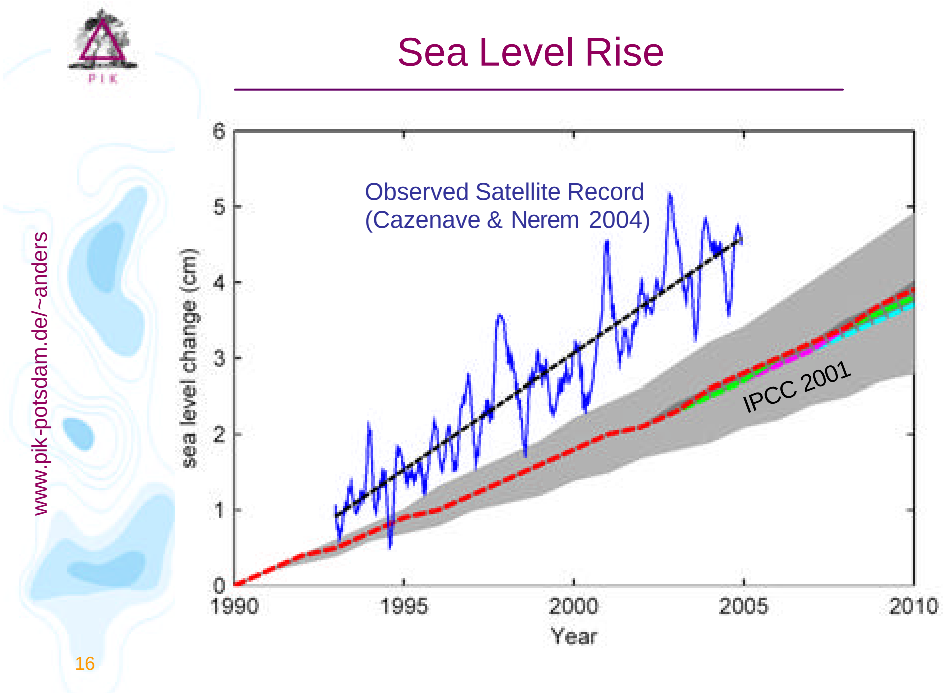
The other big ice sheet is on Antarctica with a completely different dynamics. It is too cold in Antarctica to see melting on land, the melting occurs in the ocean. The ice is floating towards the sides and when it hits the ocean it becomes an ice shelf, not an ice sheet anymore. These ice shelves hold back the sliding ice from land, and this is where also the ice is melting. The, now famous, Larsen B Ice Shelf, for example, had burst into small pieces within five weeks in 2002. It was a large ice shelf. Not anymore. These small pieces do not just melt faster, but they also cannot hold any shear stress, i.e. they cannot hold back the down slide of land ice masses to the ocean. This is why strong acceleration of the ice slide in this region has been observed in response to this event.

As I said, we really do not know how fast the melting is going to occur, if we want to get some indication for what kind of sea level rise we might be facing in the long perspective we could have a look into the past.



Here you see the global mean temperature on the x-axis and the difference of sea level given in meters from today. Here, in the center, we have the present day and now I am going to discuss a few time slides of the past. Let us start with the last glacial maximum in the bottom left. It was definitely much colder then - it was an ice age after all. A lot of water was stored in huge ice masses on land in the northern hemisphere. Thus the ocean had about 120 meters lower sea level compared to the present. But we also had the other extremes. During the Pliocene, about three million years ago, with temperatures slightly higher than at present, we had a sea level about 20 meters higher than at present. In the Oligocene, 30 million years ago, it was even warmer and the sea level was even higher. We can now plot in here the equilibrium temperature value according to the climate sensitivity, that I mentioned earlier. For a doubling of CO_2 from the pre-industrial value to the 560 ppm, we obtain about 3 degree of warming, which brings us in the vicinity of about 50 meters of global sea level rise on the long term. This is completely in line with the melting of the two major ice sheets, as I said, with at least 60 meters of global sea level rise stored in large ice sheets, even without taking the additional effect from the thermal expansion of the ocean into account.

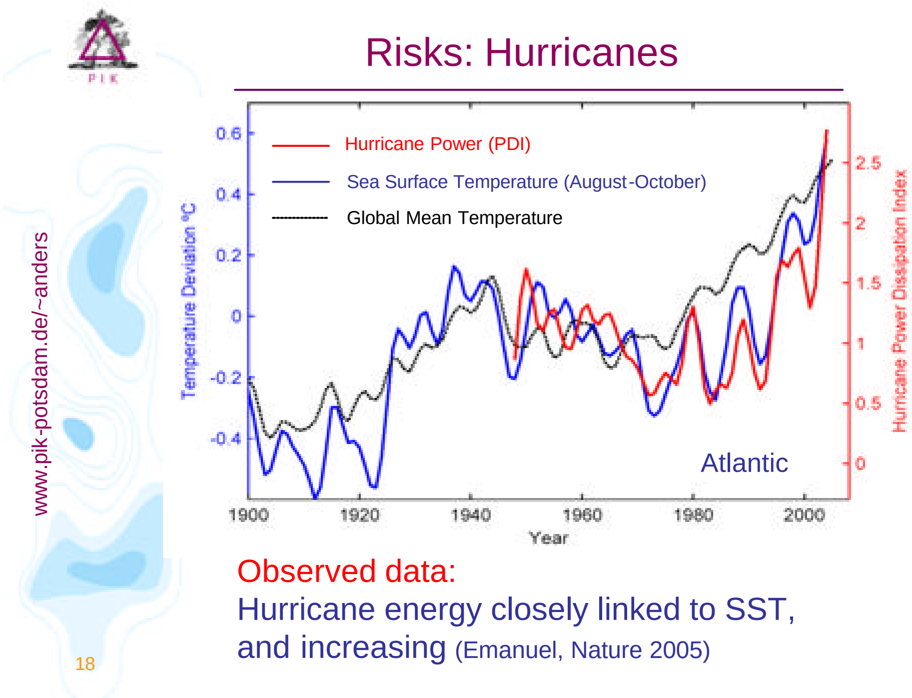
So, let us see what kind of sea level rise we have observed so far, this is again the projection given by the Intergovernmental Panel on Climatic Change in 2001. You see that all models and all scenarios had projected an increase in global sea level.



Next to the projections we find the observed record from satellite measurements. If anything, it has been faster than the projections from the year 2001.

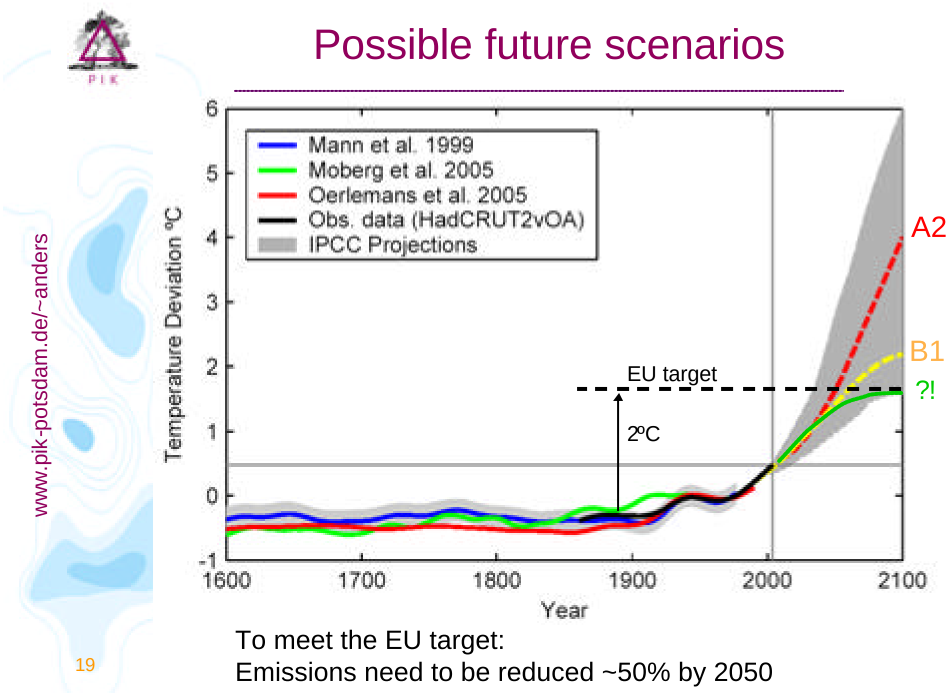
Another risk concerns hurricanes. In the last two years we had a number of sad records that were set by hurricanes. In 2005, we had the first hurricane ever observed in the South Atlantic of the Brazilian coast. It was the first time that Florida was hit by four hurricanes in one season; the first time ten Typhoons hit Japan in one season. This is an indication that this is actually a global phenomenon and not an Atlantic one but we can discuss this later, if you wish. There are some discussions, that it should be an Atlantic problem but I don't believe this is true. In 2005, the first time 28 named storms were recorded since 1851. They had to start the Greek alphabet in order to name these storms. First time 15 hurricanes were observed, for the first time a hurricane approached Europe, off the Portuguese coast. The lowest ever observed pressure was measured in Hurricane Wilma which is a measure for the strength or the power within a hurricane.

Let us see if we can give some physical reasons why there should be more hurricanes in a warmer world. The red line here gives you the power within the hurricanes as a time series for the last 50 years roughly. The blue line gives the sea surface temperature during the main development period of the year between August and October in the tropical Atlantic. You see a very strong correlation of the blue and the red line. This is actually known physics that a warmer ocean would lead to stronger hurricanes.



Next, you might want to ask why is the sea surface temperature increasing and here we can only give indications of course, but you see the global mean temperature as the dash-line. It increase during the past 30 years, that is the global warming that we have discussed earlier. The global mean temperature is pretty much in line with the increase in sea surface temperature.

Let us now talk about some possible future scenarios.



Here I plotted again the reconstructions of the northern hemisphere temperature, the famous Michael-Mann-curve is the blue one here, and you see the uncertainty. But now the uncertainty gets much smaller with reference to the future global warming that we might be facing. Even the observed data – that is the black curve again – are getting all of a sudden much smaller when you look at what the IPCC projected for the period until the year 2100. We are going to discuss different possible scenarios here today, and I don't know a lot about these scenarios, how they come along, how emission scenarios are made but I know that the European Union has set up a political target: The EU says that we should not exceed two degrees of global warming if we want to avoid – that's a quote now – "dangerous climate change", this is a very normative statement "dangerous climate change". If we accept this goal, we really have to stay at the lower edge of this grey shading which again includes all the models and all the scenarios.

If we accept this goal, we would have to get some kind of this green curve here, and we just have to ask ourselves if we can achieve this. It is a very difficult business to translate CO_2 concentrations to CO_2 emission. If you are willing to ask the question how much CO_2 emission reduction do I need in order to stay below this two-degrees-target, and if you say, ok, I have a certain probability distribution for my climate sensitivity, then you can answer the question of what is the emission reduction that we need in order to stay with 50% probability below this two-degrees-target in the future. If we want to achieve this, that means that in order to meet the EU target, emissions need to be reduced by at least 50% globally by the year 2050. Note that this is a global reduction we need and we can discuss on how this should be distributed on the different countries.

With this I would like to thank you for your attention.