This presentation was prepared on the occasion of the Arctic Expedition for Climate Action, July 2008.

Author: Stefan Rahmstorf, Professor of Physics of the Oceans, Potsdam.

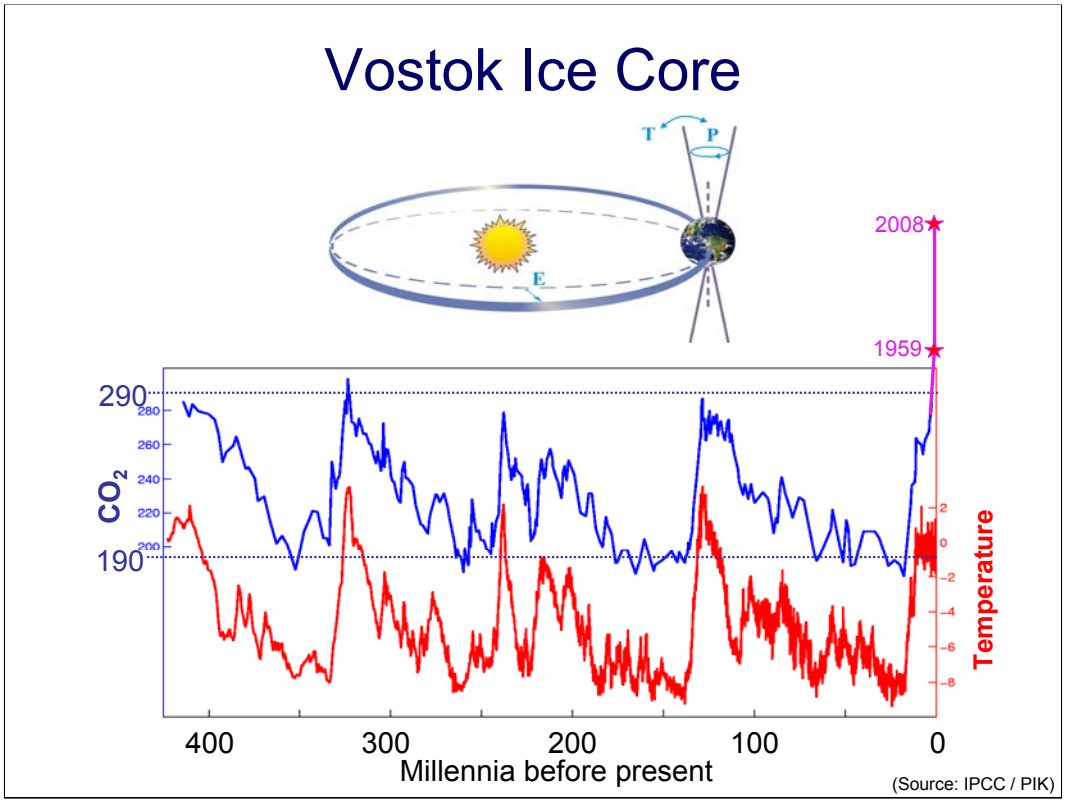
The selection of the 5 “most important” data sets is of course subjective. The 5 core data sets are supplemented by related information and animations.

While I am not the source of any of those 5 data sets, any errors in this presentation should be entirely blamed on me.

This presentation can be downloaded in pdf format from http://www.ozean-klima.de

Note that for technical reasons the animation movies are not embedded; the links where these can be obtained are given in the notes.

1 Vostok Ice Core

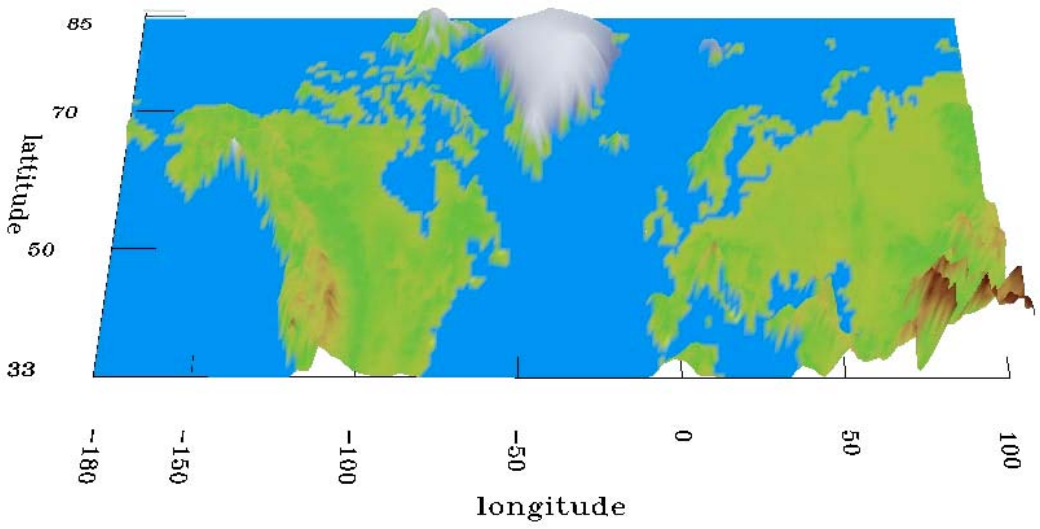


The ice core drilled in the 1970s-80s by a French-Russian team at Vostok station in Antarctica reveals the carbon dioxide concentration in the atmosphere (blue) and the temperature (at Vostok, red) for the past 400,000 years. Primarily we see the last four glacial cycles, each lasting about 100,000 years. These are caused by variations in the Earth's orbit, as shown in the schematic on top.

The Vostok data put the recent increase in CO2 concentration (purple) in perspective: never in the past 400,000 years (and very likely much longer) has the CO2 concentration been nearly as high as it is now.

Temperatures and CO2 concentration over the glacial cycles are closely linked through a two-way feedback: The changes in the Earth orbit affect climate, which then changes the CO2 concentration (with a certain time lag). CO2 in turn changes the climate; it amplifies the climate changes initiated by the orbital cycles. Taken together, the orbital and the CO2 changes can explain the observed climate changes well, as we will see in the following animation.

Orbital Cycles



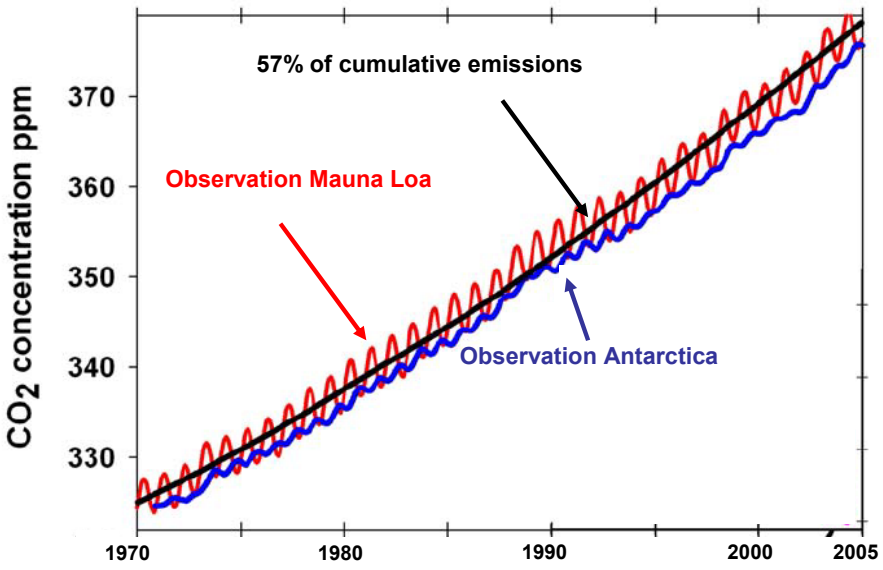
(Source: PIK / Andrey Ganopolski)

Animation movie of the changes in continental ice cover over the last two ice age cycles (195,000 years). The model simulation shown here was performed with the CLIMBER-2 coupled climate model. The model is driven by the orbital cycles mentioned in the last slide and by the CO2 changes obtained from the Vostok ice core data. Based on that it computes global climate, including temperatures in atmosphere and ocean, clouds, rain and snow, winds, ocean currents, sea ice and continental ice cover (which is shown here). The growth and decay of the ice sheets in the model can be compared to geological data and is quite realistic: ice ages start and end at the right time, and the volume and extent of the ice sheets agrees reasonably well with the data.

Note: The animation can be downloaded at http://www.pik-potsdam.de/~stefan/Movies/index.html

2 Keeling Curve

The Rise of CO_2



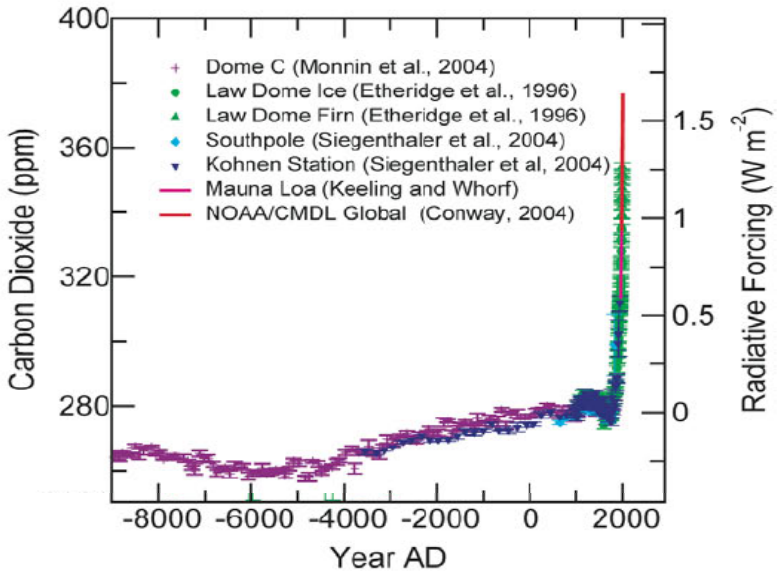
(Source: Ralph Keeling)

Regular measurements of CO2 concentration in the atmosphere were started by Charles David Keeling in 1958 on the Hawaiian volcano of Mauna Loa. The graph shows this famous “Keeling curve” for the past 35 years in red. It shows the increasing upward trend as well the seasonal cycle, which is due to the inhalations and exhalations of the biosphere with the change of the seasons.

The blue curve shows the same for a station in Antarctica. CO2 concentration is slightly lagging behind the rise at Mauna Loa, because most of the emission sources are in the Northern Hemisphere. The seasonal cycle in Antarctica is reversed and smaller, as less forest exists in the Southern Hemisphere.

The black curve shows 57% of the cumulative human-caused CO2 emissions. This shows that about 57% of what we emit remains in the atmosphere, while the other 43% are taken up by the oceans and by the biosphere. As an aside, this shows that the CO2-rise does not come from natural sources: the natural Earth system is not releasing CO2, but to the contrary it has taken up much of the CO2 we have added to the atmosphere. This is confirmed by ocean measurements, which show that CO2 in the ocean is also increasing. This CO2 dissolves in the water and forms carbonic acid, making the ocean waters more acidic.

The Rise of CO_2

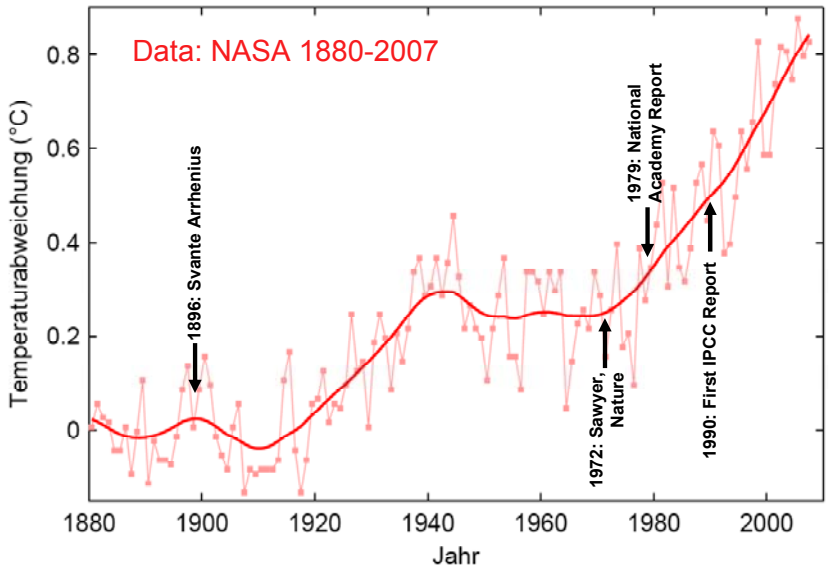


(Source: IPCC 2007)

This graph shows the Keeling curve (red) together with a bunch of ice core data for the past 10,000 years. On the right hand scale, the CO2 increase is given in terms of “radiative forcing”. That is the disturbance of the planet’s radiation budget caused by the rise in CO2. The CO2 we have added since the beginning of industrialisation has caused a radiative forcing of 1.7 Watts per square meter of Earth’s surface. It is easy to calculate that this amount of radiative forcing should have caused a global warming of about 0.7 to 0.9 ºC, if we assume a medium climate sensitivity of 3 ºC (this is the amount of warming one gets for a doubling of CO2) and take the inertia of the oceans into account.

3 Global Temperature

Observed Warming



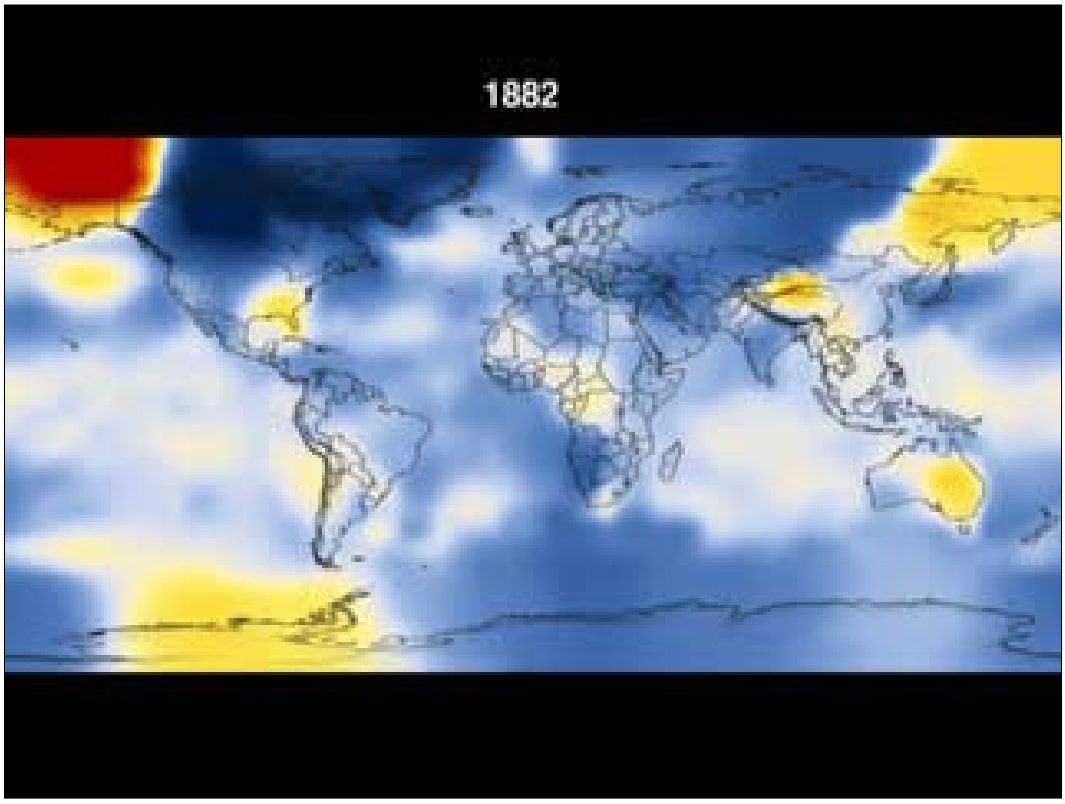
Increase in global mean surface temperature: ~0.8°C since 1900
Similar increase in sea surface temperatures

The thin line with dots shows the global mean temperature for each year, as measured by weather stations and ships around the world. The thick line is a version smoothed over 11 years, to show the longer-term (non-linear) trend.

We can see three phases here:

1. An initial warming up to 1940. The rise in greenhouse gases and an increase in solar activity have both contributed to this.
2. A plateau from 1940 into the 1970s. During this period the solar activity was constant, greenhouse gases increased, and so did aerosol pollution (smog) which has a cooling effect. This plateau is not so pronounced in Southern Hemisphere data, confirming that aerosol pollution is a main cause here for offsetting the greenhouse warming.
3. A strong and ongoing warming since the 1970s. Since greenhouse gases accumulate over time (unlike smog), and since smog was also reduced in Europe and the US by cleaner technologies, the rising greenhouse gases have dominated this warming. Note that about three quarters of the warming since the 19th century has occurred after 1970. Solar activity is declining since about 1980, but the effect is too weak to have noticeably slowed global warming.

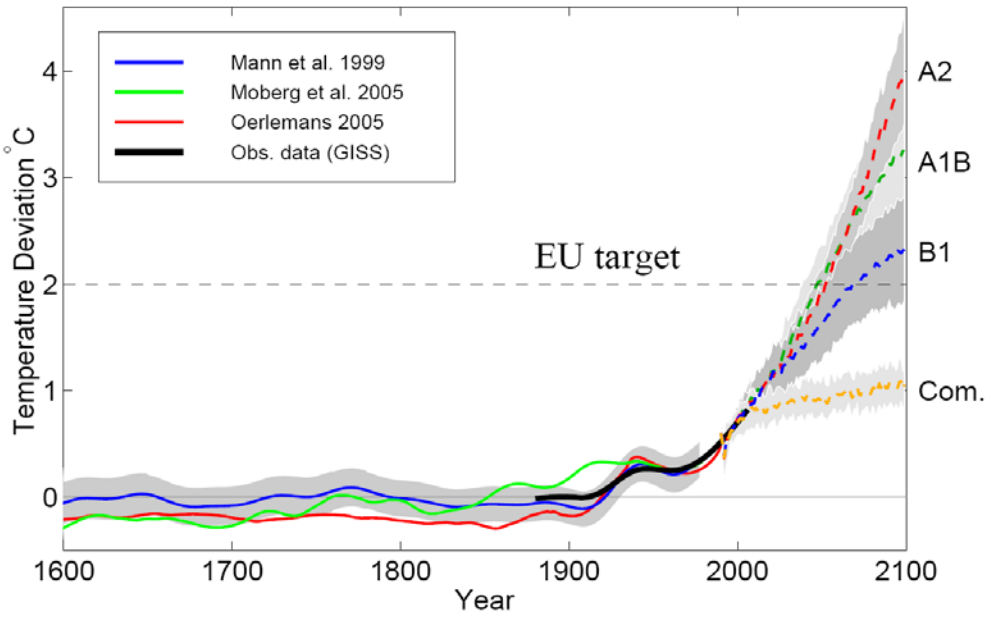
Some historically important scientific publications are labelled along the curve. Arrhenius first computed the warming expected from a doubling of CO2 concentration. The latter three publications have predicted the warming that subsequently occurred.



Animation of the NASA global temperature data, of which the previous slide showed the global average.

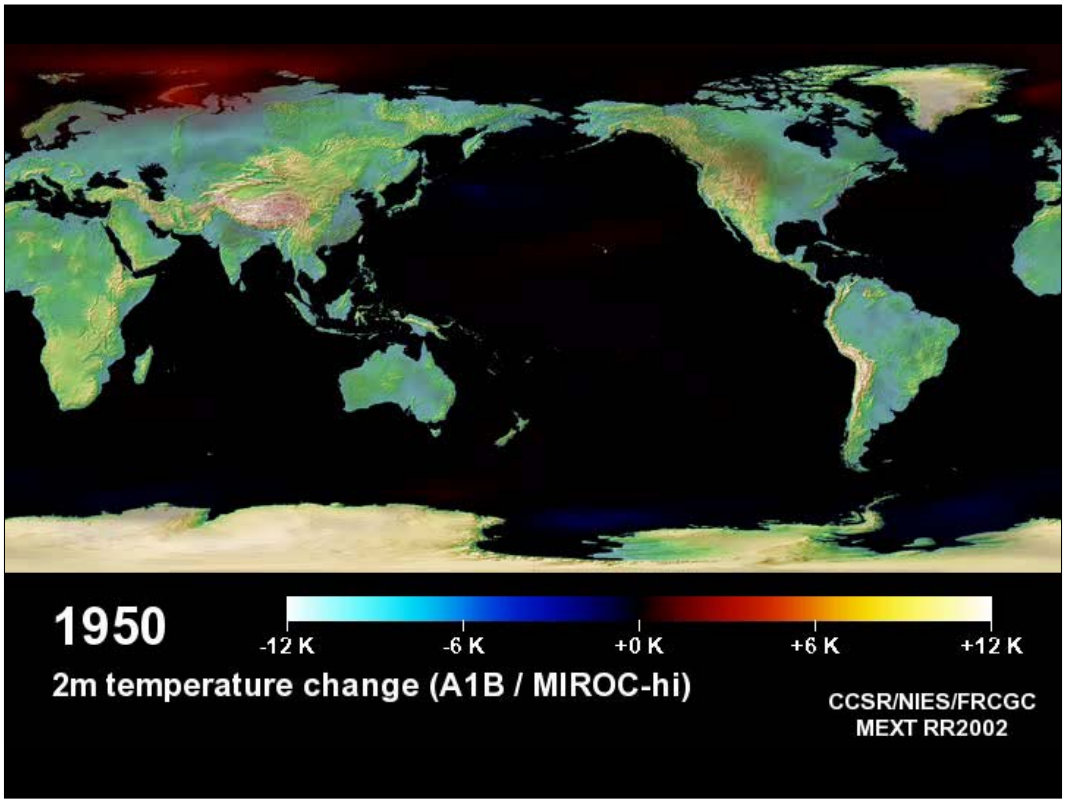
Note: The animation can be downloaded from http://data.giss.nasa.gov/gistemp/animations/

Projected Future Warming



(Source: PIK / Projections: IPCC 2007)

The NASA GISS temperature data shown previously (here in black) are combined here with three reconstructions of temperatures for earlier centuries, and with projections for the future. The latter show three different greenhouse gas scenarios (B1, A1B and A2) which differ in the assumption about how much we will emit in future. The scenario labelled “Com” shows what would happen if we stabilise the greenhouse gas concentration in the atmosphere immediately: A small warming would still occur in this case, as the climate system catches up with our past emissions. The European Union’s policy target of limiting global warming to a maximum of 2 ºC above preindustrial temperatures is also indicated.

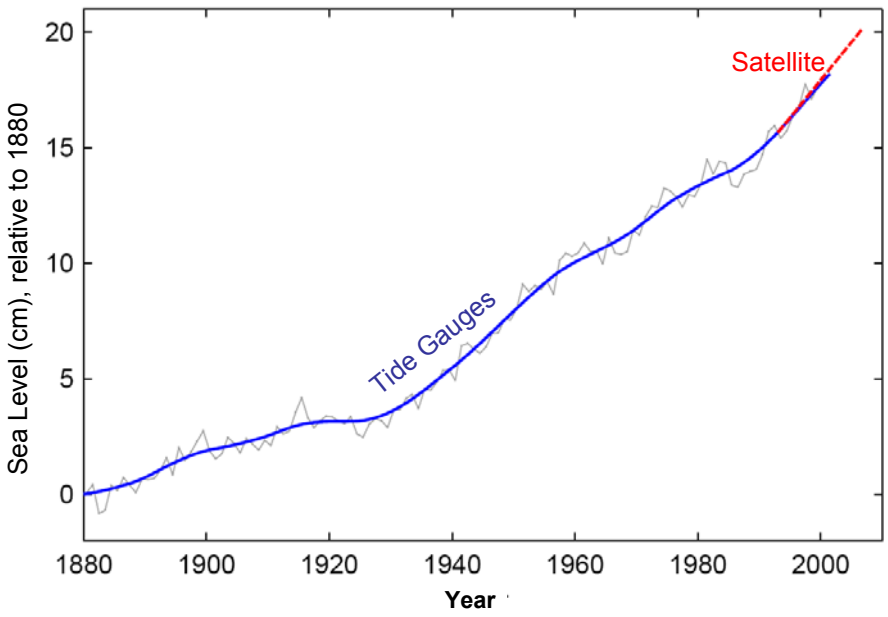


Animation movie showing a model simulation for the A1B emission scenario (see previous graph), performed with the fastest super-computer on the planet, the Earth Simulator in Japan. Very clear is the amplification of the warming in the Arctic and in the Himalayas, due to the shrinking ice and snow cover. Note also that the land areas, where we live and grow our food, is much larger than that over the oceans (and hence larger than the global average).

Note: The animation can be downloaded from http://www.team-6.jp/cc-sim/english/

4 Sea Level Rise

Sea Level Rise

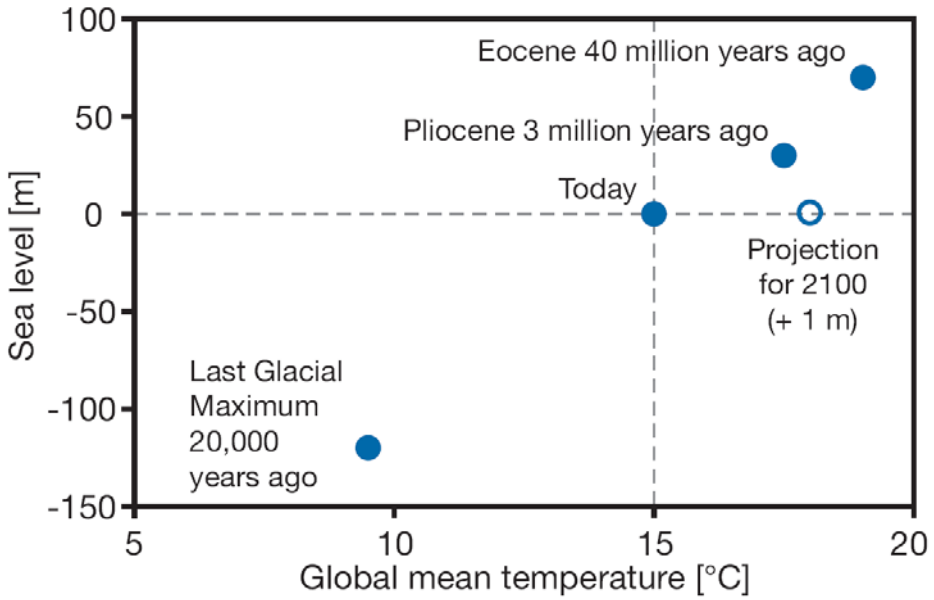


(Source:PIK after IPCC 2007)

The observed rise in sea level since 1880 is about 20 cm. It has accelerated: over the past 15 years it has exceeded 3 millimeters per year. The data are mostly based on tide gauges at coastal stations. Since 1993 we have accurate global measurements of sea level from satellite.

This sea level rise is modern; we know that there was not even a small fraction of this rise over the preceding millennia. It is also a logical and expected consequence of warming, since warm water expands and takes up more space, and melting glaciers and ice sheets add water to the oceans.

Past Sea Level vs. Temperature

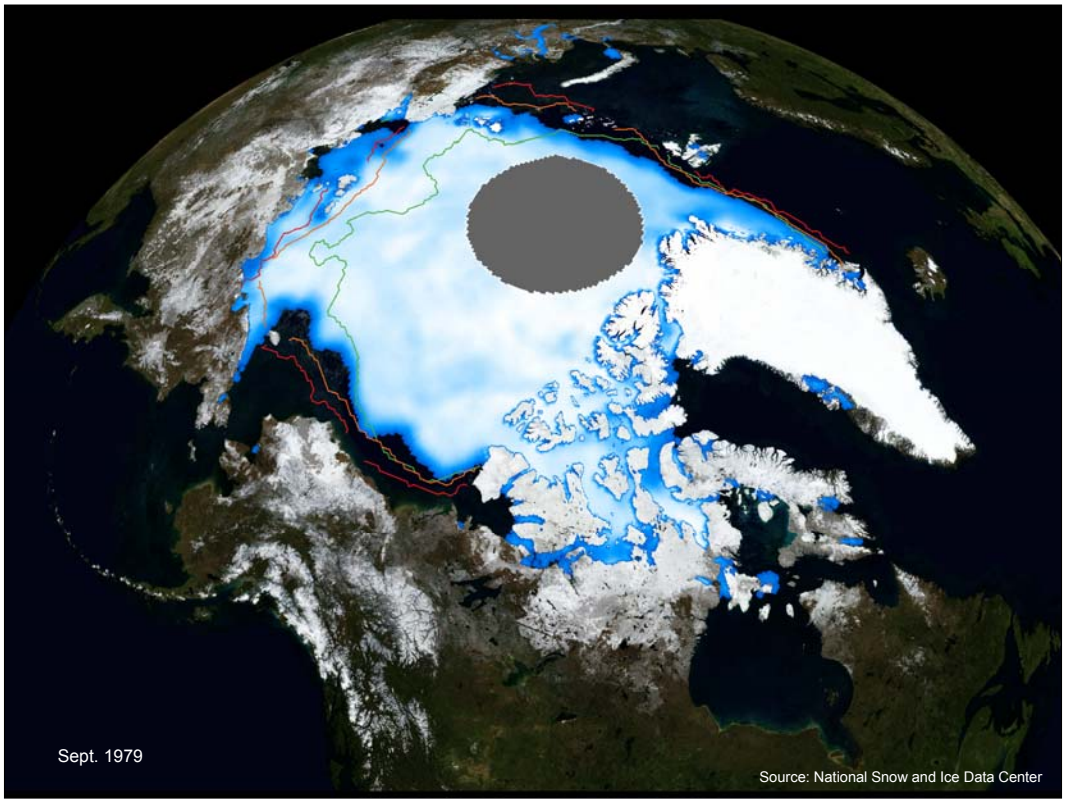


(Source: WBGU after David Archer 2006)

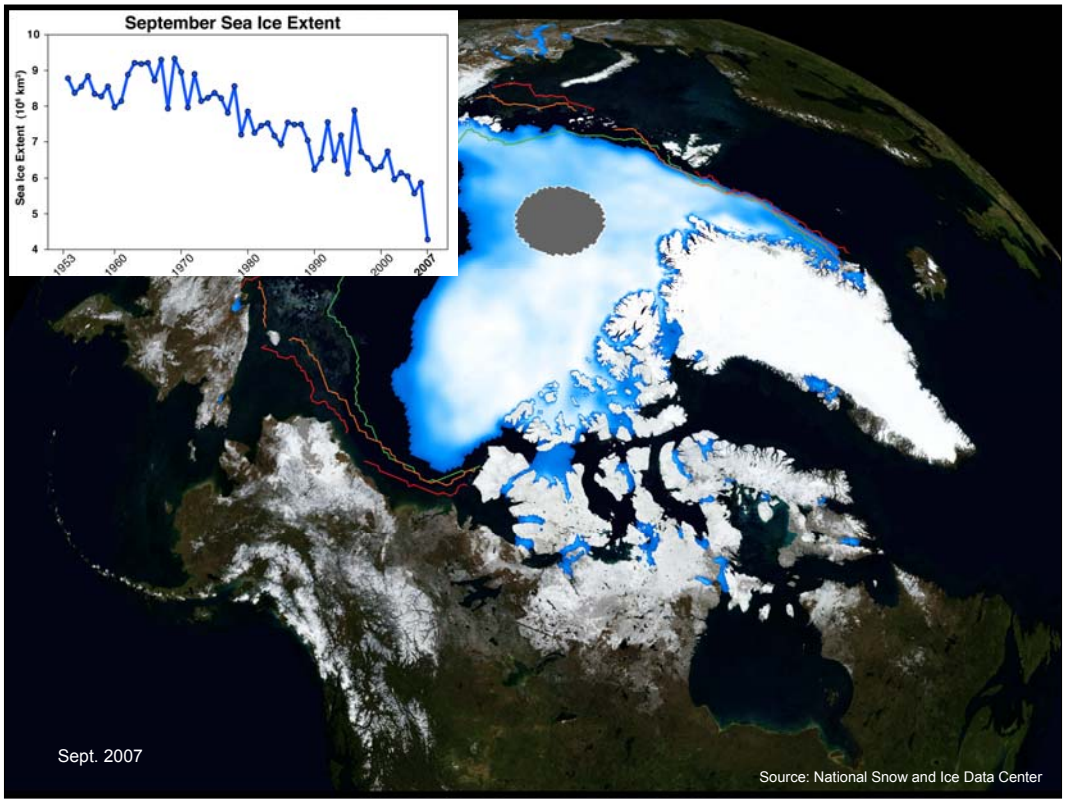
This graph shows how temperature and sea level were closely related in Earth's history. During the last Ice Age, temperatures were about 6 ºC colder than now, while sea level was 120 meters lower. During the Pliocene, when it was last significantly warmer than now (by about 2 ºC), sea level was 20-30 meters higher. During the Eocene there was almost no ice on the planet, and sea level was about 70 meters higher.

The history of climate thus sends a strong warning: past climate changes by just a few degrees in global temperature have come with very large sea level changes, by tens of meters. In the long run, this is likely to happen again. The sea level rise by the year 2100 (likely below one meter) is only the small beginning of a much larger rise that will unfold over coming centuries and perhaps millennia, caused by our carbon emissions in this century.

5 Sea Ice Retreat



Sea ice cover in the Arctic Ocean as seen from satellite, in September 1979. September is the month with the smallest sea ice cover of the year.



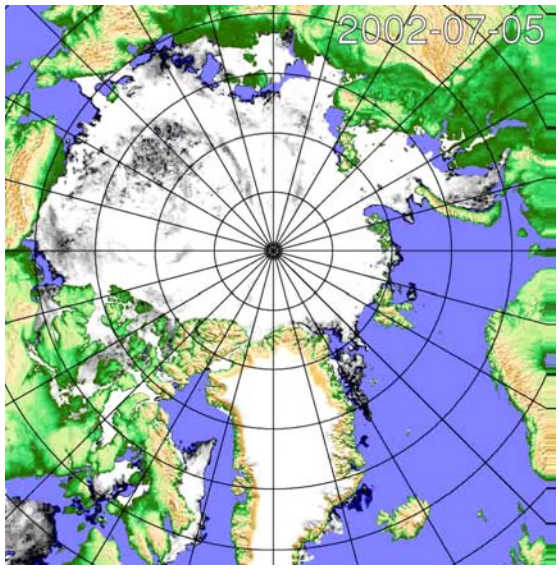
Sea ice cover in the Arctic Ocean as seen from satellite, in September 2007.

The inset shows how the ice cover has evolved over time. In 2007 it reached a record low. The ice extent was only half the size of what it has been in the 1960s and 1970s.

The ice extent is shrinking faster than predicted by climate models. The loss of ice will amplify warming, since the white ice acts like a mirror that reflects about 90% of the incoming solar energy back into space. When it melts it is replaced by dark ocean, which absorbs about 90%.

Sea ice melting in itself does not contribute to sea level rise, as sea ice is already floating on the water. The amplified warming of the polar region could, however, accelerate melting of the Greenland ice sheet seen center right of the image. When this land ice melts and ends up in the ocean, it does raise global sea level. There is enough ice on Greenland to raise sea levels globally by 7 meters.

Sea Ice Cover 2002-2007



Animation of the sea ice cover (updated daily) can be downloaded at
http://www.iup.uni-bremen.de:8084/amsr/amsre.html