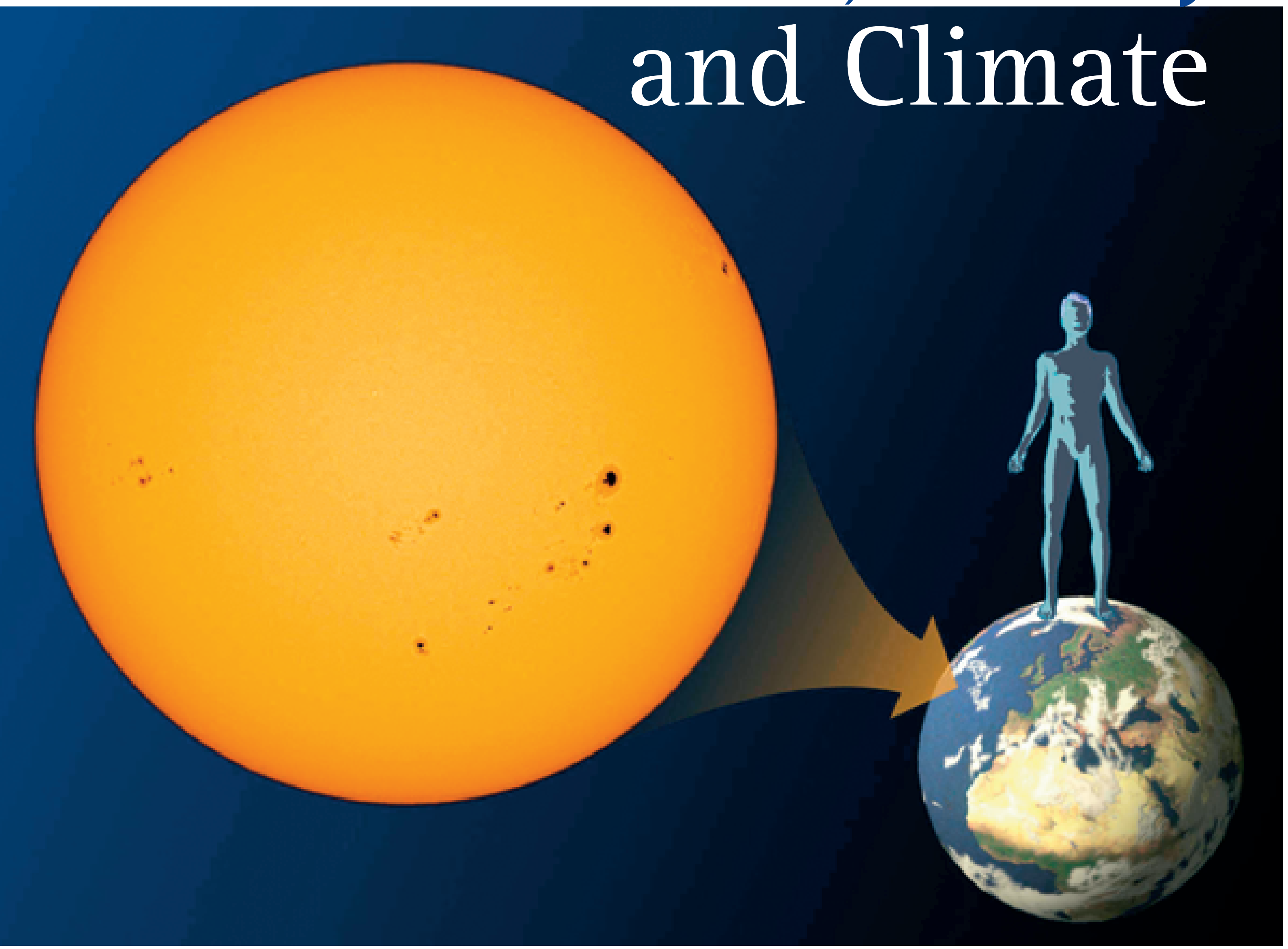
Sun, **Man,** and Climate



The third report of the Intergovernmental Panel on Climate Change was issued recently. As with the first two reports, those critics who deny man's influence on the climate and attribute the observed warming to changes in solar radiation have, once again, spoken out. In the following article, ULRICH CUBASCH *of the* MAX PLANCK INSTITUTE FOR METEOROLOGY *in Hamburg explains what we should make of this "solar hypothesis".*

Every five years or so, the Intergovernmental Panel on Climate Change (IPCC), a body supported by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) summarizes the current state of knowledge about climate, publishing the findings in a thick book. Hundreds of scientists from around the world, including researchers from various Max Planck Institutes, contributed to the recently published third report. As with any scientific publication, this report undergoes expert review. It is available from bookshops and can also be read on the internet (www.ipcc.ch). The report concludes that man has influenced the climate since industrialisation and will continue to do so to an even greater extent in future.

In almost ritual fashion, a book appeared at the same time as each of the last two IPCC reports – written by authors little known on the international scene and with no expert scientific review - which questioned the IPCC findings, claiming they did not take sufficient account of solar activity. The tenor of the books was that the observed warming was attributable to variations in solar irradiation and there had already been warm and cold periods in the past which overshadowed anything which man might cause.

This, at first sight apparently harmless scientific dispute has tangible political implications: if the IPCC is right, then appropriate measures must be taken to reduce man's influence on climate in order to stabilise it. However, if the advocates of the solar hypothesis are right, then mankind need take no action. The written question to the German federal government in spring 2001 should also be viewed against this background (http://dip.bundestag.de/btd/14/065/1406529.pdf).

It is simply not true, as advocates of the solar hypothesis presume, that the other climate researchers are disregarding the effect of the sun through lack of knowledge or are deliberately ignoring it. Various research groups have been studying this factor for some time and their findings are included in the IPCC report. It even explicitly deals with the points of criticism put forward by supporters of the solar hypothesis.

For a realistic assessment of the eternal triangle between sun, man, and climate, the climatic system and its components must first be considered. Textbooks state that climate is the long-term manifestation of either the condition or the course of the weather, and that climate is defined by the statistical collection of weather conditions for a given region during a specified interval of time, usually several decades (see Glossary of Meteorology, American Meteorological Society, 1986). The atmosphere is not an isolated system. It interacts with the hydrosphere (ocean and water cycle), cryosphere (ice and snow), biosphere (plants and animals), pedosphere (soil), and lithosphere (rock). These "spheres" form the subsystems of the climatic system.

The different timescales, in which the climate subsystems fluctuate, determine the dynamics of the climate system. The fluctuations of the atmosphere subsystem, for example, are commonly known as "weather": clouds and atmospheric pressure areas alter within a few hours or days. In contrast, the flow systems of the oceans' deep waters or conditions in large ice masses change within a timescale of hundreds or thousands of years. Fluctuations within the spheres and mutual interaction between climate subsystems are known as "climate noise". Small internal disruptions in the climate system produced by non-linear interactions can potentially have a major effect.

In addition, external stimulating factors also play a part. These include changes in solar irradiation, conditioned by the fact that the earth's orbit around the sun and the position of the earth's axis alter with time. Moreover, solar irradiation is not constant through time but is subject to fluctuations. Finally, volcanism is one of the external forcing factors which, in the current climate debate, is set against the anthropogenic factors, namely the additional greenhouse effect and atmospheric pollution. Yet the timescales involved are frequently overlooked in this issue, contributing considerable confusion to the conclusions.

ALL FIGURES: MPI FOR METEOROLOGY - CUBASCH / ILLUSTRATION: ROHRER

SPOTS IN AN 11-YEAR CYCLE

The position of the earth's axis and the parameters of its orbit are subject to the laws of physics and, as such, hold no surprises. Not so the variable intensity of the sun: man has known since the Middle Ages that sunspots occur in an 11-year cycle. Numerous observatories have regularly recorded the number and size of these spots since the 17th century. But only through satellite measurements has it been revealed that sunspots are associated with the intensity of solar irradiation: the sun's radiant intensity increases with the number of spots.

Various satellites have been providing direct measurements of solar radiation for around 20 years, without the errors which arise through absorption in the atmosphere. Records of sunspots had already revealed that, in addition to the 11-year cycle (Schwalbe cycle), there is also a periodicity of around 80 years – the Gleissberg cycle – which has also been observed in stars resembling suns. The 11-year cycle constitutes a fluctuation margin of around 0.10 percent of the solar constant, the Gleissberg cycle around 0.24 to 0.30 percent. There are also a number of other cycles found in data for solar intensity – in ^{14}C and ^{10}Be fluctuations in tree rings and ice cores - and in stars resembling suns.

Various research groups are engaged in determining past and future fluctuations in solar radiation from sunspots and other parameters (such as the length of the sunspot cycle, number of sunspots, variable diameter of the sun and from comparisons with stars resembling suns) and using solar dynamic models. Figure 1 shows the results from various research groups for the last 1000 years. They display marked differences, even differing in sign, the further back in time one goes. ►

The climate model can be "forced" with these solar data and calculations compared with observations to create a picture of how good the simulations are. For the sake of clarity, however, the results for various periods are considered.

Satellite measurements are available for the period between 1980 and 2000 which provide significant direct information on solar variability and observations exist which describe the effect of solar variability on the circulation of the high atmosphere. These revealed that, every month of the year at the geopotential height of the lower stratosphere (the layer between 16 and 30 kilometres high) south of around 50 degrees north, a consistent pattern occurs which rises and falls with the 11-year sunspot cycle. This pattern shifts with the seasons toward the meridians, or lines of longitude. The stratosphere reacts to the sun's fluctuating radiation with varying intensity according to the phase position of the QBO (quasi-biannual oscillation: a wind reversal in the stratosphere which occurs almost every two years). The effect is stronger in the easterly phase of the QBO than in the westerly.

There is no definite proof of a temperature variation on the ground with the 11-year cycle, yet there are indications that changes in the stratosphere affect the troposphere. Signs of the effect of the 11-year sunspot cycle can also be found in the sea.

To "mimic" these effects realistically, the climate model must be equipped with a high-resolution representation of the stratosphere. Models such as this, which now also simulate QBO, have been developed in recent years. They require considerable mainframe computing power with the result that, until now, it has only been possible to calculate individual cases in detail.

There is currently much discussion in the technical literature about positive feedback and the resulting strengthening of the solar signal, and the first model results are now available on this: in times of above-average solar irradiation the spectrum of sunlight shifts into the UV range. This produces a distinct warming of the stratosphere due to the increased absorption of UV radiation by stratospheric ozone. At the same time, at times of increased UV radiation, more ozone is also produced which, in turn, absorbs more solar radiation. All in all, this effect alters the vertical structure of the atmosphere, thereby influencing not only stratospheric but also tropospheric circulation, which may be significant for long-term weather forecasting.

Interactive Chemical model

To record this effect completely, an interactive chemical model and a spectral high-resolution radiation parameterisation must be linked to the climate model. This is currently in progress in several research laboratories supported by the German Federal Ministry of Research under the AFO 2000 programme.

One problem which is much disputed is the influence of interstellar particle currents which depend on solar activity. Some publications show that these particle currents act on cloud cover and could, therefore, exert a profound influence on climate – by around 1.5 watt/m². Other publications question this hypothesis since it has not so far been possible to prove the physical mechanism on which it is supposed to be based. Moreover, the correlation between temperature change and solar cycle has become weaker over the past five years. The particle effect is not currently considered in models as there is not yet any proven scientific basis for this. However, there are plans to test this hypothesis in CERN's radiation laboratory (CLOUD project at: http://xxx.lanl.gov/abs/physics/0104048).

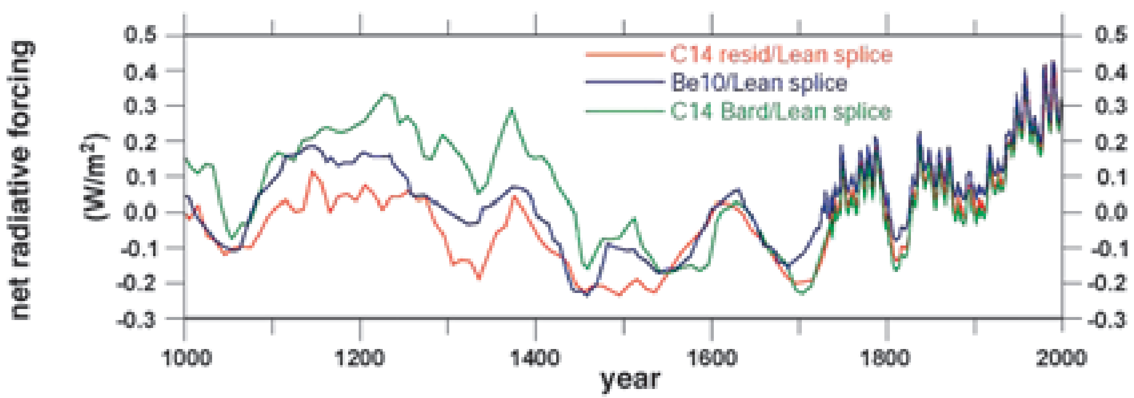


Fig. 1: Example of reconstructions of solar variability (deviation from mean), based on measurements of carbon and beryllium isotopes. They are supplemented, from the mid 1600s, by reconstructions from observations of sunspots and, in the past 20 years, by direct satellite measurements. It can clearly be seen that the reconstructions diverge further from one another, the further one goes back in time and that even differences in sign occur.

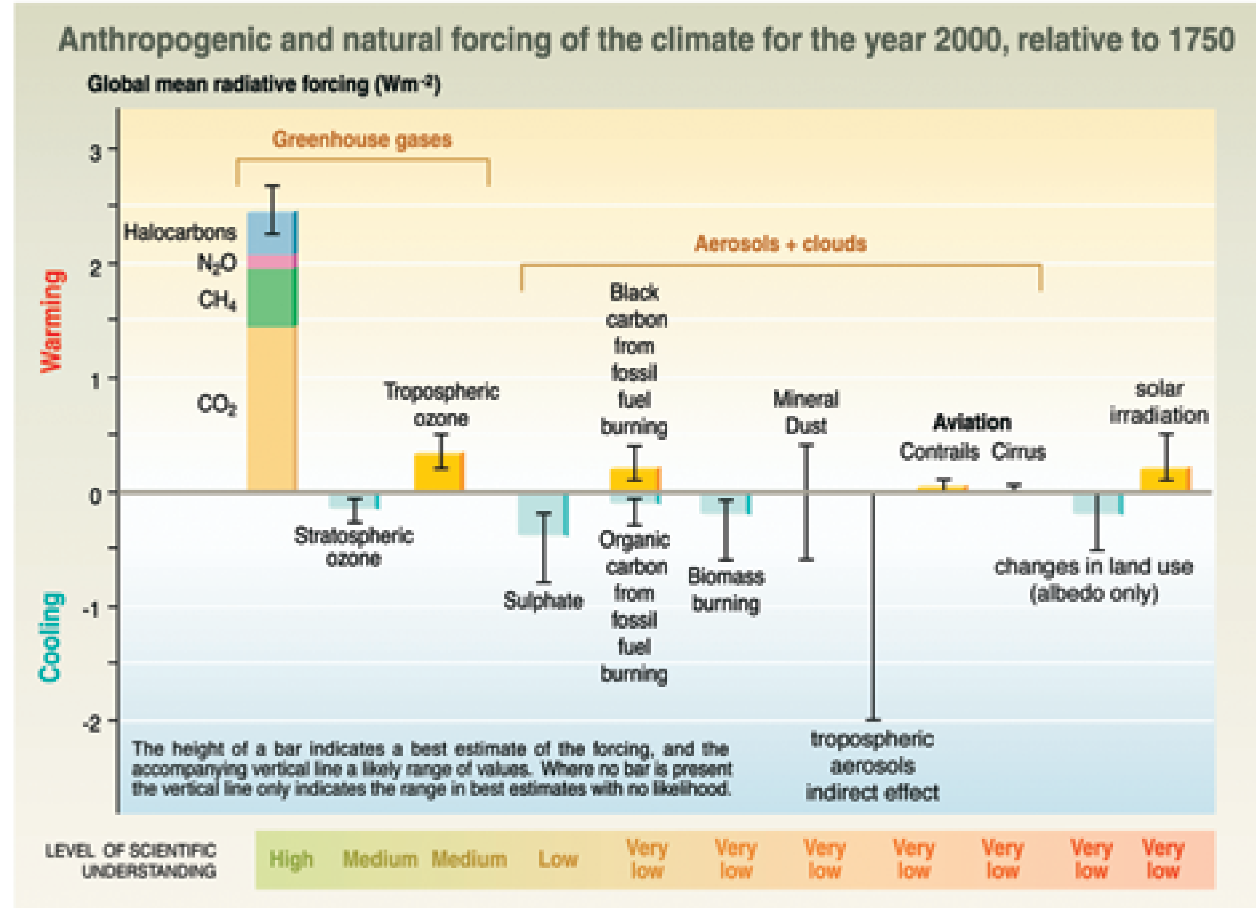


Fig. 2: Radiative forcing of the climate system for 2000, relative to 1750: changes in radiative forcing stem from changes in the composition of the atmosphere, in land use, and solar irradiation. Human activities influence each of these factors – apart from solar activity. The bars in the chart indicate the extent to which individual factors contribute to forcing: some produce a warming, others a cooling effect. Changes in forcing induced by volcanism are only episodic, producing a cooling which lasts only a few years and are therefore not shown here. The vertical line in each bar shows the uncertainty of the estimate. The state of scientific knowledge about the different forcing factors varies as indicated.

The modellers' interest in the role of solar irradiation grew in connection with the issue of anthropogenic influence on climate. They wanted to examine whether observed climate change was caused by (natural) solar fluctuations or by human activity. These changes also take place at timescales which extend beyond the 11-year cycle. The amplitude of the 11-year cycle (around one third of the 80-year Gleissberg cycle) and the proportion of UV (seven percent) are small compared with the uncertainties which arise if solar variability is derived from isotopic time series of beryllium and carbon and from sunspots (fig. 1). For these and also financial reasons, the effects mentioned in the previous section are not explicitly "calculated".

As a result of variations in solar radiation produced by the 80-year Gleissberg cycle, solar irradiation absorbed at the earth's surface varies by 0.50 to 0.75 watt/m². This figure must be viewed in the light of estimates of radiative forcing produced by the increase in anthropogenic greenhouse gases from the pre-industrial period (1750) to the present day - around 2.4 watt/m² (fig. 2).

Calculations with climate models reveal that changes in solar radiative forcing may affect the surface temperature of the earth by several tenths of a degree. However, these calculations also make it clear that changes triggered by the sun are not sufficient to reproduce the warming observed over the past hundred years but only to explain it to some 20 to 30 percent. The most successful approach is to take equal account of solar variability, volcanism, and anthropogenic influence (fig. 3). Another means of establishing the extent to which observed climate change is anthropogenic or solar in origin is the "finger print method". This is based on the fact that the greenhouse effect produces a slightly different warming pattern in the horizontal and vertical line from that generated by increased solar irradiation. Here, too, it is clearly evident that, in recent decades, the anthropogenic pattern prevailed.

So the IPCC comes to the conclusion: “The balance of evidence suggests a discernible human influence on global climate”, continuing: “In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.”

Meanwhile computers have increased in speed to such an extent that the models used to carry out 100-year climate projections five years ago can also be harnessed to simulate the climate processes of the last 1000 years. It is assumed that, at the beginning of this period, man’s influence was minimal from a global perspective. Obviously there are no actual temperature measurements but a wide variety of records (crop yields, dike repair costs, ship sailing times) as well as proxy data (such as tree rings or sediment cores), from which the climate can be reconstructed historically. A study which appeared in 2001 presents a calculation of the climate of the past 1000 years with a one-dimensional climate model, whereby solar activity and volcanism, both derived from proxy data, are prescribed as the forcing influence. This model enables us to simulate global temperature development (Fig. 4).

Three-dimensional Simulations

The same forcing data are being used in the Helmholtz Society’s KIHZ (Climate Change in Historic Times) project by the GKSS Research Centre, with the participation of the Max Planck Institute for Meteorology, to force a complete three-dimensional climate model. Amongst other things, this enables European temperature distribution at the end of the Maunder Minimum to be simulated realistically. A major contributory factor to this “little ice age” appears to lie in the interaction between solar variability, volcanism, and atmosphere-ocean-sea ice coupling.

This kind of three-dimensional simulation offers the opportunity to summarise individual proxy data and portray global climatic connections in chronological sequence. They are therefore of interest not only to climate researchers and geologists but also to academic historians.

If we go further back into the earth’s history, then our calculations have to take account of the alteration in the parameters of the earth’s orbit as well as continental drift. The question then arises as to what feedback mechanisms must be operating to produce major fluctuations in climate, such as ice ages, from changes in radiation. In the past it was only possible to calculate episodes (for example 1000 years Eemian, i.e. the last interglacial period 130,000 years ago) using complete complex models. Due to the lack of processes, less complex models cannot fully reproduce climatic developments. Here, too, the problem of isolated proxy test data arises, which would be better combined using a three-dimensional model. Vast quantities of calculations are required, although comparable in expense with geological field campaigns. One idea is to optimise geological data collection using model calculations. In discussions about climate change, current and future climate are frequently confused. To calculate future climate development, so-called scenarios have been designed which forecast population growth, industrialisation and energy consumption, and energy mix for the next 100 years. These estimates are converted into changes in greenhouse gas concentrations, which are then used to “feed” the climate models. The current scenarios issued by a UN subsidiary organisation provide, depending upon their different guidelines, temperature projections between 1.4 and 5.8 degrees Celsius above present-day levels (Fig. 4). The maximum value in these projections is almost one order of magnitude higher than the figure estimated by supporters of the solar hypothesis for the solar effects of the past 100 years (around 0.6 degrees Celsius), and it also exceeds that reconstructed for the interglacial period during the Middle Ages. Consequently, no argument against taking measures to stabilise greenhouse gases can be derived from the uncertainties surrounding considerations of solar intensity.

Research into anthropogenic climatic influences revealed years ago that more information was needed about solar variability and its impact on climate. As a result, research programmes were developed to trace fluctuations in solar intensity, through further satellite measurements, through improved solar and climate models, and by collecting additional proxy data.

Meanwhile computing power has increased thanks to developments at the German Climate Research Centre financed by the BMBF (German Ministry for Education, Research and Technology). This has made it possible to use finer resolution in the stratosphere, to calculate the chemistry interactively, and to conduct longer simulations. Various BMBF projects (AFO 2000, DEKLIM), as well as EU projects and the HGF’s KIHZ project are bringing modellers and geologists together, thereby creating the conditions for adopting an interdisciplinary approach to climatic issues. In addition, projects are planned which aim to discover the interplay between the interstellar particle stream and climate.

It will be a few years before definite answers are available to all the issues associated with climate, sun, and man. In this research field, as with every scientific discipline, individual results and working hypotheses must continuously be examined. The naïve – or deliberate? – misinterpretation of this critical research together with the mixing up of “hypotheses” and “facts” has recently led to some confusion and created the erroneous impression that climate research and its findings, as a whole, should be questioned.

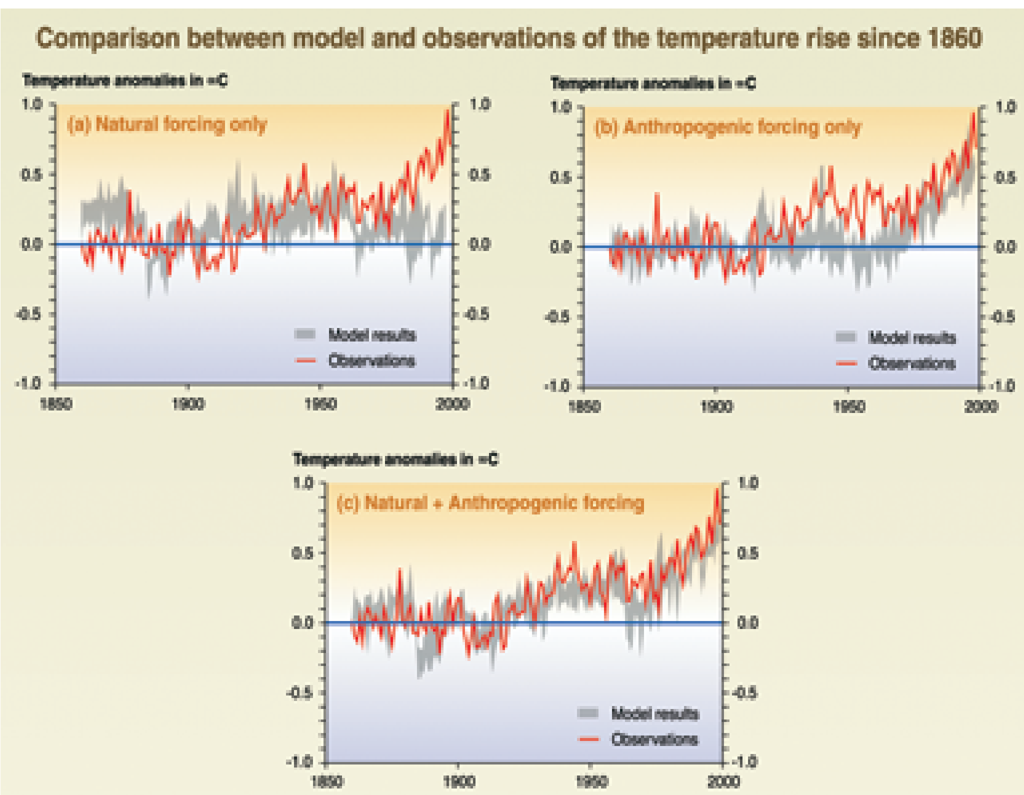


Fig. 3: Climate models can be used to produce separate calculations for temperature changes due to natural and anthropogenic causes. Fig. 3a shows changes due only to natural forcing, i.e. solar variability and volcanism. Fig. 3b indicates the impact of anthropogenic factors (greenhouse gases and sulphate aerosols). Fig. 3c represents changes due to both natural and anthropogenic factors. The blue band expresses model projections including an estimate of their uncertainty, the red curve the climate changes observed. The best approximation to the observation curve is obtained if both anthropogenic and natural forcing factors are considered.

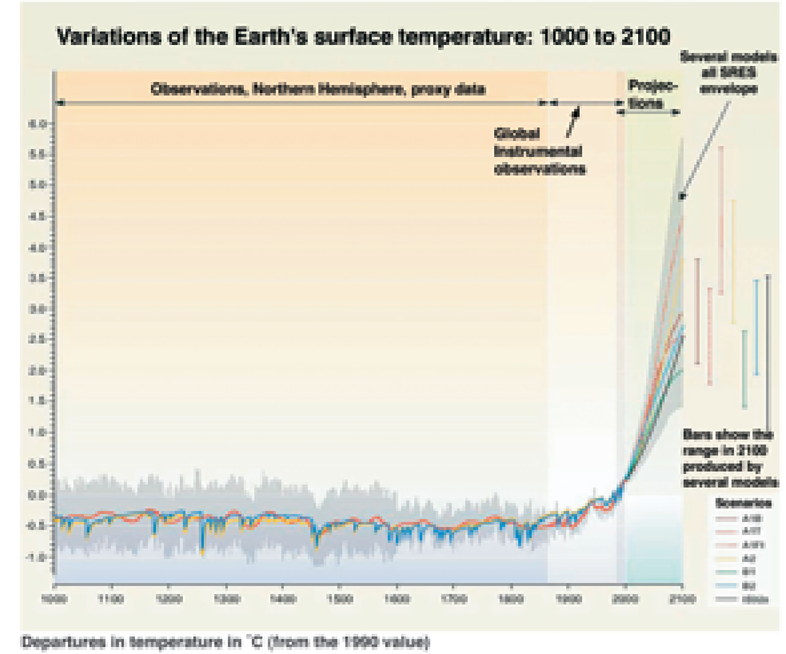


Fig. 4: Change in globally averaged near-surface temperature in relation to the year 1990. Between the years 1000 and 1860, only the mean for the northern hemisphere was calculated as too few data are available for the southern hemisphere. The data for this period were derived from tree rings, corals, ice cores and historical records.
The red line shows the 50-year mean, the grey band the 95 percent confidence interval of the annual data. Between 1860 and 2000, values measured by instruments are shown, the red line shows the 10-year mean. Between 1990 and 2100, the temperature projection for six standard SRES scenarios is shown as well as the IS92a scenario from the penultimate IPCC report based on a model of mean climate sensitivity. The grey band marked “all scenarios, all models” shows the result band width if all 35 SRES scenarios and all the various models are taken into account.
Also marked: the result of two simulations with a result balance model (blue and beige curve), which use the various estimates (14C, 10Be) for solar fluctuations and volcanism and the observed CO_2 concentration as input parameters. The short-term negative temperature variations due to volcanism and the increase at the end of the 20th century can clearly be identified.

Dr. habil. Ulrich Cubasch heads the "Models and Data" group at the Max Planck Institute for Meteorology in Hamburg. His interests lie in calculating, as realistically as possible, past and present climatic fluctuations by means of three-dimensional models of the climate system and using these models to produce projections of future climate change. Cubasch was in charge of drafting the reports of IPCC research group I – "The scientific basis of climate change" – and is co-author of the book "Anthropogener Klimawandel". The "Models and Data" group is a project sponsored by the BMBF to support climate research in Germany.