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Climate sceptic arguments and their scientific background

Climate change facts compiled by ProClim

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Introduction

Research on anthropogenic global warming was intensified following the first IPCC assessment report published in 1990. This concluded that there might be an influence of anthropogenic greenhouse gases on the temperature at the Earth's surface. Since that time numerous international and national scientific research programs and thousands of individual projects have been undertaken, strongly improving the knowledge about the climate system, its changes and influencing factors. However, due to the complex characteristics of the climate system there are still important unknowns and uncertainties concerning past and future evolution of the climate. These open questions are discussed in the scientific community and are the topic of extensive ongoing research activities. Given current understanding, however, it is possible to make estimates of the probable future evolution of climate, depending on the amount of greenhouse gases emitted in the course of this century.

The fourth assessment report of the Intergovernmental Panel on climate change (IPCC 2007) has summarised the current scientific understanding of the climate system, its processes and the anthropogenic influence on this system. It concludes that anthropogenic activities (emission of greenhouse gases and land-use changes) are very likely the dominating origin of the global temperature increase and the related changes in the climate system observed over recent decades. It further concludes that these changes will continue in the future if there will not be a substantial reduction of global greenhouse gas emissions.

The already observed, and especially projected future climate change, has important impacts on the natural environment and human society and therefore implies the need for extensive mitigation and adaptation measures. These measures, for example, the reduction of energy consumption, have considerable social, political and economic consequences. Because of their broad impact these issues have led to significant interest in the topic, including many studies – not all scientific – opposing the view of an anthropogenic influence on climate. Since the physics, the characteristics and the interactions in the climate system are complex, it is quite difficult for the public to identify the sound scientific arguments that are based on facts.

This fact sheet gives an overview of the main "climate sceptic" arguments and their scientific background. The arguments are grouped in three different categories:
A) Global warming, B) Forcing factors, C) Carbon dioxide (CO_2).

Topics/Arguments:

A) Global warming:

- A1 Global temperature cannot be calculated because of unreliable measurements
- A2 Global warming is an artefact of the Urban Heat Island effect
- A3 The most important argument of IPCC (Mann et al. "hockey stick" curve) has proved to be incorrect
- A4 Satellite data show no warming of the troposphere in contrast to model predictions
- A5 Sea level isn't rising everywhere
- A6 There is no apparent increase of extreme events
- A7 In earlier times the climate was much warmer than today

B) Forcing factors:

- B1 Other factors have potentially caused the present warming
- B2 Water vapour is the most important greenhouse gas, CO_2 is unimportant
- B3 Climate change is driven by the sun
- B4 Climate change is driven by cosmic rays
- B5 Anthropogenic CO_2 emissions are much smaller than natural CO_2 emissions
- B6 Volcanoes emit more greenhouse gases than human activities
- B7 There was global cooling between 1940 and 1970 although CO_2 concentration increased

C) Carbon dioxide (CO_2)

- C1 CO_2 measurements in ice cores are not reliable
- C2 CO_2 increase is just the result of temperature change
- C3 CO_2 is just a fertiliser for plants and therefore positive
- C4 The observed increase in CO_2 is much smaller than assumed in climate models
- C5 The greenhouse effect of CO_2 is small because CO_2 absorption bands are saturated

A1 Global temperature cannot be calculated because of unreliable measurements

Argument:

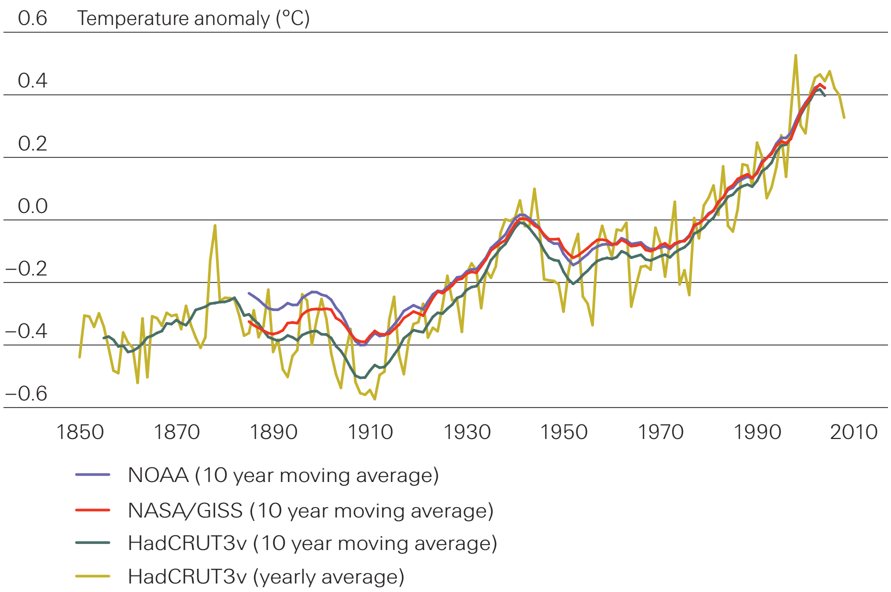
Global temperature values are very uncertain because many measurements are not very reliable and have been measured in different environments (eg height above sea level (asl) or urban heat island).

Discussion:

The global temperature anomalies are calculated from temperature anomaly data at a set of stations. For each station included in the analysis, the difference of the measurements to the average of a normal period of 30 years is calculated individually. This means the absolute temperature values are unimportant; only the difference from the mean value is used for the calculations. Therefore systematic errors or deviations, such as height asl, in the measurements of a station, have no influence on the calculation of global mean temperature, as long as the error or deviation remains constant over time.

However, data is collected and recorded by thousands of individuals with equipment and procedures subject to change over time. The data sets are corrected for known errors and inhomogeneities, but inevitably contain errors and inconsistencies. All data sets are compared to their neighbouring stations to detect unusual behaviour and external influences. It is likely that at least part of undetected measurement errors cancel each other out. Nevertheless, the global maps of temperature change illustrate, that the analysed temperature changes generally have a clear physical basis associated with large-scale climatological patterns, and the greatest changes occur in remote locations where effects of local human influence are minimal. Moreover, three independent calculations of global temperature with different procedures, corrections etc. show a coherent pattern of trends and variations (see figure 1). All this strongly suggests that the influence of error, be it in measurements, analysis, corrections or computer coding, is not dominant, or that the random component of such errors tends to average out in large area averages and in calculations of temperature change over long periods.

Figure 1:
Global surface temperature anomalies (10-year moving average) from three independent calculations: the CRU (Univ. of East Anglia), the NASA/GISS and the NOAA data sets, respectively. For the CRU data also the yearly means are presented. The anomalies are respective to the 1961–1990 average (=0°C line). Data sources are CRU (Jones and Moberg 2003), NASA (Hansen et al. 2001, Reynolds et al. 2002) and NOAA (Quayle et al. 2005), respectively.



Moreover, data sets of cities are corrected for the Urban Heat Island effect, although the urban stations have little influence on the global temperature change (Hansen et al. 2001, Peterson 2003, Parker 2004).

Conclusion:

There are many possible reasons for measurement errors in individual measurements, but there are a number of methods to reduce their impact, by using anomalies, spatial comparison, comparing different data sets, etc. This allows the uncertainties of global temperature calculations to be restricted to a level much smaller than the detected long-term trends.

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A2 Global warming is an artefact of the Urban Heat Island effect:

Argument:

The warming of the global average surface temperature is an artefact due to the well-known Urban Heat Island Effect (UHI). The UHI describes how the temperatures in big cities are higher than in the surrounding areas due to the heat absorption of buildings and streets. It is claimed that the cities have grown and therefore increased UHI is responsible for the observed warming.

Discussion:

The existence of the UHI is an undisputed fact. However, the claim of its influence on the global temperature rise is based only on the possibility of an influence. It has never been shown in a thorough analysis. Global temperature records are corrected for the UHI, as far as this is necessary [IPCC 2007, ch. 3.2.2.2]. There are a number of independent reasons, why the influence of the UHI on global temperature trends is most probably very small (< 0.002ºC per decade since 1900 [IPCC 2007]) or negligible:

- The relatively strong correlation between observed decreases in the daily temperature range, with increases of both precipitation (leading to more moist surface conditions) and total cloud amount, support the notion that the reduction in diurnal temperature range is in response to these physical changes and not due to the UHI, which could also reduce daily temperature range by heating cities in the night.
- Over the Northern Hemisphere land areas, where urban heat islands are most apparent, both the trends of lower-tropospheric temperature and surface air temperature show no significant differences. In fact, the lower-tropospheric temperatures warm at a slightly greater rate over North America (about 0.28°C/decade using satellite data) than do the surface temperatures (0.27°C/decade). [IPCC 2001, chpt. 2.2.2.1]
- Land, sea, and bore hole records are in reasonable agreement over the last century [IPCC 2001]
- The trend at rural stations is only 0.70°C/century from 1880 to 1998, which is actually larger than the full station trend (0.65°C/century) [Peterson et al., 1998]
- The attempt to adjust trends in urban stations around the world to match rural stations in their regions showed that in 42% of the cases, the cities were getting cooler relative to their surroundings rather than warmer. [Hansen et al. 2001]
- There seems to be hardly any contamination of urban in situ stations by urban warming. No statistically significant impact of urbanisation could be found in annual temperatures. There is a tendency of surrounding rural stations to be slightly higher, and thus cooler, than urban areas. Many sections of towns may be warmer than rural sites, but meteorological observations are likely to be made in park “cool islands”. [Peterson, 2003]
- If the urban heat island theory were correct, then instruments should have recorded a bigger temperature rise for calm nights than for windy ones, because wind blows excess heat away from cities. There was no difference between the calm and windy nights. Globally, temperatures over land have risen as much on windy nights as on calm nights [Parker, 2004].

Conclusion:

The Urban Heat Island effect is real but has a negligible influence on the observed global temperature trend (< 0.002ºC per decade), as has been concluded from a number of control analyses.

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Hansen J, R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, T. Karl (2001): A closer look at United States and global surface temperature change. *J. Geophys. Res.* 106(D20), 23947–23963.

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A3 The most important argument of IPCC (Mann et al. "hockey stick" curve) has proved to be incorrect

Argument:

It is claimed that two groups of scientists (McIntyre and McKitrick 2005, McIntyre and McKitrick, Soon and Baliunas 2003) have proven the paper cited in the IPCC report from Mann et al. (1998) is incorrect. They further claim that therefore the main argument of the IPCC for the anthropogenic influence is not valid anymore.

Discussion:

The scientific discussion about the methods and the data used by Mann et al. is a normal scientific process to improve knowledge. However, it has been shown that the points of critique in the cited papers do not affect the results of Mann et al. in a relevant way (von Storch and Zorita. 2005). The alternative results presented by McIntyre/McKitrick as well as by Soon/Balliunas were shown to be biased by omitting relevant data and application of inappropriate methods (Mann et al. 2003, Bradley et al. 2003). While independent calculations confirm the results of Mann et al. (Rutherford et al., 2005), the results of McIntyre/McKitrick (2003) show a warm period in the 14/15th century, ie during the beginning of the Little Ice Age. This is in contrast to all other independent reconstructions.

Apart from this discussion von Storch et al. (2004) have published a critique of the Mann et al. study claiming that their calibration method underestimated the long-term variability. However, Wahl et al. (2006) demonstrated that this critique was based on an erroneous application of the Mann et al. method. In their reply, von Storch et al. (2006) admitted the error, but claimed that an additional analysis supported the original critique. However, this additional analysis did not address the Mann et al. method, but the quality of the input data. Moreover, Rahmstorf (2006) highlighted that a second model only shown in the supporting online material of von Storch et al. (2004) showed much better agreement with the Mann et al. result than the model shown in the paper.

A recent review of the National Research Council (NRC 2006) has stated that some of the methodological choices in Mann et al. could have been better, but that they were quite plausible at the time when the work was done and that possible improvements do not have a material effect on the final conclusion.

Furthermore, the Mann et al. reconstruction is not a crucial point for the attribution of climate change to anthropogenic greenhouse gas emissions. There are a number of other arguments which – taken together - lead to the conclusion, that the anthropogenic influence is probably the most important reason for the warming of the last few decades, eg patterns of temperature changes, changes of extreme temperatures (Christidis et al. 2005), changes of incoming and outgoing radiation (eg Harries et al. 2001, Philipona et al. 2004, Philipona et al. 2005), changes of natural forcing factors (eg Ammann et al. 2007, Lockwood et al. 2007) or different model simulations (eg Meehl et al. 2003, Shindell et al. 2001) which all indicate a strong influence of the anthropogenic greenhouse effect on the warming of the last few decades (IPCC 2007). Thus even if the claims were true, this would not alter the IPCC conclusions and the projections of future warming, because the projections are based on physical modeling and not on extrapolation of past variability.

While the Mann et al. reconstruction was the most extensive reconstruction available at the time of the preparation of the IPCC report 2001, it is certainly not the last word concerning the climate of the last millennium. Additional temperature reconstructions were also included (IPCC 2001). For all existing reconstructions there are open questions concerning the included data (eg possible changes of the proxy – temperature relationship over time) as well as concerning the calculation methods (statistical methods, calibration, etc.). Nevertheless, several other reconstructions using other data and methods have shown more or less the same pattern with relatively warm conditions in the medieval times, colder conditions during the Little Ice Age a few hundred years ago and a rapid warming during the 20th century. None of the recent reconstructions contradict the IPCC statement that the 1990s were the warmest decade of the last millennium. However, the extent of natural climate variability during the last 1000 years is still under discussion, and results vary between about 0.5 and 1.0 ºC (see Figure 2).

In the meanwhile Mann et al. have published a new improved reconstruction based on a broad combination of data sets and using different methods. They have also compared tree ring data vs. non-tree ring data. This new reconstruction shows more long-term variability than the old "hockey stick" reconstruction, but is in line with the other reconstructions and the interpretations of the IPCC (Mann et al. 2008).

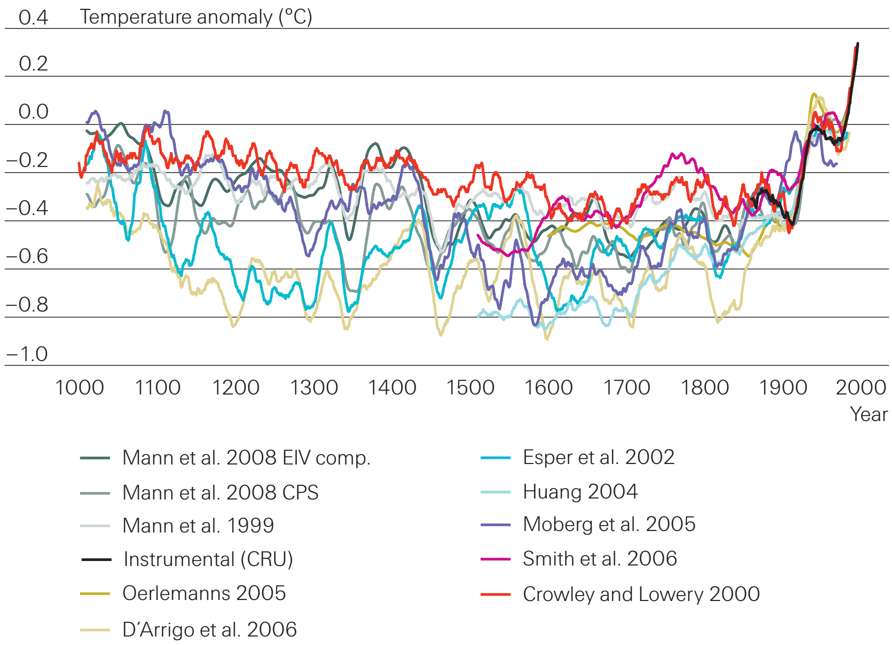

Figure 2:
Different reconstructions of the northern hemispheric temperature for the last 1000 years. The reconstructions are based on a combination of tree ring, ice core, coral, sediment and historical data (Mann et al. 1999, Crowley and Lowery 2000, Mann et al. 2008), borehole data combined with tree ring, ice core and coral data (Huang 2004), glacier length (Oerlemans 2005), sediment and tree-ring data (Moberg et al. 2005), and speleothem layer thickness (Smith et al. 2006). Two reconstructions are from extra-tropical tree-ring data only, using the regional curve standardization method (Esper et al. 2002, D'Arrigo et al. 2006). Some reconstructions have been adapted to the 1961-1990 normal period. The index data from Esper et al. 2002 has been calibrated against the instrumental data. For the Mann et al. 2008 reconstruction, the combined land+ocean series of the northern hemisphere are shown for two different scaling methods ("EIV" and "CPS"). All reconstruction data is from the World Data Center for Paleoclimatology of NCDC/NOAA. Instrumental data is from the Climate Research Unit (CRU), University of East Anglia (Moberg and Jones 2003).

Conclusion:

The Mann et al. "hockey stick" reconstruction of 1998 is one of many reconstructions of climate variability over the last millennium and shows consistent results. The reconstruction contains usual uncertainties, and evokes normal discussions about the methods applied. However, neither the notion of man-made climate change nor projections of future climate change are based on the results of the Mann et al. study. Today there exist many reconstructions using very different proxy data and analysis methods, which do not contradict the main conclusions drawn earlier. Normal scientific progress since 1998, including improvement of methods and inclusion of much more data, suggests that the long-term variability is somewhat larger than previously thought.

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A4 Satellite data show no warming of the troposphere in contrast to model predictions

Argument:

Although climate models predict that the temperature in the troposphere should warm slightly more than at the surface due to the greenhouse effect, it is argued that satellite measurements and radiosondes show no significant warming in the troposphere, This discrepancy is used either to demonstrate that there isn't any warming at all and surface warming is incidental or to point out the inability of current climate models to reproduce the actual development of the temperature.

Discussion:

The reconstruction of atmospheric temperatures from satellite data (Microwave Sounding Units, MSU) is complicated by several factors, especially for tropospheric temperatures from MSU channel 2 (Mears and Wentz 2005):

- the life time of satellites is only a few years. This means long term trends have to be composed of data sets from different satellites (nine until 2005) with different instrumentation. Trends therefore depend on the procedures used to merge these data sets.
- 10–15% of the MSU channel 2 signal used to derive tropospheric temperatures, arises from the stratosphere. Since the stratosphere is cooling more rapidly than the troposphere is expected to warm, a considerable part of tropospheric warming might be cancelled.
- All satellites slightly change their local equator crossing time and exhibit a decay of orbital height over time. Spurious trends can therefore be caused by slight changes in the satellite's local measurement time, and therefore shifts over the diurnal cycle.

There are different ways of accounting for all these factors which both influence the resulting trend and increase related uncertainties. (Santer et al. 2003).

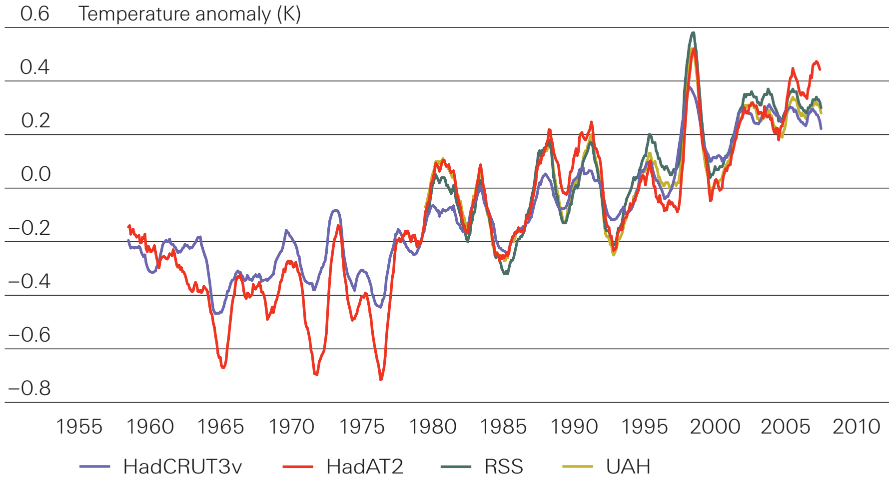
For several years the analyses of satellite temperatures of the group at the University of Alabama (UAH, University of Alabama Huntsville, Spencer and Christy) was the most important reference. Their analysis first showed no warming in the troposphere. After correction for orbital decay of satellites in 1998 there was a warming trend of ~0.04ºC per decade from 1979–2000 (Christy et al. 2000). Since 2003 other groups have made independent analyses of MSU data resulting in warming trends of 0.11ºC (Mears et al. 2003), 0.20ºC (Fu et al. 2004), and 0.22–0.26ºC per decade (Vinnikov and Grody 2003). Including additional data, the 1979–2004 trend of UAH had increased to 0.08º per decade.

In 2005 an error in the UAH data set concerning the correction for the diurnal cycle effect was detected. This error mainly affected the tropical troposphere, where the biggest differences between measurements and model results had occurred. The corrected data set exhibits a global trend which is 50% higher than before and also shows a warming of the tropical troposphere (UAH 2005). However, there are still some unresolved problems with the UAH dataset:

(1) Corrected UAH data still shows an odd annual cycle over the Antarctic (Swanson 2003)
(2) Difference between the UAH and the other trends mainly comes from the first 4 years (1979–1982), while after 1983 the UAH trend is similar to the others (see Figure 3).

Current data sets now show a global average warming from 1979-2006 of the lower troposphere from satellite data of 0.14ºC (UAH), and 0.18ºC (Remote Sensing Systems RSS; Mears and Wentz 2005), respectively. Considering the data uncertainty of these trends of ±0.09ºC (Mears and Wentz 2005), and the remaining problems of the dataset with the lowest trend, there is no apparent difference of troposphere temperature trends to the surface warming of 0.17ºC per decade, during the period 1979-2006 or to climate model calculations.

Figure 3:
Global lower troposphere temperature anomalies (relative to 1979-1998), based on radiosonde data (HadAT2, Thorne et al. 2005; vertically weighted to create MSU-equivalent time series) and satellite MSU data (UAH, Christy et al., 2000; and RSS, Mears et al. 2003) compared to global surface data (HadCRUT3, Brohan et al. 2006).



The analysis of global troposphere temperature trends from radiosonde data is even more complicated than from satellite data:

- the spatial density of radiosonde data is very inhomogeneous, there is especially limited data over the oceans
- the difference of instrument types, configuration, observation practices and data handling of radiosondes is quite marked
- the homogenisation of radiosonde time series data is very difficult because of missing or useless station history and due to high temporal variability compared to the length of the time series. Numerous apparent artefacts have been detected in radiosonde data series (Lanzante et al. 2003)
- the problem of daytime heating of the instruments is well-known, but unresolved. However, correction methods for this bias have improved over time, which probably leads to an artificial cooling trend due to the reduction of this uncorrected error (Sherwood et al. 2005)

Previous analyses of radiosonde data have shown a discrepancy to the warming expected by model calculations, mainly in the tropics. Recent analyses present evidence that the difference to model data might be an artefact of systematic reductions of the error due to solar heating of temperature sensors (Sherwood et al. 2005). Differences in trend of daytime compared to nighttime in radiosondes have been detected, especially in the tropics. The characteristics of the different evolution of day time and night time data, as well as physical considerations, suggest that these differences are an artefact, probably due to improvement of data correction (see above). The estimated error due to this artefact alone is of sufficient magnitude to explain differences between troposphere and surface temperature trends (Sherwood et al. 2005). A recent review of the radiosonde data shows trends which are in line with the development at the surface, ie 0.15ºC per decade since 1958 (compared to 0.13ºC at surface) and 0.16ºC per decade since 1979 (compared to 0.17ºC at surface), (Thorne et al. 2005). The NOAA (U.S. National Oceanic and Atmospheric Administration) analysis of radiosonde data shows a trend of +0.19ºC per decade for the period 1976-2006 (NOAA 2007), which is somewhat higher than the surface trend.

After the inconsistencies of global satellite data sets and climate models have been taken into account it has been claimed, that there is still a discrepancy between satellite data and climate models in the tropical atmosphere (Douglass et al. 2008). However, this claimed discrepancy only emerges if statistical uncertainty in observed temperature trends arising from inter-annual temperature variability is neglected, and inappropriate metrics for statistical significance are used. In addition, new and improved analysis of measurements shows only very small and insignificant differences between observations and model results in the tropics.(Santer et al. 2008).

Conclusion:

All observational data sets and model results are consistent regarding the relationship of temperature variations and trends between the surface and the troposphere, on the monthly to annual time scale, including the tropics. Some differences remain on the decadal time scale from models to the UAH data and the radiosonde data, if the latter is not corrected for the instrument heating bias (Santer et al. 2005).

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A5 Sea level isn't rising everywhere

Argument:

It is argued that in some locations, measurements show no sea level rise (eg Tasmania or Tuvalu).

Discussion:

Global average sea level has risen by about 17 cm over the 20th century. The rate of sea level rise has increased in the course of the 20th century and is estimated to be 1.8 cm per year on average between 1961 and 2003 (IPCC 2007).

Sea level changes are mainly determined by tide gauges and satellite altimetry. For interpretation there is a distinction between sea level change, because of vertical shift of the coast lines (due to tectonic movements) and the change of water mass in the oceans (due to melting of land ice) or the change of water volume (due to thermal expansion). To detect the effects of global warming on sea level, tide gauge data has to be corrected for tectonic shifts. Sea level changes are also recorded by satellites which can give an integral measurement over the globe. Satellite measurements (Leuliette et al. 2004) show a slightly higher positive sea level trend than tide gauges (Holgate and Woodworth 2004, Church et al. 2004). A combination of both data sets shows an acceleration of global sea level rise (Church and White 2006).

Sea level does not change uniformly over the globe (Lombard et al. 2005). Sea level is influenced by several factors, eg atmospheric and ocean circulation. Thus sea level changes differ from station to station, so a station with a different trend than the global mean does not contradict the overall global trend of mean sea level. Especially in the tropical and southern Pacific, sea level is also influenced by El Niño, which can alter the trends on time-scales of a decade or so. Tide gauge measurements at Tuvalu, which show no significant trend over the last one or two decades, change to a sea level rise of about 1.2 mm per year if corrected for El Niño effects (Patel 2006).

Conclusion:

As for temperature increase, sea level rise is not uniform over the globe and thus local measurements are not expected to represent the global trend. Tide gauge as well as satellite measurements consistently show that sea level has risen over the 20th century and the rate of that rise is increasing.

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A6 There is no apparent increase of extreme events

Argument:

There hasn't been any significant increase of extreme events until now, although this is projected for a warmer world.

Discussion:

The detection and attribution of changes in extreme events is indeed very difficult. This is because extreme events are by definition very rare and their limited number is insufficient for appropriate statistical analysis. Thus the change has to be very large to get a statistically significant signal. For example, for regional events with a return period of one year, a trend could only be detected if the event probability has doubled over a century (Frei and Schär 2001). For more rare events with return periods of decades the change has to be even stronger. The only possibility to detect trends in extreme events would be to add together different kinds of events and large regions. It is delicate, however, to summarise different event types with different processes and developmental paths involved, eg storms and floods. For the very rare events there have to be huge frequency changes (increases of several 100%) until such trends will get statistically significant. However, for less rare events (eg exceeding the 90% percentile) trends can be observed more easily and also attributed to anthropogenic climate change. There have been a number of studies which show that there have been changes in aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones at continental, regional and ocean basin scales. There has been an increase of heavy precipitation events and areas affected by droughts since 1950. [IPCC, 2007]

The projected increase of extreme events is mainly based on the knowledge of atmospheric physics. It is known that water vapour saturation pressure increases with temperature, which means that warmer air can contain more water and thus produce more intense precipitation. It is also known that warmer air enhances evaporation and therefore intensifies the hydrological cycle. Moreover, warmer air can take up more latent energy, increasing the potential maximum strength of storms.

Extreme events are never the result of only one cause, but they are the consequence of the coincidence of several factors and conditions. Thus global warming cannot "cause" an extreme event, but it can change the probability of occurrence of such events by alteration of the involved factors and processes. One detection and attribution study has shown that anthropogenic global warming has increased the probability of occurrence of a summer heat wave as observed in Europe 2003 by 50%. There are indications of a link of the recent increase in Atlantic hurricanes to global warming, since this increase has been linked to the increase of sea surface temperatures (SST) in the main development region (Emanuel 2005, Webster et al. 2005, Hoyos et al. 2006) on the one hand and the attribution of these SST increases to anthropogenic greenhouse gases. (Trenberth and Shea 2006).

The investigation of extreme events by looking at trends of damages is rather difficult, because other factors influence the evolution of damages like changes of socio-economic factors, (strong increase of buildings in endangered areas, population growth, prediction and warning possibilities, evacuation possibilities, improved building, flood control, disaster awareness etc). There are, however, results which point to a trend besides economic evolution: weather-related losses have been increasing much faster than population and non-weather-related events. Specific event types have increased much more quickly than average (Mills 2005).

Conclusion:

Since trends of very rare events have to be very large to produce a statistically significant signal, a detection of a human signal cannot be expected for some years. For somewhat more frequent extreme events like major hurricanes, heat waves or heavy precipitation events a signal has recently been detected.

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A7 In earlier times climate was much warmer than today

Argument:

The Climate was much warmer in the past and CO_2 concentrations have been much higher than today. Therefore this is natural and not harmful.

Discussion:

It is well documented and not disputed that there have been epochs with warmer temperatures and higher CO_2 concentrations than today. During the last interglacial (125 000 years ago), while global temperatures were not much higher than today, average polar temperatures were about 3 to 5ºC warmer, leading to a sea level rise of 4 to 6 meters (IPCC 2007). In the early to mid-Pliocene (4.5 to 3 Million years ago) global temperatures were about 3ºC warmer than today (Ravelo 2004), with CO_2 concentrations estimated between 360–400 ppm (eg Raymo et al. 1996) and sea level at least 20m higher (eg Shackleton et al. 1995).

About 55 million years ago the climate was considerably warmer than today, high latitudes were ice-free with polar winter temperatures ~10ºC warmer than at present (Pagani et al. 2005). CO_2 concentrations were at about 1000 to 1500 ppmv. This means a sea level about 70 meters higher than today. Possible reasons are a feedback effect through release of methane from methane hydrates on the sea floor. The shift to this warmer climate changed the behaviour of ecosystems world-wide (Bowen et al. 2004, Harrington et al. 2004). The shift to an "ice house stage" at about 34 million years ago was possibly through a CO_2 decrease due to enhanced chemical weathering, with the building of the Himalaya and increased biological productivity. (Tripati et al. 2005)

The fact that the climate changes substantially due to natural reasons does not mean that it cannot change for anthropogenic reasons. Conditions of the earth in a warmer climate as reconstructed from the past may also be very inconvenient for our civilisation. For example, it would be difficult to adapt to a sea level rise of several tens of meters.

Furthermore, the problem is not a different state of the climate, but the process of climate change, especially the rate of change. The rate of warming on the global scale that is projected for the 21st century is far above what has been observed in the past: the warming of several degrees 55 million years ago took place over a period in the order of 10 000 years (Zachos et al. 2003, Tripati and Elderfield 2004). The warming after the last ice age, which is in the same order of magnitude, a few degrees Celsius, took place over several thousand years instead of one hundred years as expected for the current warming.

Humankind can't do anything against natural climate change. However, natural changes normally are much slower and therefore easier to adapt to. It does not seem advisable to induce an artificial and disadvantageous change to the Earth's climate.

Conclusion:

The fact that climate has changed for natural reasons does not exclude the possibility of an anthropogenic influence. The projected changes on the global scale due to enhanced greenhouse gas concentrations are much faster than any natural changes observed in the past. The problem is not a possible new state of the climate system but the enormous challenge of human civilisation adapting to this new state.

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B1 Other factors have potentially caused the present warming

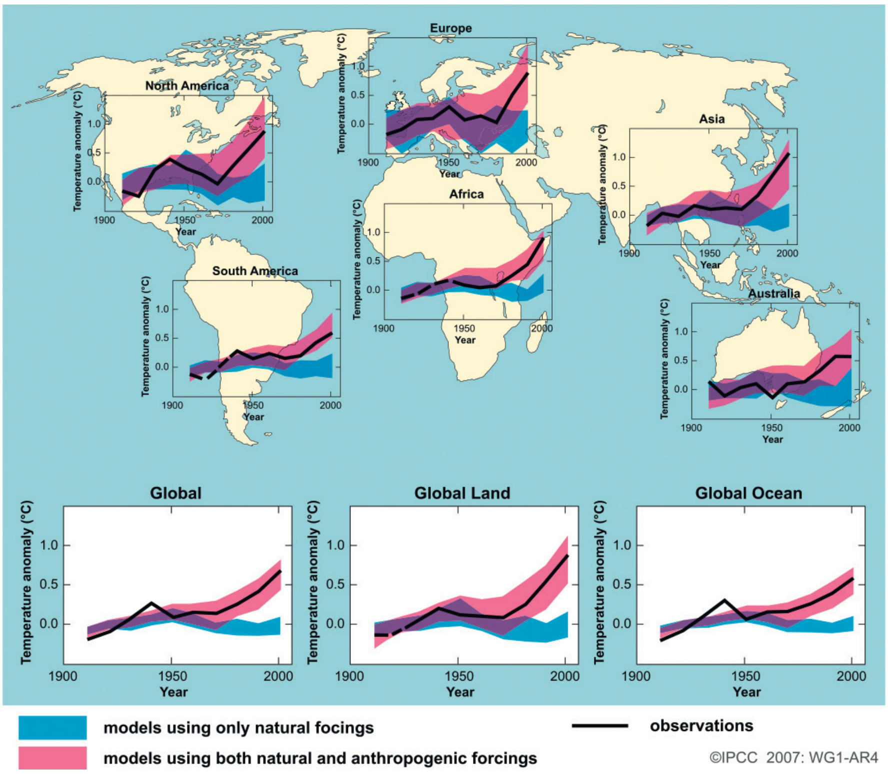
Argument:

There have always been climate changes without human influence and therefore other factors could be causing the present warming, such as changes in solar irradiance or cosmic ray flux. It is further claimed that CO_2 is only given as the primary reason because the other factors are not understood.

Discussion:

It is well-known that the climate has changed in the past as well as that there are many factors influencing climate on various time-scales. However, the fact that there are natural changes does not rule out the possibility that an artificial increase in greenhouse gas concentration can also change the climate.

Figure 4:
Global and continental temperature change. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906 to 2005 (black line) plotted against the centre of the decade and relative to the corresponding average for 1901–1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5–95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5–95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings.



There are several reasons, why it is likely that the recent warming is due to anthropogenic greenhouse gas increase:

- All known natural factors influencing climate either act on much longer time-scales (shift of continents on tens of millions of years, orbital parameters which cause ice age cycles on tens of thousands of years) or have not changed significantly over the last few decades (solar irradiance, cosmic ray flux, volcanic activity). There is no known natural factor whose recent evolution could explain the recent warming.
- Calculations of climate models, which are able to reproduce the climate of the recent past, can only simulate the recent warming if the effect of anthropogenic greenhouse gases is taken into account. Natural factors alone would lead to a slight global cooling over the last decades (Ammann et al. 2007).
- Due to the widespread pattern of recent warming, over land as well as in the ocean, (Barnett et al. 2005) together with ice mass losses from glaciers (Oerlemann 2005), arctic sea ice and Greenland ice sheet (Rignot and Kanagaratnam 2006), it is very unlikely that the warming is due to internal climate variability.
- The observed patterns of changes are similar to what would be expected from an enhanced greenhouse effect: warming of the troposphere vs. cooling of the stratosphere, stronger warming during night-time than during day-time, spatially uniform warming in contrast to the more heterogeneous warming from solar forcing (eg Meehl et al. 2003).
- Direct measurements of radiation show an increase of long-wave radiation at the surface for clear-sky conditions (Philipona et al. 2005) which can only be due to greenhouse forcing, and of the Earth's outgoing long wave radiation due to greenhouse gas increases (Harries et al. 2001).

Moreover, no reason has been presented why a remarkable increase in greenhouse gas concentration should not lead to a warming of the lower atmosphere in contrast to established physical knowledge and experiments.

Conclusion:

According to present knowledge of physical processes in the climate system there is no known factor other than rising greenhouse gas concentrations which could explain the warming of the recent decades. Additionally, spatial patterns of warming clearly point to greenhouse gases as the source of warming.

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B2 Water vapour is the most important greenhouse gas, CO_2 is less important

Argument:

Water vapour is a more important greenhouse gas than CO_2, a fact neglected by climate scientists.

Discussion:

It is well-known that water vapour is an important greenhouse gas. The greenhouse effect of water vapour is included in all climate calculations, estimates, and climate models.

It is acknowledged that water vapour is the principle absorber of long-wave radiation emitted from the earth's surface, besides clouds (which are not a gas) and CO_2. Water vapour represents about 0.3% of atmospheric mass – CO_2 about 0.06% – and thus 80% of all greenhouse gases by mass. However, the importance for absorption of radiation is less important, because the molecules have different absorption qualities.

The fraction of absorption of the different components cannot be determined exactly, because the absorbing spectra overlap, ie the radiation of a certain frequency can be absorbed by different gases or clouds. With radiation models, it is possible to determine the minimum absorption, ie the decrease of absorption if this particular gas would be removed from the atmosphere, and the maximum absorption, if only this particular gas would be in the atmosphere. The fraction for water vapour is between about 35 (minimum) and 65% (maximum absorption), for CO_2 between about 10 (min.) and 25% (max) (Ramanathan and Coakley 1978). These numbers refer to the whole present-day greenhouse effect of 33ºC, i.e. natural plus anthropogenic effects.

However, the above numbers and weights of influence reflect steady state conditions. When looking at changes of climate and the reasons for theses changes, the important point is changes of forcings. Climate changes are determined by changes of forcings and the corresponding feedbacks. Considering the decadal to multi-decadal time-scale, which is relevant to the discussion about man-made climate change, CO_2 is a forcing, while water vapour acts as a feedback. The reason is the different life time, which is decades to centuries for CO_2 (a decade for methane) compared to a few days for water vapour. The atmospheric content of water vapour depends on the temperature of the air and adapts very quickly to temperature changes induced by external forcing. Climate model experiments show that if one would remove all the water from the atmosphere, the water content would be back to 90% after 14 days and to 99% after 50 days.

The magnitude of this feedback seems to be captured well by climate models. Soden et al (2002) could show that models could reproduce the three year cooling due to the Pinatubo eruption quite well, including the water vapour decrease measured by satellites which enhanced the cooling by about 60%. Thus the volcanic aerosol forcing and water vapour feedback represented in the model produced a result very similar to reality.

There are still some uncertainties concerning regional evolution (especially in the tropics) and the question of changes of relative humidity. In general, model results suggest that relative humidity will remain more or less constant, which means more water vapour with higher temperature.

Conclusion:

The greenhouse effect of water vapour is well-known and well represented in climate models. However, while CO_2 acts as a forcing of climate change, water vapour acts as a feedback due to its short life-time in the atmosphere and thus is not listed as a forcing agent, in this case greenhouse gas.

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B3 Climate change is driven by the sun

Argument:

Climate change is driven by the sun and has nothing to do with greenhouse gases.

Discussion:

Changes in solar activity undoubtedly are an important factor of natural climate variation. There is evidence that seasonal and latitudinal variations in solar irradiance due to changes in orbital parameters trigger the onset and offset of ice ages on the 10 000 to 100 000 year time scale. Long-term changes in solar activity also influence global temperature on the multi-decadal to millennial time scale. Changes in solar activity and the direct effect of resulting variations in total solar irradiance, together with changes in volcanic activity, can explain the multi-decadal to centennial variations of northern hemispheric temperature during the last millennium (eg Shindell et al. 2003).

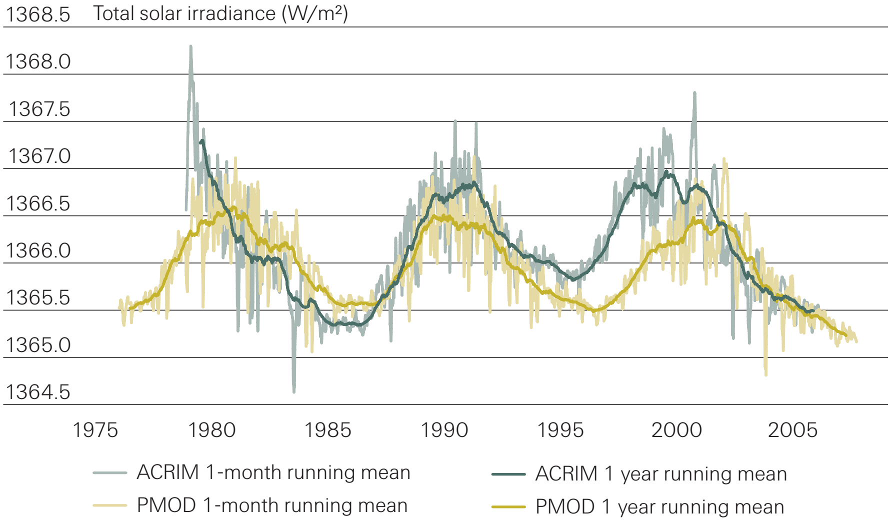
However, the sun is not the only influencing factor and cannot explain all variations and trends of global temperature. Considering the variety of solar and temperature time series the probability is, of course, quite high to find a series with "apparent" correlation to temperature over a given time period or region. Many of these correlations claimed in the literature (eg Friis-Christensen and Lassen 1991, Shaviv and Veizer 2004) have been shown to be only due to inadequate data processing or spurious correlations (Damon and Laut 2004, Rahmstorf et al. 2004 resp.). Other correlations (eg the cloud-cosmic ray correlation, Svensmark and Friis-Christensen 1997, or the correlation to the solar cycle length) have diminished when the time period has been extended (Wagner et al. 2001, Benestad 2005).

Since variations in solar radiation are too small to explain observed temperature there are claims about processes which amplify the direct solar effect. Basically there is no need for processes which amplify the direct forcing of solar irradiance variations to explain temperature variations of the past millennium. However, uncertainties in the amplitude of long-term variations of solar irradiance (Hall and Lockwood 2004, Lean et al. 2005, Foukal et al. 2006) as well as of temperature are large, up to about a factor of three for both. Therefore from this data the existence of significant amplifying processes can neither be deduced nor excluded. Mainly two such possible amplifying processes have been proposed, the influence of changes of UV radiation on stratospheric ozone and circulation, and the influence of cosmic ray flux on cloud cover. The existence of the former process is accepted (Hood 2003, Crooks and Gray 2005), but the influence of this effect is estimated to be rather small with an amplifying of 15-20%. For the influence of changes in cosmic ray flux, a theory of a possible mechanism has been proposed (see section on cosmic rays). However, observational evidence of the link to temperature so far is weak and restricted to specific regions, cloud layers, time scales and time periods. It cannot be excluded that in future indirect mechanisms linking sun and climate can be identified. It seems rather unlikely, however, that these indirect forcings are significantly stronger than the direct influence of total solar irradiance (TSI).

There is considerable evidence that the influence of solar variability on the warming in the second half of the 20th century is small compared to anthropogenic forcing (eg Ammann et al. 2007, Lean and Rind 2008). Direct measurements of total solar irradiance from satellites show no significant trend since the beginning of measurement in 1978 until today (Fröhlich 2007, Dewitte et al. 2005, Willson and Mordinov 2003 updated, see Figure 5). Trends of other solar related parameters like sunspots, geomagnetic activity or cosmic ray flux since 1950 are very small compared to earlier variations during the last millennium or are, at least over the last 20 years, even negative (Lockwood et al. 2007). The analysis of past solar variations and temperature provides no evidence of time-lag reactions of more than one or two decades. There might be some lagged long-term reaction over the next centuries on the increase of solar activity from the 17th to the middle of the 20th century due to the thermal inertia of the ocean, but this contribution would be smaller than the already observed effect and be very small over the period of a few decades.

Figure 5:
The PMOD (Physikalisch-Meteorologisches Observatorium Davos) and the ACRIM (Active Cavity Radiometer Irradiance Monitor) composite of Total Solar Irradiance as one-month and one-year running mean, respectively, of daily values. The linear trend of the PMOD series over the time between the minima 1976 and 2007 is –0.075W/m² per decade, the one of the ACRIM series over the time between the minima 1987 and 2007 is –0.065W/m² per decade. Data

Source: PMOD (Fröhlich and Lean 2004) and ACRIM (Willson and Mordinov 2003)



Regression analysis has shown that the contribution of solar variations to the warming of the last three decades is at most 30%, if it is assumed that past temperature variations are 100% due to solar variability, which is unlikely (Solanki and Krivova 2003). More realistic assumptions lead to a solar contribution of less than 10%. A multivariate analysis of anthropogenic, ENSO, volcanic and solar influence on global surface temperature from 1889–2005 shows, that solar activity over the last 50 years is negligible and explains only 10% of the warming during the last 100 years (Lean and Rind 2008).

Climate model calculations show a very small solar contribution to recent warming and consistently point to a negative effect of combined solar and volcanic forcing over the last 50 years (Ammann et al. 2007). There is no model study which can explain the recent warming without the influence of rising greenhouse gases. Natural forcing alone (solar and volcanic) always leads to a slight decrease of temperature since 1950.

Moreover, the observed patterns of changes are similar to what would be expected from an enhanced greenhouse effect, ie, warming of the troposphere, but cooling of the stratosphere and the upper atmosphere and stronger warming during night-time than during day-time. In the case of solar forcing one would expect a warming at all atmospheric levels and a stronger warming during day-time than during night-time.

Conclusions:

While solar variations are an important factor in past climate variations, changes in solar activity cannot explain the rapid temperature increase over recent decades and are likely to add only a very small contribution to that warming. Observed patterns of warming (vertical atmospheric distribution and day-night distribution) are consistent with the physical processes of a greenhouse effect and contradictory to the expected effects of solar forcing.

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B4 Climate change is driven by cosmic rays

Argument:

Climate change is driven by cosmic rays which influence the building of clouds and cloud radiative properties.

Discussion:

The link between cosmic ray flux (CRF) and climate has mainly been proposed by Svensmark and Friis-Christensen (1997). The theory suggests that ionisation of the atmosphere by cosmic ray flux produces additional cloud condensation nuclei that influence the radiative properties of clouds and thus influence the surface temperature.

There are several unresolved questions concerning this proposed link:

- The mechanisms could not so far be shown experimentally.
- The correlation to clouds can only be found in low cloud cover, although the ionisation mainly occurs in the upper atmosphere. Yu (2002) suggested a possible explanation for this phenomenon. The correlations to low clouds could only be found on the interannual time scale in some marine regions (Usoskin et al. 2004).
- The correlation to low cloud cover does not correlate well after 1995. Marsh and Svensmark (2003) have suggested that this was due to calibration problems in 1994/95. However, correlations of low cloud cover to total solar irradiance (TSI) are better than to CRF (Kristjansson et al. 2002) without corrections to cloud data.
- The analysis of the correlation of low cloud cover and ionization rate could not corroborate the suggested link (Sloan and Wolfendale 2008).
- Udelhofen and Cess (2001) found an 11-year cycle of cloud cover over the US which was in phase with the solar cycle but not with CRF, showing an opposite correlation to CRF than the one found by Svensmark. Other studies could not identify a CRF-cloud correlation at all (Wagner et al. 2001, Sun and Bradley 2002).
- Although the formation of condensation nuclei takes place within days, a CRF-cloud link until now has only been found on interannual time-scales and mainly over the ocean.
- There are considerable concerns related to the homogeneity of the cloud data set used (ISCCP, International Satellite Cloud Climatology Project). It has been shown that the cloud time series evolution is spatially correlated to the covered area of certain satellites (Norris 2000, Pallé 2001), and it has been recently confirmed that the trends observed in the ISCCP data sets are strongly related to the satellite viewing geometry and might not be related to physical changes in the atmosphere (Evan et al. 2007).
- CRF is closely correlated to solar activity and to TSI and sunspot numbers. Therefore it is very difficult to distinguish between the influence of TSI and CRF, at least by statistical analysis.
- Claims of a CRF-climate link on the million year time scale (Shaviv and Veizer 2003) have been disputed (Rahmstorf et al. 2004).

Simulations of the proposed physical mechanism in a global climate model, which incorporates the relevant micro scale physical processes, reveal that cosmic ray changes are two orders of magnitude too feeble to cause the proposed cloud changes. (Pierce and Adams 2009).

Independently from the proposed link, CRF has shown no significant trend over hat last 50 years and thus cannot explain the temperature rise during the last decades anyway.

Conclusion:

Mechanisms of the CRF-cloud link have not yet been experimentally confirmed: the correlations between CRF and clouds are only found on specific time-scales for specific regions and over rather short periods, and the close correlations to TSI makes it almost impossible to distinguish from the TSI influence. There is only poor consistency between the different correlations so far presented. Thus there is not much evidence for an influence of CRF on climate, although the theory might be physically plausible.

It can not be excluded that in future indirect mechanisms linking sun and climate can be identified. It seems rather unlikely, however, that these indirect forcings are significantly stronger than the direct influence of TSI. Models can simulate the climate in the recent past pretty well with the direct TSI forcing only.

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B5 Anthropogenic CO_2 emissions are much smaller than natural CO_2 emissions

Argument:

Anthropogenic CO_2 emissions are much smaller than natural CO_2 emissions, about 3% of total emissions, and therefore have a negligible influence on atmospheric CO_2 concentrations.

Discussion:

There is a large amount of natural CO_2 emissions from the oceans and the terrestrial biosphere. These emissions are about 90 GtC (Gigatons carbon) per year from the ocean, and 120 GtC from land surface. However, the oceans and the terrestrial biosphere at the same time absorb about the same amount of 90 and 120 GtC per year respectively. Thus the natural system of emissions and uptake is balanced and the atmospheric content of CO_2 remains more or less stable without external change. The ongoing external input of CO_2 in the atmosphere by fossil fuel burning (5.4 GtC per year) and through land use changes (1.7 GtC per year) cannot be fully absorbed by the oceans and the biosphere (just under 2 GtC per year each). This leads to an important change of the atmospheric reservoir of 3 GtC per year, which corresponds to an increase of the atmospheric content of about 0.5% per year. Thus only about half of the added carbon is taken up by the land and ocean reservoirs. Since the atomic characteristics (isotopes) of carbon released from fossil fuel burning and carbon emitted by ocean or plants are different, it can be shown that the current increase in CO_2 concentration in the atmosphere is due to an increase in carbon from fossil fuel burning.

It is not clear if the amount of uptake on the land and in the ocean will continue. There is evidence that the uptake might decrease with increasing temperature and rising CO_2 concentration (IPCC 2007).

Conclusion:

The comparison of the total CO_2 emissions from global ecosystems to anthropogenic emissions is irrelevant for atmospheric CO_2 concentration variations, because there is a balance between natural emissions and uptake, whilst only about half of the additional anthropogenic emissions are absorbed. Anthropogenic emissions thus create a net positive deviation of the atmospheric CO_2 content.

B6 Volcanoes emit more greenhouse gases than humans

Argument:

Volcanoes emit more greenhouse gases than anthropogenic emissions. They are neglected by climatologists.

Discussion:

Volcanic emissions (eg out-gassing beside volcanic eruptions) have always existed. These emissions just contribute to the turnover of CO_2 (carbon cycle). Unless there has been a change in volcanic emissions or activity over the last century, these emissions cannot be a reason for changes in greenhouse gas concentrations. There is no evidence at all for any long-term trend in volcanic activity over the last decades.

A recent review of volcanic CO_2 emissions gives a range of 210–360 $MtCO_2$/year (Hards 2005). This is equivalent to about 1% of anthropogenic emissions. These estimates are based on direct sampling or C/3He ratios and include explosive volcanism as well as passive out-gassing (Morner and Etiope 2002). Dessert et al. (2003) suggested that continental basalt acts as a carbon sink and extracts about 180 $MtCO_2$/year from the atmosphere, and therefore this amount should be subtracted from volcanic emissions to estimate the volcanic contribution to the atmospheric CO_2 budget. Passive degassing is mainly occurring on the flanks of volcanoes or in geothermal areas such as at Yellowstone. However, not all volcanoes are degassing in the same way, and this degassing might be intermittent. Surface measurements in the Yellowstone area have shown outgassing of about 1.6 $MtCO_2$/year (Werner and Brantley 2003). Estimates for Etna, one of the world's most actively degassing volcanoes are in the range of 15–25$MtCO_2$/year (Hards 2005). The degassing emissions of the about 500 historically active volcanoes are estimated to add up to around 50 $MtCO_2$/year (Morner and Etiope 2002).

The fact that volcanic eruptions do not produce any detectable signal in remote CO_2 measurements (eg Mauna Loa) is evidence that these emissions are of much lower magnitude than anthropogenic emissions.

Conclusions:

Estimates of volcanic CO_2 emissions are much lower than anthropogenic emissions. Moreover, there is no evidence of a change of volcanic activity over the last decades, and it is therefore very unlikely that volcanic emissions have contributed to the increase of atmospheric CO_2 concentrations.

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B7 There was global cooling between 1940 and 1970 although CO_2 concentration increased

Argument:

CO_2 cannot be an important driver of climate change because global temperature has decreased between 1940 and 1970, although CO_2 concentration has increased in that period.

Discussion:

There are several factors which can influence climate on the decadal time-scale. The main natural factors are solar and volcanic activity; the main anthropogenic factors are greenhouse gas and aerosol emissions. The evolution of global temperature is the sum of the effect of all these factors and is superposed by internal natural variability on the inter-annual time-scale. Thus it is evident that global temperature will not exactly follow the evolution of one single factor. A missing correlation for a certain period does not prove at all that a certain factor does not influence climate.

The combination of these forcing factors is well represented in climate models and can reproduce the evolution of global temperature in the 20th century (IPCC 2007). From 1900–1940 global temperature was mainly influenced by a combination of the increase of solar activity and the beginning of the rise of greenhouse gas emissions. Recent estimates agree that both factors contribute about half of the corresponding forcing. After 1940 the increase of solar forcing levels off and there is a strong increase in aerosol emissions which predominantly have a cooling effect. In the 1970s the increase of aerosol emissions levels off as well as the corresponding forcing. In contrast, greenhouse gas emissions increase at an accelerating rate. Therefore, during the period 1940–1970 the forcing of rising greenhouse gas concentration is counterbalanced or even more than compensated for by the forcing of aerosols, due to ambient air pollution and partly by solar forcing.

Conclusions:

There are several factors influencing the evolution of global temperature. The slight decrease between 1940 and 1970 is mainly the result of increasing aerosol emissions (cooling effect) which counterbalanced the increasing greenhouse effect (warming effect) at that time.

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C Carbon dioxide (CO_2)

C1 CO_2 measurements in ice cores are not reliable

Argument:

The reconstruction of CO_2 concentrations in ice cores is flawed, for example, through chemical reactions in the ice, contamination by drilling fluid, contamination during transport and storage, bias by forming of clathrates, or arbitrary corrections of gas age.

Discussion:

The problem of possible contamination of ice core measurements is well-known and the handling of ice cores therefore is very delicate. Different laboratories, analysing ice from different locations (Vostok, Dome C, Taylor Dome) with different accumulation rates, using different extraction methods, all show very similar results for the evolution of CO_2 concentration in Antarctica. This gives considerable credibility to this data.

The possible contaminations are accounted for by:

- *Chemical reactions in the ice bubbles:* Measurements in ice cores can be contaminated, because certain greenhouse gases can be produced or depleted by chemical reactions between impurities in the ice and possibly by bacteria. Greenland ice cores seem to be contaminated by in situ decomposition of calcium carbonate from dust embedded in the ice (Smith et al. 1997, Stauffer et al. 2003). However, dust levels are low in the Antarctic, and chemical reactions are therefore less likely. When dust levels in Greenland ice cores are as low as in the Antarctic, then there are only small differences between Greenland and the Antarctic. It is not likely that there are other unknown chemical reactions which change the concentrations in Greenland and the Antarctic, in the same way, at the same time.
- *Contamination by drilling fluid:* The ice analysed is taken from the inner part of the core, which reduces the possible influence of contamination from outside. Drilling fluid does not penetrate far into compact ice, as it evaporates relatively quickly from the core surface. For gas measurements, only undamaged parts are used.
- *Contamination during transport and storage:* The air trapped in the ice core is hardly changed with transport and storage, for at least 10 years, as long as it is kept below −10ºC, as several studies have shown. Research teams are well aware of this and take extensive precautions to ensure the core remains cool.
- *Bias due to forming of clathrates:* At higher pressure (ie deeper layers) fractionation due to clathrate formation. This problem is known and is accounted for.
- *Arbitrary corrections of gas age:* There is a difference between the age of the ice and the age of the trapped gas due to the time lag between the ice deposition and the final enclosure of the bubbles. This difference depends on the location and the climatic conditions, eg, the ice accumulation rate. It therefore differs from location to location. In Greenland a mean gas-ice age difference of about 200 years has been determined (Leuenberger et al. 1999), at Law Dome (Antarctica) values between 40 and 70 years have been found.

There are other claims concerning the reliability and comparability of the current direct CO_2 measurements at Mauna Loa:

- *Bias of Mauna Loa measurements through volcanic emissions:* Mauna Loa measurements are corrected for the influence of volcanic emissions. Moreover, there are many independent measurements throughout the world, which show very similar concentrations as Mauna Loa: http://cdiac.esd.ornl.gov/trends/co2/sio-keel.htm
- *Ice core and Mauna Loa measurements cannot be compared:* The Law Dome ice core series overlaps both Mauna Loa and the other pre-industrial ice core data (like Vostok or Dome C). The observed CO2 concentrations at Law Dome are similar to these long term ice cores, as well as the Mauna Loa measurements.

Conclusions:

Ice cores are treated very carefully to avoid contaminations and thus provide reliable information on past CO_2 concentrations. Furthermore, different and independent analysis shows consistent results. The possibility of significant corruption of the results by contaminations can therefore be practically excluded.

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C2 CO_2 increase is just the result of temperature change

Argument:

CO_2 variations in ice core measurements only occur some time after temperature variations, so that temperature must be the cause of rising CO_2 concentration and not the consequence.

Discussion:

From the knowledge of physical, chemical and biological processes it can be concluded that atmospheric CO_2 concentrations and temperature are influencing each other. They form a classical feedback-system. Rising temperatures change some biological and chemical processes on the land surface and in the ocean and lead to enhanced total fluxes to the atmosphere increasing CO_2 concentration. Higher CO_2 concentrations, on the other hand, lead to an increase of temperature due to the greenhouse effect. In such a feedback system, the change of one of the two factors will lead to a change of the other. So the fact that on the timescale of ice ages CO_2 concentration reacted to the temperature changes induced by orbital forcing (Milankovich cycles), does not exclude a reaction of temperature on anthropogenic alteration of CO_2 concentrations.

At the transition from glacial to interglacial periods, CO_2 increase lagged behind Antarctic warming by about 800 (±200) years and preceded the Northern Hemisphere deglaciation (Caillon et al. 2003). This is about the response time expected from the reaction of deep ocean circulation. Thus the reaction of CO_2 on temperature changes to an amount in the order of ice age – interglacial differences, which we observe today, takes several hundred years. Therefore it is very unlikely that the present CO_2 increase is a reaction to the observed temperature increase.

In contrast, the well-known radiative effects of CO_2, which can be shown in laboratories and reproduced by physical models, act almost immediately. This strongly suggests that at least part of the present temperature increase is due to enhanced greenhouse gas concentrations.

Conclusion:

Atmospheric CO_2 concentration and global temperature influence each other. Therefore the change of one of the two affects the other. Contrary to the ice age, when temperature changes triggered by orbital changes induced the feedback loop, the increase of the CO_2 concentration is currently the initiating factor.

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C3 CO_2 is a fertiliser for plants and therefore positive

Argument:

Plants profit from higher CO_2 concentrations in the air and will grow faster.

Discussion:

The response of plants to elevated CO_2 concentration in the air is non-linear and varies for different species. Field experiments in general show that any increase of productivity is likely to be short-lived (eg Körner et al. 2005 for forest systems). This is on the one hand due to the fact that other environmental conditions – eg, the availability of nutrients such as nitrogen and phosphorus (Reich et al. 2006), water availability, or temperature – appear to become limiting factors, and on the other hand plants adapt their uptake behaviour to the higher concentration. An experiment with combined CO_2 fertilisation/climate/environment interactions showed no significant biomass signal (Shaw et al. 2002).

In the IPCC 2001 models, the supposed increase in crop yields was based on laboratory and chamber studies and had shown about a 20–30% increase in yields for a doubling of CO_2 (Allen et al. 1987, Cure and Acock 1986). This compensated losses due to climate change or even resulted in a net increase. Recent more realistic field studies have shown that this increase might have been overestimated by about a factor of two, possibly changing net gain into no change and no change into net loss (Long et al. 2006).

In general, most crop physiologists expect decreasing crop yields with global warming: higher temperatures shorten the life cycle of most cereals, higher ozone levels reduce yields, and there will be higher exposure to extreme conditions (heat, drought, precipitation; Porter 2005).

Conclusion:

There is considerable evidence that the fertilizer-effect of higher atmospheric CO_2 concentrations is short-lived and that negative effects are increasing with rising concentrations.

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C4 The observed increase in CO_2 is much smaller than assumed in climate models

Argument:

The 1% per year increase in CO_2 assumed in climate model simulations is much too high, because observed increases in CO_2 concentration are much smaller.

Discussion:

The assumption of a regular 1% per year increase in CO_2 is used mainly for comparison reasons, ie, it is easier to compare model results if the forcing is identical. It is also used for the calculation of 2 x CO_2 and 4 x CO_2 calculations. However, for the projections of the climate evolution in the 21st century cited in the IPCC reports the IPCC SRES emission scenarios are used as model input for greenhouse gas concentrations.

Conclusion:

The 1% per year increase of atmospheric CO_2 concentrations is an assumption used for model comparisons but not for climate projections. The latter use as a basis the emissions from IPCC emission scenarios.

C5 The greenhouse effect of CO_2 is small because CO_2 absorption bands are saturated

Argument:

The anthropogenic greenhouse effect can only be small because CO_2 absorption bands are already saturated, ie, the actual CO_2 concentration already eliminates all radiation of its absorption frequencies.

Discussion:

There are two main CO_2 absorption bands (at 4.5mm and 14.7mm), where one of them is in fact almost saturated in the central part. This is, however, not true for the side parts. Very precise measurements are necessary to identify this. The quite weak specific greenhouse efficacy of CO_2 is mainly due to this saturation. However, the increasing saturation of CO_2 absorption bands implies that the temperature response is not linear to the CO_2 concentration, but logarithmic. Therefore climate sensitivity is more or less constant for a doubling of CO_2 concentrations independent of the starting point. That means eg that the warming is about the same for a CO_2 increase from 280 to 560 ppm as for an increase from 560 to 1120 ppm. The saturation effect is fully accounted for in climate models.

Conclusion:

The increasing saturation of the CO_2 absorption bands is fully accounted for in climate models and is reflected in the logarithmic response of global temperature on increasing CO_2 concentrations.

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