Synopsis

Man-made Versus Natural Climate Change

INTRODUCTION

Have human activities influenced the global climate in a noticeable way? Is the increase in global mean surface temperatures during the past 100 years unique in a Holocene perspective? These are central questions in global change research. In March 1999, the Royal Swedish Academy of Sciences hosted a 2-day workshop in Stockholm to discuss these aspects of global climate change, both from an observational and a modelling point of view. Scientists from a range of disciplines were invited to present their views. This short paper is an attempt to summarize the discussions which took place during the meeting. The aim of the workshop was to obtain a deeper understanding of the processes involved in the observed climate changes. There was no attempt to reach consensus or to find a majority view. Responsibility for the contents of this paper lies with the authors. However, workshop participants were given an opportunity to comment on a draft version of the paper.

The first day of the workshop was devoted to presentations from invited contributors. The second day was spent discussing aspects of the issues involved. Participants in the discussing group were invited contributors as well as invited scientists, mainly from the Swedish geosciences community (1).

OBSERVATIONS OF PAST CLIMATE

A large number of methods for the reconstruction of past climate have been developed. With new and improved dating techniques, it is possible to present chronologies that are long, well dated and semi-quantitative for past climate at a number of localities. Ice-core data, deep-sea cores and several other records were discussed. The Little Ice Age (ca AD 1300–1800), the Medieval Warm period (ca AD 900–1300), the 3000–2000 year BP mostly cold period and the 8000 BP event as well as several others, appear to have been events known from a number of locations. However, the results presented by Mann et al. (2) suggest that some of these events may have been confined to specific regions and do not reflect global patterns.

Global climate was at least 5–6°C colder during cold phases of the Pleistocene, although even larger changes have been suggested (3). Major changes in climate associated with stadials and interstadials are likely to have been coupled to changes in the orbital parameters. Changes in climate on glacial/interglacial timescales are, presumably, global because of feedback from the Northern Hemisphere ice-sheets, and probably also by CO_2. However, variations in CO_2 represent not only a forcing factor, but they also occur as a result of climate change (4). In addition to these low frequency changes in climate, there have been frequent fluctuations on time scales too short to be explained by orbital parameters (5, 6). The amplitude of these short term, rapid fluctuations is sometimes considered to have been particularly large in the North Atlantic area, where the fluctuations are known from Greenland ice-core data (7), and also from deep-sea records (8).

Ice-core records are considered to be one of the primary paleoclimatological data sources available. In the workshop discussions it was emphasized that the annual wintertime precipitation amounts on the glacier as well as temperature changes influence the isotope ratio. Uncertainties in the estimates of wintertime precipitation contribute to the uncertainty in the derived temperatures. Based on Greenland ice-core data (3) it is suggested that the Holocene climate fluctuated on similar time scales as the non-orbitally forced changes in the late Pleistocene climates, although with much smaller amplitudes (6, 9).

Over the past 200 years, records of lengths of mountain glaciers can also be used to infer temperature changes. A study by Zou and Oerlemans (10) shows that since about 1850 glaciers worldwide exhibit a clearly retreating trend, which is consistent with the global temperature increase found in the instrumental record by Jones et al. (11). Analyses of underground temperature measurements in boreholes indicate that the global surface temperature increased by about 1°C during the past 500 years and that most of this increase occurred since the late 19th century (12).

In recent studies by Mann et al. (2, 13), a new method for combining regional paleoclimatological temperature indicators into a hemispheric temperature average has been proposed. The studies by Mann and co-workers generated considerable discussions during the meeting and several of the participants expressed the opinion that this method opens up a new perspective on the analysis of paleoclimatological data. Critical comments were, however, raised regarding the choice of paleoclimatological data.

It is evident that hemispheric or global averages of temperature data are less variable in time than temperature data which represent only one point in space or a regional average. The results from Mann et al. (13) show less variability for the period 1000–1850 AD than individual time series. Moreover, in the analysis of Mann et al. (13) the last 100 years stand out as anomalous in the sense that similar large and rapid temperature increases appear to be absent in the previous 900 years.

The global mean temperature has increased by about 0.6°C during the last 100 years (11). The latest IPCC report shows that the increase in temperature has been greatest over the Northern Hemisphere continents, but most of the globe has become warmer during the last 30 years (14). During the last two decades the global mean temperature, according to surface observations, has increased by about 0.2°C.

CLIMATE MODELS

To investigate the mechanisms which may affect climate change a physical model of the climate system is required. Such a model can range from simple, zero-dimensional energy balance models to sophisticated and complex, coupled ocean-atmosphere general circulation models (AOGCM). The choice of a particular model to investigate climate change must be based on a selection of the physical processes which are assumed to be significant for a specific research problem. To investigate the mechanisms underlying recent climate change (past 200 years) an AOGCM is an appropriate tool and the discussions focused on the shortcomings and limitations as well as the usefulness of the present generation of AOGCMs.

It is believed that much of the uncertainty in the simulation of present climate, as well as projections of future climate change due to an increased greenhouse gas forcing, is related to clouds. Clouds also indirectly affect the climate system through feedbacks to water vapor and large-scale dynamics. At present, many of the feedbacks between clouds and the climate system are poorly understood and a multitude of cloud process studies are needed to advance our understanding in this area.

Despite all the limitations and uncertainties of climate model process descriptions, models can reproduce important aspects of observed climate fluctuations. The ability of an AOGCM to simulate past climate change can be divided into two parts. One is a forced change due to a prescribed variation of, for instance, solar energy output or greenhouse gas concentration. The forced climate change can be compared with observed temperature changes both with respect to amplitude and phase in time. The second type of climate variations is stochastic in nature. It results from a purely internal redistribution of heat and momentum, which generates appreciable surface temperature fluctuations also on a global scale. The amplitudes of stochastic, unforced variations in several climate models have been compared (15), and they differ considerably between models. Comparison with observations is difficult as it is not possible to isolate the internally generated fluctuations from those forced by external agents in observations. A general conclusion from Barnett (15) is that many AOGCMs, but not all, tend to underestimate the natural variability of the climate system. Attribution studies using AOGCMs as a tool for understanding the causes of climate change have thus to be interpreted with some caution.

Climate change associated with greenhouse gas concentration change has been at the focus of attention for many years. The AOGCMs used to make climate change scenarios into the next century have been improved substantially over the past decade and the ability of these models to reproduce natural variations has been improved. Despite these improvements we still see an appreciable scatter in the results from greenhouse-gas change experiments. The scatter can be due to many factors, but it is believed that the representation of cloud processes is the main contributor.

FORCING

The study of forced climate change requires a close link between observations and climate modelling. Observations may suggest a forcing-response relation, but a model has to be used to understand whether such a relation is physically possible. It is necessary to establish that the magnitude of the forcing is sufficient to trigger the observed fluctuations. The forced signal must also be possible to distinguish from natural, unforced climate noise.

Friis-Christensen and Lassen (16) found a high correlation between variations in the length of the sunspot cycle and changes of global mean temperatures over the past 100 years. This is suggestive of a direct link between solar forcing and climate, but it must be determined whether variations in solar output energy are sufficient to trigger the observed magnitude of climate variations. Friis-Christensen and Lassen (16) point out that the solar energy received by the globe cannot vary more than about 0.4 W m^{-2} over sunspot cycles and this is not enough to explain observed temperature fluctuations through direct energy-balance considerations. If there is a cause-effect relation some amplifying feedback mechanism is required, and this mechanism has not yet been established. Over the past 20-year period direct measurements of solar output variations have been made through satellite observations. Relations between solar spectra, sunspot variations and the solar constant for this period can be used to indirectly determine solar output variations over the past 300 years (17). It can be concluded that solar forcing has contributed to climate variability during this period.

Sulfur emissions through volcanic activity is another forcing mechanism, which may explain some of the observed climate variability. It is known that volcanic activity occurs intermittently, during some periods volcanic eruptions are frequent (for example during the 19th century) while other time periods are almost free from volcanic activity (such as beginning of 20th century). Volcanic aerosols may remain in the upper atmosphere (stratosphere) for a few years after an eruption, and global climate change effects on the time scale of a few years have been determined from recent volcanic eruptions (18). Energy-balance calculations show that volcanic activity variations may have contributed to part of the observed temperature fluctuations over the past 150 years (19), but the estimates have large uncertainties due to uncertainties about the concentration and residence time of the aerosols.

Albedo changes due to variations in large-scale ice cover have had a significant impact on the global energy balance on the time scale of ice ages. During the past 6000-year period, changes in the global ice cover have been small. Albedo changes are also caused by changes in land cover. The largest changes in land cover during the Holocene period, the greening and desertification of North Africa in the middle Holocene, are presumably of natural origin (20). These changes strongly amplified climate changes triggered by external forcing owing to changes in orbital parameters. However, changes in land cover due to anthropogenic activities during the last 1000 years have been large and widespread enough to give a presumably significant temperature decrease.

Over the past 150 years, atmospheric concentrations of greenhouse gases such as carbon dioxide and methane have increased by 30% and 130%, respectively. Calculations show that these concentration increases give an increase in the surface radiative forcing of about 2.4 Wm^{-2}. AOGCM experiments with a combination of variations in solar, volcanic, greenhouse and atmospheric aerosol forcings have been analyzed, with the purpose of identifying which particular forcing mechanism dominates and, thus, may be used to explain the observed temperature change (21). A general conclusion is that it is very difficult to explain the observed temperature increase over the past 25 years without taking an increase of greenhouse gas concentrations into account.

CONCLUSIONS

The following brief statements represent an attempt to summarize the general conclusions of the discussions between the workshop participants. We are, of course, well aware that some participants may disagree with some of the statements. The summary is simply our interpretation based on our own scientific judgement and on the input provided by all workshop participants.

i) The large and rapid warming of the global mean surface temperature during the past century appears to be unprecedented during the past 600 years. It is still uncertain whether the warm "episodes" recorded in some parts of the world during parts of the medieval period (AD 900–1300) reflect a global warming comparable to the present one.

ii) Although it is difficult to make quantitative comparisons between the recent global warming and the natural climate variations during the Holocene (i.e. the past 10 000 years) prior to AD 1000, regional temperature fluctuations of a magnitude similar to the recent warming might well have occurred, e.g. 8000 BP.

iii) Coupled atmosphere-ocean climate models (AOGCMs), although in many ways highly sophisticated, still suffer from fundamental weaknesses, in particular in their treatment of clouds and water vapor. Nevertheless, such models are a key tool for quantifying the response of the climate system to imposed forcings as well as estimating the internal-unforced-climate variability.

iv) Natural factors, i.e. low volcanic activity, increases in solar variations and/or internal (unforced) variability, are potentially large enough to explain much of the global warming observed between 1900 and 1940. However, the increased greenhouse effect may also have contributed to the warming.

v) The rapid global warming since 1975 can not be plausibly explained by changes in solar radiation or volcanic activity; increased volcanism during this period is actually estimated to have led to a cooling tendency.

iv) The above conclusions indicate that the increased greenhouse effect is very likely to have contributed to the observed increase in global mean, surface temperature during the past century. This indication is particularly strong when considering the past 25 years.

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