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THE SCIENTIFIC BASIS FOR CLIMATE CHANGE

Statement by the Royal Swedish Academy of Sciences

Planet Earth has experienced repeated changes of its climate throughout time. Periods warmer than today as well as much colder, during glacial episodes, have alternated. In our time, rapid population growth with increased demand for natural resources and energy, has made society increasingly vulnerable to environmental changes, both natural and those caused by man; human activity is clearly affecting the radiation balance of the Earth.

The Intergovernmental Panel on Climate Change (IPCC) Working Group 1 (The Physical Science Basis) has given a broad, systematic summary of the scientific literature on climate change and has concluded that the anthropogenic emission of greenhouse gases has led to an increase in the surface temperature of the Earth. As noted by the Panel, quantification of the influence on the global climate is complex and many regional effects remain uncertain.

The present statement is concerned with the scientific basis of climate change. It has not been an objective to deal with areas outside the natural sciences. However, it is clear that changes in climate require a response from society that involves a wide range of other disciplines, with development and application of new technologies.

A. We note the following

1. The surface temperature of the Earth has never been constant, but has undergone changes, sometimes rapid, on a multitude of timescales, many of which are incompletely understood. Since about 1900, the global mean surface temperature has increased by 0.6 to 0.8 °C. The warming has not been regular, but has rather occurred in steps that might be interpreted as multi-decadal fluctuations superimposed on a long-term warming trend (See Fig.1).

2. There are large variations in the temperature trend between different parts of the world, being the largest at the high latitudes of the Northern Hemisphere and especially in the Arctic. During the last 30 years of reliable satellite observations, the Arctic summer sea ice has retreated by c. 1% per year. During the same period, no such sea ice reduction has occurred around Antarctica, where temperature changes have been smaller.

3. The climate record of the present interglacial (about the last 12000 years) shows a number of climate fluctuations on a millennial-centennial timescale (both warming and cooling) of a few degrees. It remains to be established to what extent such fluctuations have a global signature. Possible causes are variations in solar activity, internal processes of the climate system and major volcanic eruptions.

4. Temperature on Earth is kept in balance, allowing life in its present form, thanks to the presence of so-called greenhouse gases in the atmosphere. These are dominated by water vapour and carbon dioxide (CO_2) and include a variety of other gases with smaller contributions. The concentrations of several greenhouse gases are significantly influenced by human activity. In addition to CO_2, they include CH_4, N_2O and CFCs. The effect on climate is both direct and indirect through the associated increase in atmospheric water vapour with temperature.

The concentration of CO_2 in the atmosphere during the last 2000 years has been about 280 ppm. During the last 150 years, CO_2 and CH_4 have increased and there are strong indications that they now are the highest for at least the last 800 000 years. The total increase of CO_2, for example, amounts to 23% between 1958 (when accurate measurements began) and 2009 i.e. a rise from 315 to 386 ppm. Isotope records show that the CO_2 increase is primarily related to anthropogenic emissions in contrast to earlier periods in Earth's history. Most of the increase is due to the burning of fossil fuels, but about 20% is due to land use change, including deforestation and biomass burning.

5. During the past century, there has also been an increase in the concentrations of aerosol particles in the atmosphere due to emissions from burning of fossil fuels and biomass. Whereas some of these particles (soot) contribute to the warming, others, e.g. sulphate and organics, reflect sunlight back to space and tend to cool the planet. The present understanding is that the net effect of all particles is a cooling that has masked a significant part of the general warming trend of the last century.

6. Glacier melting and retreat, reductions of Arctic summer ice, rising sea level (2-3 mm/year during the last 20 years) and ocean warming are broadly consistent with increasing global temperatures. However, insufficient observations of sea level (problems with sampling) and Arctic sea ice (reliable data cover only the last 30 years) make it difficult to unambiguously separate the anthropogenic trend from natural fluctuations. Sea-surface temperature varies regionally on multi-decadal timescales, illustrating the complexity of the climate system, the need of more reliable long-term data records, and the need for a more in-depth understanding.

7. Other possible changes related to a warming climate, such as more intense or more frequent tropical and extra-tropical cyclones and more intense precipitation cannot be identified at present. The large increase in damage due to severe weather in different parts of the world is essentially due to increased societal exposure and not to more extreme weather.

8. Climate undergoes considerable natural changes on multi- decadal and shorter timescales. These include internal dynamical changes such as those related to the El Niño phenomenon, the North Atlantic Oscillation, the Pacific Interdecadal Oscillation and other natural climate modes. The climate in most parts of the world is dominated by such natural climate fluctuations. When in their negative phase, they may well counteract a warming trend on decadal timescales; in their positive phase, they will enhance it. Climate is also affected by volcanic eruptions (usually short lasting, e.g. Mount Pinatubo 1991) and by solar variations due to Earth orbital changes (on

longer timescales). Variations in solar activity and solar-wind may also have an influence on climate, but the extent to which this is the case and the mechanisms through which it happens are still debated.

9. We have no reliable indication from satellite measurements of any longer term trend in solar irradiation, except the well-known 11-year sunspot cycle. Space observational records, available for the last 30 years, are too short to support previously used indirect estimates of solar irradiation based on sunspot numbers and isotope studies. Other methods (surface or indirect techniques) of estimating solar irradiation, or any other space related influence, such as from cosmic particles (affecting clouds), are at present less well understood.

10. The relationship between climate forcing and the response to climate forcing is complex and can only be reliably identified for periods of several decades and for hemispheric and global domains. This is supported by both empirical and modelling studies. Trends of shorter periods are unreliable and masked by the chaotic behaviour of the climate system. However, based on detailed theoretical and modelling studies, IPCC concludes that the observed warming of the climate from around 1970 is in broad agreement with the increase of greenhouse gases and aerosols and consequently considers this to be the most probable main cause of the present global warming.

11. While the effect of greenhouse gases is well established, the effect of aerosols (mainly providing a compensating cooling) is much less understood. This is one reason why models provide a broad range of response. Other reasons for differences in the response of models are internal processes in the climate system (including the role of clouds), which are essentially unpredictable beyond a period of less than a year. The relation between the change in climate and changes in greenhouse gases and aerosols is complex, and there is no simple direct (spatial or temporal) relationship.

12. In addition, we note that increased content of carbon dioxide in the atmosphere potentially leads to more rapid growth of vegetation, although the effect is difficult to predict in view of other limiting environmental factors such as availability of nutrients, water supply and suboptimal temperature regimes. However, increased atmospheric carbon dioxide concentration is also causing acidification of the oceans, with potentially severe effects on marine ecosystems.

B. What might happen in the future?

1. Because of the current slow rate of implementation of alternatives to the burning of fossil fuels and biomass, and the increasing energy requirements in the world, CO_2 is expected to continue to increase significantly during this century (during the last five years, the increase has been c. 10 ppm). Limitations in the hydrocarbon resource base will reduce the future increase in the anthropogenic emissions. Nevertheless, the long-term risk is the effect of CO_2 accumulation due to its steady build-up related to its long residence time in the atmosphere. Towards the

middle of this century, a concentration of between 450 and 500 ppm can probably not be avoided. Without remediation, high levels of CO_2 may exist for millennia. The increase in the concentration of other greenhouse gases such as CH_4 and N_2O is less clear and not directly related to the use of fossil fuel.

2. Emission of aerosols is expected to slowly diminish as this is more easily accomplished technologically and will likely be done to eliminate severe local and regional health problems, particularly in India and China. Because of the very short residence time of such aerosols, their atmospheric concentration and their effect on climate will then also diminish.

3. IPCC has undertaken modelling studies to estimate the effect of anthropogenic greenhouse gases and aerosols on climate during the next 100 years based on different emission scenarios. These studies indicate a global surface warming at the end of the 21st century of 1.5-3.5 °C compared to present-day conditions. A large part of this warming is related to positive feedback from water vapour that increases rapidly with higher temperature.

With the warming projections examined by IPCC other changes may follow, for example in the hydrological cycle, that might cause more problems than the temperature changes themselves. Whilst the lower range of warming may be acceptable, at least in some regions, the upper range is likely to cause very severe problems worldwide.

4. A consequence of increasing temperature during the 21st century is that sea level also is expected to rise, caused by temperature expansion of seawater and the expected continued melting of land ice. The rate of sea level rise is likely to increase due to an accumulation of heat in the oceans and the slow progressive thermal expansion of seawater. The possibility also exists, albeit probably remote, of reduced stability in parts of the land ice, implying more rapid sea level rise.

5. Regrettably, we are not yet in a position to determine with any precision what is going to happen. For the time being we cannot rule out that there are hitherto overlooked anthropogenic effects on the climate system, with consequences which either reduce or enhance the influence of increased concentrations of greenhouse gases. One factor is the formation and dissipation of clouds. Increased low-level cloudiness lowers surface temperature, and reduced cloudiness promotes warming. Present indications are that the cloud effect is broadly neutral to climate change. Other important aspects are feedback processes affecting the carbon cycle in the climate system and emission of CH_4 such as from tundra regions.

C. General advice

In spite of the slow and apparently irregular process of climate warming so far, two central issues with potentially severe societal consequences on a global scale stand out. Firstly, the long atmospheric residence time of CO_2 is expected to affect the composition of the atmosphere for centuries to come, probably with irreversible consequences for the Earth on human time scales. Secondly, there is the possibility, albeit small, of extreme and rapid changes in the climate system, resulting in fast sea level rise or wide-spread persistent drought in areas crucial for food production. A comprehensive response to climate change must, therefore, include both a scientific approach, with the main aim of achieving a better quantification of severe and unacceptable risks, and a societal approach aimed at risk reduction based on present knowledge. The points of advice below address mainly the first of these aspects.

1. Support improvements and long-term commitments in global observing systems (including satellites), making weather prediction and climate monitoring and projections more reliable; also in more accurate modelling and data-assimilation systems.

2. Support fundamental research towards a better understanding of the climate system and its predictability on a broad range of timescales. Promote multidisciplinary research towards a broader understanding of the Earth as an integrated system, including studies of a wide spectrum of forcing, both internal (e.g. aerosols) and external (e.g. solar forcing and cosmic radiation) and associated feedback processes.

3. Analyse in detail the paleoclimate records (historical, archaeological and geological) to more accurately define the character, in space and time, of past climate changes and their consequences for the environment. This will assist in improving climate models and provide a firmer foundation for assessing the possible impact of changes in climate during the coming century.

4. Contribute towards improving energy conservation and the development of safe energy systems which do not emit greenhouse gases.

5. In view of the potential long-term negative effects of increasing atmospheric CO_2 and other greenhouse gases on climate and ocean chemistry (for example, acidification), development of mitigation technologies should be given priority. These should seek ways of reducing CO_2 emission and the other components of anthropogenic forcing (including CH_4, N_2O, tropospheric ozone and black carbon aerosols) as well as focusing on CO_2 sequestration, involving both the biosphere and the geosphere.

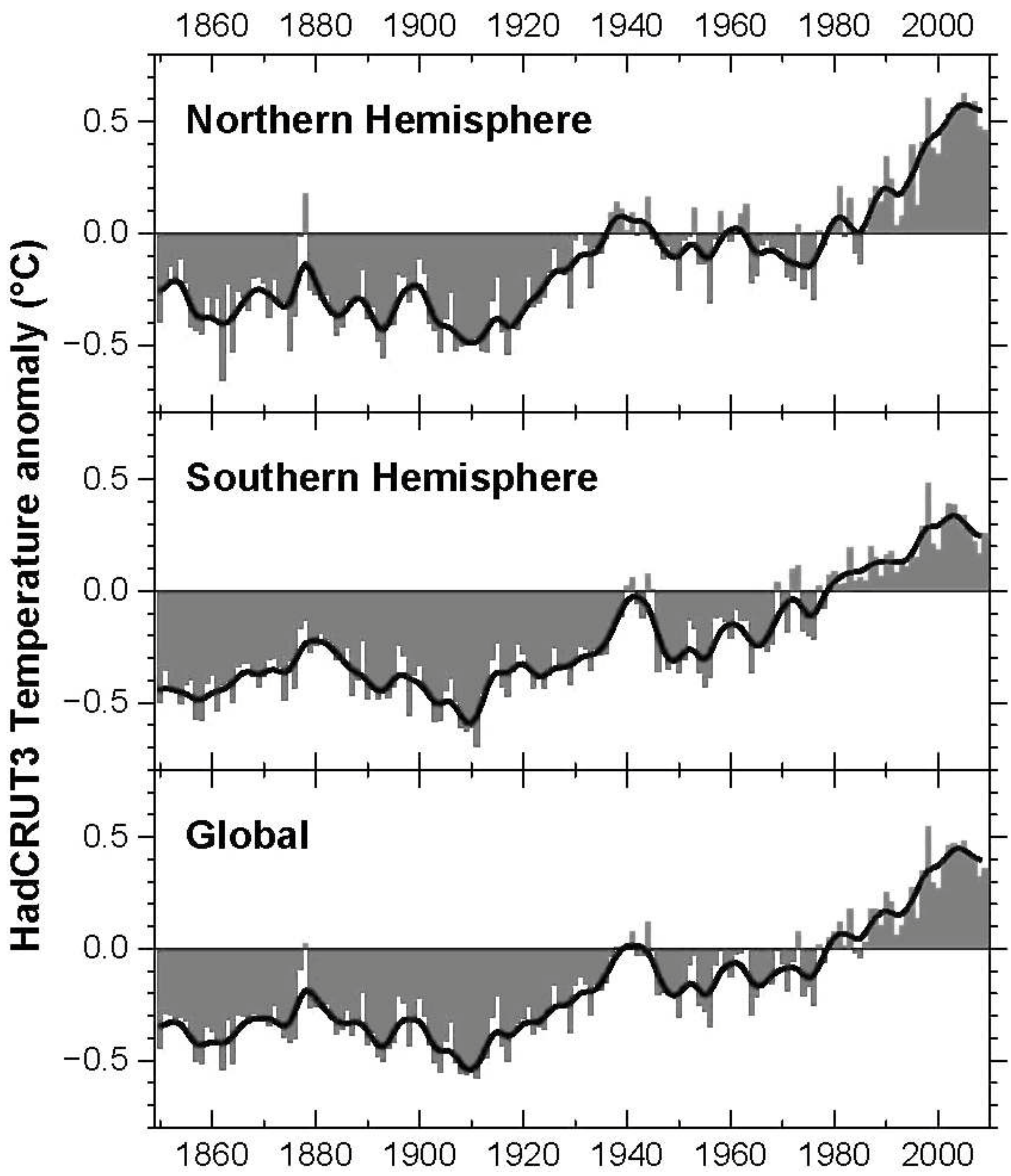

Fig. 1 Surface temperature anomalies – Global and Northern and Southern Hemispheres (from Hadley Centre, UK, 2009)