ACADEMY STATEMENT

THE SCIENTIFIC BASIS FOR CLIMATE CHANGE

KUNGL. VETENSKAPSAKADEMIEN, BOX 50005, SE-104 05 STOCKHOLM, SWEDEN TEL +46 8 673 95 00, INFO@KVA.SE ⋆ HTTP://KVA.SE, BESÖK/LEVERANS, VISIT/DELIVERIES: LILLA FRESCATIVÄGEN 4A, SE-114 18 STOCKHOLM, SWEDEN

Background

The Earth's climate is variable and has undergone many changes, both gradual and rapid, throughout its history. During mankind's time on Earth, periods with temperatures comparable to those of today have alternated with colder ice ages. These often relatively dramatic climate changes have accompanied mankind's evolution and successful development. A rapidly expanding population and growing economic development over the last two centuries, with increased demands for energy and other natural resources, have resulted in society becoming increasingly vulnerable to environmental changes, both those that are natural and those caused by mankind.

Every few years, Working Group 1 (physical science) of the UN's Intergovernmental Panel on Climate Change, IPCC, has published broad evaluations of the scientific literature dealing with climate change; the most recent being from 2013. The panel concluded that anthropogenic emissions of greenhouse gases have resulted in an increase in the temperature of the Earth's surface over the past century.

The following statement is based on scientific facts and assessments and its purpose has not been to cover areas outside the natural sciences. Changes to the climate, both natural ones and those caused by mankind, will require actions to be taken by society and will include many other disciplines, not least the development and application of new energy technologies.

A. We note the following:

1. The temperature at the Earth's surface has never been constant. Changes have taken place over many different time scales, from decades to millions of years. The last 2.5 million years, the Quaternary Period, has been characterised by extensive periods of glaciation alternating with warmer interglacial periods. During the current warmer period (the Holocene, i.e. the last 12,000 years), global temperatures were at their highest between 9,000 and 7,000 years ago. Subsequently, the temperature gradually dropped until the "Little Ice Age" that lasted for around five hundred years up to the start of the 20th century. There were, however, some interruptions, such as the warm period during the Middle Ages, around 1000-1200 CE. Our understanding of the reasons for these changes is still incomplete, even if many contributing processes are known, see item A 3. Since the 1800s, the average global temperature at the Earth's surface has increased by almost 1°C. This warming has not been constant; it has taken place in steps. These could be interpreted as natural fluctuations, stretching across several decades and which are superimposed on a longer term trend of rising temperatures (see figure 1a).

2. There are great variations in temperature trends in different parts of the world. Over the last 40 years, temperatures have most increased at high latitudes in the northern hemisphere. Over the last 30 years, during which there have been reliable satellite observations, Arctic sea ice in the late summer has retreated by about 13 per cent per decade. In the same period there has been a small increase in the sea ice around the Antarctic, where temperature changes have been negligible.

3. Probable causes of the natural temperature changes during the Quaternary Period are astronomical (orbital) factors and the related spatial and temporal variations in solar radiation, large volcanic eruptions, and internal processes in the climate system.

It is difficult to explain the warming over the past 50 years by natural factors alone, which means that human activity has contributed. One thing that supports this conclusion is the pattern of warming in the lower atmosphere (troposphere) and cooling higher up (stratosphere). However, the warming at the end of the 1800s and in the early 1900s may well have been dominated my natural factors.

4. The occurrence of greenhouse gases in the atmosphere allows the Earth's temperature to remain at a level that permits life in its current form. Without these gases, the average temperature of the Earth would be tens of degrees lower. These greenhouse gases are dominated by water vapour and carbon dioxide (CO_2), but also include a number of other gases. The levels of some greenhouse gases are significantly influenced by human activity. In addition to CO_2, these are methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs). The effect these have on the climate is both direct and indirect through the increase in atmospheric water vapour, which is a direct result of the increasing temperature.

The atmospheric concentration of CO_2 has been around 280 ppm for several thousand years. Over the past 150 years, CO_2 and CH_4 have noticeably increased, with data from Antarctic ice cores showing that their levels have now reached the highest point for at least 800,000 years. The total increase in CO_2 was 26 per cent between 1958 (when precise measurements started) and 2013. Levels rose from 315 to almost 400 ppm. Isotope measurements show that, unlike previous periods in the Earth's history, this increase in CO_2 is primarily due to anthropogenic emissions, with the majority of the increase due to burning fossil fuels. A small part is probably due to changing land use, including deforestation and the burning of biomass. Cement manufacturing has also made in a smaller but definite contribution.

5. Burning fossil fuels and biomass has, over the past century, also led to an increased concentration of aerosols, i.e. airborne particles. Some of these particles (soot) contribute to the warming effect. Others, such as sulphates and organic particles, reflect sunlight back into space and tend to cool the planet. Current opinion is

that the net effect of all the particles is a cooling that has reduced the predicted warming otherwise caused by the past century's increasing levels of greenhouse gases. However, estimations of the aerosols' cooling effect are now lower than in the previous IPCC report.

6. The observed melting of glaciers, the reduction in Arctic sea ice, increasing sea levels and warming oceans are all consistent with the global increase in temperature. Between 1870 and 2005, sea levels rose by around 1.5 mm per year, while in the 1993-2013 period they rose by around 3 mm per year. Heat distribution in deep oceans, ice sheets and large glaciers is reacting to the increase in temperature with considerable delays. Even if the Earth's temperature stabilises, sea levels will continue to rise for several hundred years as a result of the warming that occurred during the 20th century.

The surface temperature of the sea varies regionally in periods of tens of years, illustrating the complexity of the climate system, the need for more reliable data that stretches over longer periods of time, and the need for a deeper understanding of the mechanisms behind it.

7. As a result of global warming, the number of warm days has increased while the number of cold days has decreased. However, other potential changes related to a warmer climate, such as more intensive and frequent tropical and extratropical cyclones and more intensive precipitation, globally, cannot be definitely discerned

8. The climate undergoes significant natural changes over periods that may stretch across several decades. These include inherent dynamic changes, such as those related to the ENSO (El Niño/Southern Oscillation) phenomenon, the North Atlantic Oscillation, the Pacific Interdecadal Oscillation and other natural climate variations. In most areas of the world, the weather is strongly affected by such natural changes. When ENSO is in its negative phase (La Niña) and the surface water in the eastern part of the Pacific Ocean's equatorial area is colder than normal, it can counteract a global warming trend for several years. In its positive phase (El Niño), it will boost warming. These natural variations mean that there is no clear link between the last century's increase in temperature and the increase in the greenhouse gases' radiative forcing during the same period, see figures 1a and 1 b.

9. There are no reliable indications from satellite measurements of any long-term variations in solar radiation, except for the sunspots' well-known 11-year cycle. Available measurements from the last 30 years have shown that the variation in total solar radiation over the three last 11-year periods has been less than 1 part per thousand. However, measurements have been conducted for too short a time to confirm or contradict the previous indirect estimations of variation in solar radiation over longer periods of time, based on the number of sunspots and cosmogenic

isotopes. The understanding of other processes that may conceivably have an impact on the climate, such as variations in the cosmic radiation that could influence cloud formation, is still limited. There are indications that the amount of solar radiation (particularly ultraviolet light) that reaches the Earth, and which is dependent on the sun's activity, may have some effect on large-scale circulation in the atmosphere and thus also on regional climate.

10. The issue of whether the climate system responds to external influences is complex and can only be reliably determined for periods that are several decades long and for the Earth or a hemisphere as a whole. This is supported by both empirical studies and model simulations. Trends for shorter periods are unreliable and hidden by the climate system's inherent variability. Over the last 15 years, the warming of the atmosphere appears to have slowed down. The reason for this is unclear, but a contributing factor is probably that during this time the heat has been absorbed and stored in the oceans.

11. While radiative forcing by greenhouse gases is well-founded, there is a much poorer understanding of the effects of aerosols (which primarily cause a compensatory cooling) and changed land use. This is one of the explanations why climate models produce such different results. Different models make different assumptions about the effects of aerosol particles and use different descriptions of land area and heat exchange with the oceans. One important reason for the variances in results is also that the models have different ways of describing clouds and their complex indirect effects on the climate. Even if the influence of greenhouse gases, aerosols and land area on the radiative balance were known, the temperature response for the climate system would still be uncertain. There is a discrepancy of at least a factor of three between the lower and upper limits in estimations of the size of the response (the climate system's sensitivity).

12. Carbon dioxide is fundamental to life on Earth and increasing levels of it in the atmosphere may mean that vegetation grows faster. However, this effect is difficult to predict because it may be limited by other environmental factors such as the availability of nutrients and water, or by suboptimal temperatures. Satellite observations have also shown that the Earth has become greener over the last 30 years.

13. Increasing levels of carbon dioxide in the atmosphere also cause ocean acidification, which may eventually have serious effects on marine ecosystems. This increasing acidity has been well documented in measurements conducted over the past 25 years. During this period, the pH of the ocean's surface layer fell by around 0.04; it is estimated that this pH value has fallen by around 0.1 (25% increase in acidity) since the start of industrialisation.

B. What could happen in the future?

1. The slow speed of the current conversion to alternatives to fossil fuels and biomass, combined with the world's increasing power demands, means that levels of CO2 are expected to continue increasing significantly over the next century (the increase over the last fifteen years has been around 35 ppm). By the middle of this century, a concentration of between 450 and 550 ppm is probably unavoidable. The ongoing rapid accumulation of CO2 in the atmosphere, along with its long residence time in the atmosphere, is a serious problem. Unless active measures are taken, a high concentration of CO2 may remain in the atmosphere for hundreds of years. The increase in the concentration of other greenhouse gases, such as CH4 and N2O is more difficult to assess, and is not directly linked to the use of fossil fuels. Due to natural feedback mechanisms, an increase in temperature will most likely result in a further increase in emissions of CO2 and CH4 from melting permafrost, among other things, both above and below the surface of the sea.

2. Emissions of aerosols are expected to decline, as this problem is easier to manage technically. This will probably be dealt with to reduce the risk of serious local and regional health problems, particularly in India and China. Because aerosols have a short residency time in the atmosphere, their concentration and effect on the climate will decrease relatively quickly. In a longer perspective, the increasing levels of carbon dioxide are the dominating factor in future anthropogenic climate change.

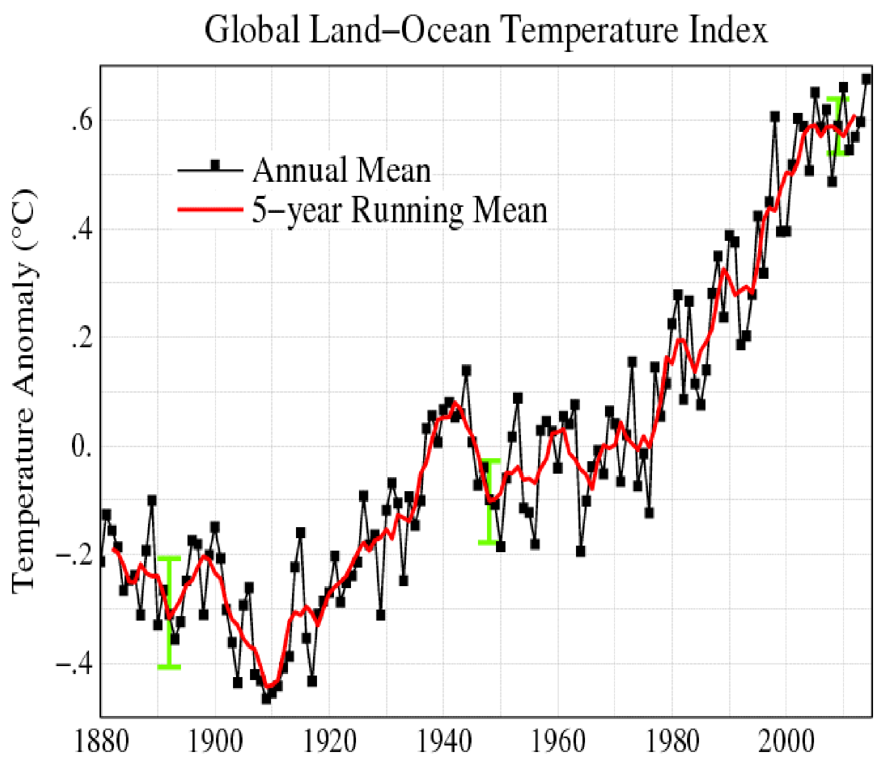
3. Based on various emissions scenarios, the IPCC has conducted simulations to estimate the effects of anthropogenic greenhouse gases and aerosols on the climate over the upcoming 100 years. These studies indicate global warming at the end of the 21st century to be 1-4°C. A considerable part of this warming is linked to positive feedback from water vapour, levels of which increase as the temperature increases. A great deal of the uncertainty about the size of this warming is due to the difficulty of assessing the role of clouds in the climate system, heat storage in the oceans, and natural temperature variations.

4. Other changes may result from the warming predicted by the IPCC, such as in the hydrological cycle, and may cause greater problems that the changing temperature itself. As the same time as a lower level of warming may be acceptable in some areas, or even have a positive effect, a higher degree of warming will probably cause very serious problems in many places in the world.

5. One consequence of the expected increase in temperature in the 21st century is a continuing rise in sea levels, caused by heat expansion in sea water and by melting ice sheets. The IPCC estimates that sea levels at the end of the 21st century could be 40 to 60 cm higher than they were in 2000.

6. Unfortunately, we do not yet have enough knowledge to be able to reliably estimate what will happen to the climate in the future. It is not possible to disregard the chance that there may be other, as yet unaccounted for, natural or anthropogenic effects on the climate system that either increase or decrease the influence of rising concentrations of greenhouse gases. One factor is how clouds are formed and dispersed; increased cloud cover at lower levels reduces the surface temperature and reduced cloud cover boosts warming. Overall, current indications are that these cloud effects have a somewhat reinforcing effect on feedback, but it is unclear how much. Other important aspects are feedback processes that influence the surface's reflective capacity (albedo) or the carbon cycle, such as emissions of CH4 from thawing Arctic permafrost on land and in shallow seas.

a.



b.

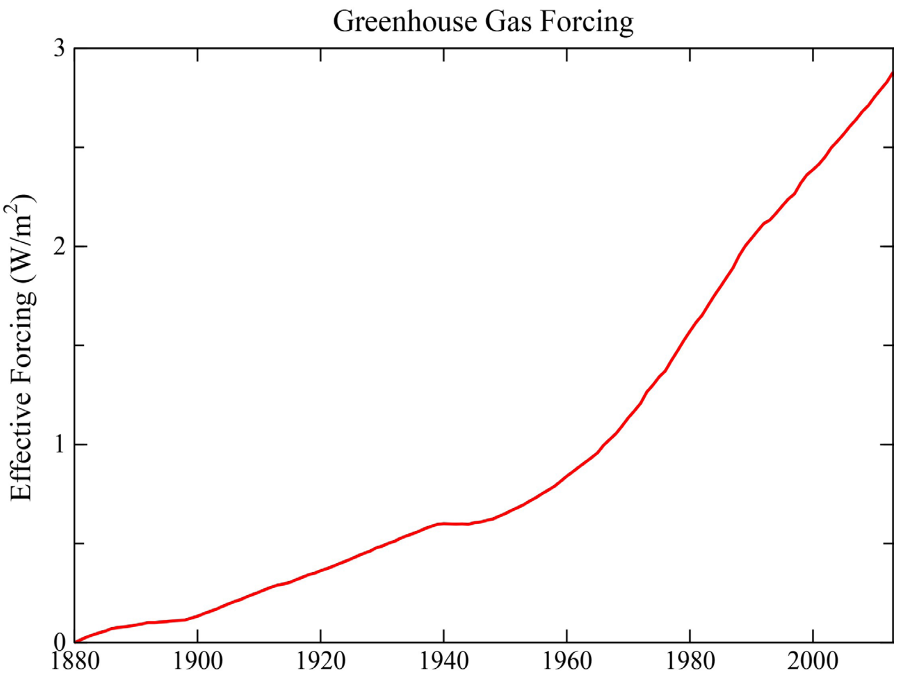


Figure 1

a. Changes to the average temperature of the surface of the Earth – annual mean and the moving five-year mean – since 1880, relative to the average temperature for the period 1951-1980. The vertical green lines show an estimated uncertainty. From GISS/ NASA,
http://data.giss.nasa.gov/gistemp/graphs_v3/

b. The development of radiative forcing from anthropogenic, long resident greenhouse gases (CO_2, CH_4, N_2O, CFCs) since 1850. Data from Makiko Sato, Columbia University. http://www.columbia.edu/~mhs119/Forcings/Fe.1850-2013.txt