SCIENTIFIC UNCERTAINTIES FEED SCEPTICISM ON CLIMATE CHANGE

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Climate change is a complex and multi-facetted phenomenon, interpreted by an extensive body of interdisciplinary science. Although a great deal is known about the climate system, an enormous amount of uncertainty remains. Since uncertainty is usually equated with ignorance, this fact feeds scepticism on man-induced impacts on the global climate and links climate change with natural causes only. A broader concept of climate change science is presented by focusing on both early and modern scientific foundations of climate models and specific types of uncertainty usually encountered when formulating quantitative assessments of risks due to climate change. Major controversial issues of such risks and their origin is addressed with paticular attention paid to the widespread criticism for inconsistency of the reports of the Intergovernmental Panel on Climate Change, based on the assumptions found not always justified by the real scientific methods. Major inconsistencies and misleading arguments on the climate change are also discussed.

Key words: *climate change, uncertainty, risk, interdisciplinarity, scepticism, Intergovernmental Panel on Climate Change*

Introduction

The existing life on the Earth is enabled by natural greenhouse effect of the atmosphere, which keeps the mean surface temperature around 33 °C higher than it would otherwise be (without this effect the temperature would be –18 °C instead of +15 °C). The greenhouse effect works because greenhouse gases (GHG) such as water vapour, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), act like a blanket around the Earth by allowing the Sun's rays to reach the Earth's surface thus keeping the heat they create from escaping into space. The ability of natural and man-induced (anthropogenic) emissions of these GHG into the atmosphere to trap heat in this way is regarded as firmly established science.

The scientists who laboured to understand the Earth's climate discovered that climate is always changing and that many factors influence it. Their studies of ancient climates showed that changes in the Earth's orbit, volcanic eruptions and solar variations were major causes of climate change. Today they add to this list the man-induced impacts on the atmospheric composition of the GHG from burning fossil fuels and deforestation as important, and, for majority of them, the only cause of climate change.

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Climate change is an extremely complex phenomenon, with many challenging policy implications. Founded on an extensive body of interdisciplinary science, a great deal is known about the climate system. Yet a large amount of uncertainties remain. which feeds scepticism on the human impacts on global climate. A broader conception of climate change, with scientific and technical issues interwoven with social and human ones, introduces types of uncertainty that are quite different from those that scientists typically encounter when formulating quantitative assessments of evidence. Since uncertainty is usually equated with ignorance, media and non-scientists in general tend to infer that scientists do not know anything about a topic just because they do not know everything about it [1]. It is therefore a widespread belief amongst scientists that communicating uncertainty to the public is difficult because uncertainty would be interpreted as an *admission* that their understanding of a subject was not complete.

This report is an attempt to summarize in a broader way the present understanding of climate change by focusing on early and modern scientific foundations of natural and anthropogenic impacts on it, as well as on some specific types of scientific uncertainty, which appears to be different from common uncertainties that scientists encounter when formulating quantitative assessments of their laboratory or field evidence. An overview of quantitative risks on climate change reported by the United Nations International Panel on Climate Change (IPCC), designated for policy makers, is compared with the sceptical views expressed by many scientists who criticise IPCC as alarmists for being not successful in applying real scientific methods and thus bringing false conclusions on the human impacts on climate change. Scientific facts in different disciplines used in the current debate on climate change and some other controversies and misleading arguments on the subject are also discussed in certain details.

An overview of climate change science

Specific features of climate change science

Climate change science has become a different branch of science from just climate science that has been practiced by climatologists over the decades. Climate change scientists are a relatively new kind of scientists with backgrounds in Earth history, geology, geography, biology, oceanography, astronomy, mathematics, physics, chemistry, and engineering, who are able to deal with massive amounts of data over relatively long time periods. After assembling and analyzing these data with analytical methods developed over many years, they are able to see significant trends revealed by analyses of these. The most obvious are the trends in temperatures, changes in sea level, volume changes in glaciers and their waning, changes in atmospheric and oceanic circulation, as well as trends in energy amounts received and distributed by Earth processes [2]. The knowledge of climate change science of the past helps them to better understand what the climate of the future would be and how mankind might mitigate some of the problems that are more certain than not to occur in the future under different possible scenarios of Earth's climate change.

The climate on Earth is usually thought of as an average of weather fluctuation, although weather is only the condition of atmosphere such as air temperature, air pressure, humidity, clouds, precipitation, visibility, and wind, measured at any particular time and place. The climate statistics is obtained by averaging weather conditions over a period long compared to the deterministic limit of predictability for atmospheric motion, which is about two weeks. Because climate change is the change in climate over a time period that ranges from decades to centuries, it should also be distinguished from climate variability, which refers to shorter-term (years to decades) fluctuations in climate, measured by changes in all the features associated with weather, such as temperature, wind patterns, precipitation, and storms.

The climate change science is a typical example of interdisciplinary science, where many scientific disciplines must be involved to explain complicated processes. The Earth's climate is product of a delicate balance of energy inputs, chemical processes, and physical phenomena, but, if this balance is upset even slightly forced by different feedback mechanisms, global climate can undergo a series of changes in a non-linear manner. Fortunately, the Earth-ocean-atmosphere system can help it to re-adjust into a new equilibrium, thus the so called runaway greenhouse effect or runaway ice age are not very likely.

Major impacts on climate change

The Earth's climate change is influenced by changes in the Earth's orbit in relation to the Sun by changing the latitudinal and seasonal distribution of incoming solar radiation at the top of atmosphere. Natural phenomena such as volcanic eruptions and variations in the energy being emitted from the Sun have also an effect on climate change. The climate is also influenced by changes of composition of the atmosphere, in particular by changes of the atmospheric concentration of GHG and cloudiness, as well as by the Earth's albedo and by interaction of the atmosphere-land-ocean system. Water vapour occurs naturally by evaporation of water from oceans, land and rivers, and may cause either cooling or warming depending on what form the water vapour occurs in, such as different types of clouds or increased humidity, for example.

The changes in Earth's orbital movement around the Sun have a long-term impact on the climate. Orbital changes occur over thousands of years, and the climate system may also take thousands of years to respond to orbital forcing. The Earth wobbles in space so that its tilt changes between about 22.1° and 24.5°. The changes in the tilt of the Earth change the strength of the seasons. The Earth's orbit around the Sun is not quite circular, which means that the Earth is slightly closer to the Sun at some times of the year than others. The eccentricity of the Earth's orbit varies and this affects the strength of the seasons. Also, the slow turning in the direction of the Earth's axis of rotation relative to the fixed stars, called precession, has a period of roughly 26,000 years [3]. As precession occurs, the seasons drift in and out of phase with the perihelion and aphelion of the Earth's orbit. The Serbian scientist Milutin Milanković calculated the slow changes in the Earth's orbit by careful measurements of the position of the stars, and through equations using the gravitational pull of other planets and stars. He has shown that the climate can also be accentuated or modified by the eccentricity (degree of roundness) of the orbital path around the Sun, and the precession effect the position of the solstices in the annual orbit of the Earth [4].

Major volcanic eruptions produce a cooling effect by ash and other particles emitted into the atmosphere where they persist for a few years and reduce the amount of the Sun's energy that reaches the Earth's surface. They can lower surface air temperature by about 0.2 °C for a few years afterward because, during volcanic eruptions, fine particles of ash and dust (as well as gases) can be ejected into stratosphere [5]. The volcanic eruptions having the greatest impact on climate are those rich in sulfur gases. These gases combine with water and form a dense layer of haze, which may reside in the stratosphere for several years, absorbing and reflecting back to space a portion of incoming energy. Also, burning fossil fuels produces sulphate aerosols which tend to cool the climate in the same way. However, strong measures taken to reduce sulphate pollution meant that industrial aerosols began to provide less compensation for an increasing warming caused by CO_2 [2]. The effects of volcanic eruptions on past climate are difficult to assess because the observational record can be interpreted in alternative way and because volcanic forcing record is not well documented. It has been alleged that the increased level of CO_2 in the atmosphere is due to emissions from volcanoes, but these account for less than 1% of the human emissions [6].

Changes of composition of the Earth's atmosphere, considered stable for millennia, is substantially different than it was just a century and half ago when humanity started to develop industry and increase its burning of fossil fuels such as coal, which add CO_2 and other GHG to the Earth's atmosphere. While nitrogen and oxygen are the main and stable constituents of the atmosphere, several GHG continue to be added to the natural GHG that absorb and emit radiation and are thus able to influence the Earth's climate. There is a belief that any increase in the levels of CO_2 in the atmosphere above natural level means that more heat is trapped causing the global warming effect and a rise in Earth's average temperature. Though the GHG such as CO_2, CH_4, and N_2O make only a small portion of the atmosphere, they have a large influence on the climate as they strongly absorb heat. Before industrialization CO_2 made only about 0.03% of the atmosphere (about 280 parts per million – ppm), but today, mainly due to human influence, it is already above 400 ppm. (The CO_2 concentration of 400 ppm was recorded at Mouna Loa Observatory in March 2013). Even these tiny quantities of GHG and deforestation have resulted in an increase in global temperatures of about 0.8 °C above their preindustrial levels [2].

The land-surface processes control the fluxes of heat, moisture and moment between the Earth's surface and the atmosphere. A number of natural phenomena influence both the circulation of the atmosphere and the climate of the Earth's surface. Interaction between the atmosphere and the underlying surfaces is sensitive to changes in surface properties such as radiative transfer, soil moisture (sensible and latent heat fluxes, runoff) and surface roughness (momentum transfer). Changes of the percent of radiation returning from the surface compared to that which strikes it (the reflectivity or albedo of the surface), as well as of cloudiness and atmosphere-land-ocean interaction can considerably impact the climate variation. Earth and its atmosphere have combined albedo of about 30%, which changes as a result of modification of the Earth surface (*i. e.*, deforestation, desertification) and cloudiness. The clouds reflect incoming sunlight back into the space (cooling effect), but also absorb infrared radiation from the Earth (warming effect), depending on the type of the clouds and their physical properties: high-altitude cirrus clouds tend to have significant greenhouse effect, while low stratified clouds have cooling effect reflecting much of the Sun's incoming energy, so that the clouds have the overall net cooling effect [5].

The oceans have a large capacity for storing energy, which gives them a possibility to play a critical role in determining weather patterns and moderating climate swings and will probably determine the global pattern and speed of climate change. They act as huge storehouses for CO_2 (total CO_2 content is 50 times greater than in the atmosphere [7]) and thus play a major role in the climate system. The uptake of anthropogenic carbon by the ocean changes the chemical equilibrium of the ocean as dissolved CO_2 forms a weak acid (as CO_2 increases, pH decreases, that is, the ocean becomes more acidic). Also, ocean waters move steadily, exchanging the heat with the atmosphere. For example, the Pacific Ocean has a warm temperature mode and a cool temperature mode, known as Pacific Decadal Oscillation (PDO). While the PDO is a geographic re-arrangement in atmospheric and oceanic circulation patterns in the North Pacific, it is known that such regional changes can also influence weather patterns over much larger areas. In the past century, it has switched back-forth between these two modes every 25-30 years, and in 1977 the Pacific abruptly shifted from its cool mode (where it had been since about 1945) into its warm mode, and this initiated global warming from 1977 to 1998, which is now over [8]. Some scientists argue that most of the warming could be the result of a natural cycle in cloud cover forced by PDO and that recent satellite measurements support the PDO as a potential major player in global warming and climate change.

Evidence coming from dendrochronology (tree rings), chemical analysis of oxygen isotopes in ice cores and fossil shells, as well as from geological evidence left behind by advancing and retreating glaciers, show that the Earth's climate has changed considerably during geological past. This evidence suggested that throughout much of the geological past, the Earth was probably much warmer than today, but also with several periods of glaciation. However, the climate change seen today differs from previous climate change in both its rate and its magnitude. For example, the 20^{th} century is reported to have been the warmest century of the last five centuries (the present-day mean temperature is at least 1.0 °C warmer than five centuries ago), with about half of this change has occurred in the 20^{th} century alone (the global average ground surface temperature has increased by at least 0.5 °C in the 20^{th} century, and since 1990, there have been some of the warmest years on record), and 80% has occurred since the year 1800 [9].

The measurements of undisturbed atmospheric concentration of CO_2 in Mauna Loa observatory in Hawaii (fig. 1) show a constant increase in emissions, which some link directly with the recorded temperature rise during the same period (fig. 2). However, the scientists believe that the oceans are responsible for a time lag at least 20 years between the time GHG reach a particular concentration in the atmosphere and the full increase in temperature, so that such a direct link may not be justified.

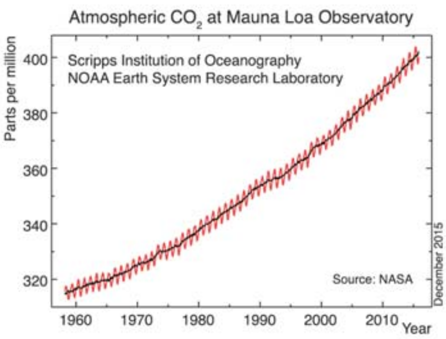

Figure 1. Recorded CO_2 concentration

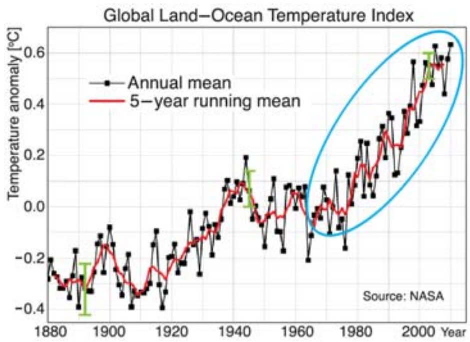

Figure 2. Annual mean land-ocean temperature rise

Recent anthropogenic emissions of GHG are considered the highest in history, and that many of the observed changes (such as warming atmosphere and ocean, diminishing the amounts of snow and ice and sea level raise) are unprecedented over decades to millennia [6]. The IPCC thus concludes that causes of the climate change are anthropogenic GHG emissions since the pre-industrial era, of which about a half have occurred in the last 40 years and that about 40% of these emissions have remained in the atmosphere while the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean (the ocean has absorbed about 30% of the emitted anthropogenic CO_2 [8]).

The IPCC claims that changes in many extreme weather and climate events observed since 1950 including an increase in warm temperature extremes have been mainly linked to human influences. According to IPCC, the pattern of warming over the past century strongly suggests an anthropogenic influence from GHG and sulfate aerosols added to the natural greenhouse effect by releasing additional GHG to the atmosphere (atmospheric concentrations of

CO_2 have increased by nearly 30%, CH_4 concentrations have doubled, and N_2O concentrations have risen by 15% [6]). The role of GHG other than CO_2 in changing the climate is already about as important as that of CO_2. Also, the atmospheric ozone is trapping incoming energy from the Sun, so that the depletion of ozone layer reduces its impact.

Evidently, changes in climate have caused impacts on natural and human systems on all continents and across the oceans indicating the sensitivity of these systems to changing climate irrespective of its cause. Some scientists argue that natural phenomena would overtop any effects of human activities and thus found good reason to believe that the rising emissions of GHG could not change the climate [10]. The basic heat-trapping property of GHG is essentially undisputed, but there is considerable scientific uncertainty about exactly how and when the Earth's climate will respond to their enhanced concentration in the atmosphere. The lag time between emission of these gases and their impact is of the order of decades to centuries, so probably the same is the time needed to reverse any effects. This implies that the policy decisions in the near term will have long-term consequences.

Scientific background of climate change

Arrhenius' greenhouse law

Modeling of climate change is not a new concept. As early as in 1895, the Swedish scientist Svante Arrhenius created the first computational climate model, and spent almost a full year calculating by hand the likely temperature changes across the Earth for increased and decreased levels of CO_2. The term *greenhouse effect* has been already identified by Fourier [11], but Arrhenius was more interested in the question of whether the ice ages might have been caused by reduced levels of CO_2. Nevertheless, his model was a remarkably good first attempt, and produced the first quantitative estimate of the warming expected from the use of fossil fuels. The British scientist Calendar in 1938 first compared long term observations of temperatures with measurements of rising CO_2 concentration in the atmosphere, to demonstrate a warming trend as predicted by Arrhenius' theory [12]. It was several decades before his work was taken seriously by the scientific community. In 1904 the Norwegian scientist Vilhelm Bjerknes identified a set of differential equations that form the basis of modern computational weather forecasting and climate models. These equations are an adaptation of the fluid flow and thermodynamics to represent the atmosphere as a fluid on a rotating sphere in a gravitational field [13]. At the time, the equations were more than a theoretical exercise, but had to wait half a century for the early digital computers, before it became possible to use them for quantitative weather forecasting. These form crucial elements for modern climate modelling together with models of orbital changes and other natural causes of climate change.

Arrhenius applied his theory to investigate how changes in the levels of CO_2 in the atmosphere could alter the surface temperature through the greenhouse effect. To do his calculations, Arrhenius had a (then) new analytical tool, the Stefan-Boltzmann law. Based on his detailed calculations and analysis, Arrhenius concluded that a geometric increase in CO_2 would cause an arithmetic increase in air temperature. In its original form, Arrhenius' greenhouse law reads as follows: *if the quantity of CO_2 increases in geometric progression, the augmentation of the temperature will increase nearly in arithmetic progression*. The equivalent logarithmic form of Arrhenius' greenhouse law is still used to calculate the radiative forcing ΔF as:

$$\Delta F = \alpha \ln(C/C_o) \tag{1}$$

Here C is CO_2 concentration measured in parts per million by volume (ppmv) and C_o denotes a baseline or unperturbed concentration of CO_2. The radiative forcing ΔF and constant α in eq. (1) are measured in watts per square meter, and α has been assigned a value of $\alpha = 5.35$ W/m^2 [14].

Using the Stefan-Boltzmann law, Arrhenius calculated the quantity of heat (H) that radiates from a body of the albedo $(1 - v)$ and absolute temperature T to another body of the absorption-coefficient β and absolute temperature θ as:

$$H = v\beta\gamma(T^4 - \theta^4) \tag{2}$$

where γ is radiation constant ($\gamma = 1.21 \cdot 10^{-12}$/scm^2). He regarded the air as a uniform envelope of the absolute temperature θ (= 0 K) and the absorption coefficient for solar heat α, while β as absorption coefficient of the air for the heat that radiates from the Earth's surface as well as the emission coefficient of the air. Arrhenius' early calculations have shown a rather high temperature rise (larger at higher latitudes) when increasing the CO_2 concentration in the air. He was changing the C/C_o ratio from 0.67 to 3.0 and found the yearly mean temperature change in the range from –3.02 to +7.30 °C for the equatorial zone with an increase towards pols [14]. He latter corrected it down to about 3 °C for doubling CO_2 [15].

Some authors have come over the revision of Arrhenius formula for calculating ΔF and have argued that his a is not constant, but it varies depending on partial pressure, specific heat and emissivity of CO_2, and that $\alpha = 5.35$ W/m^2 is an exaggerated value. Schwartz found that the temperature rise for doubling CO_2 is 0.6 to 1.6 °C, but updated his estimate by the sensitivity to be between 0.9 °C to 2.9 °C [16]. This shows a considerable amount of overlap with the IPCC *likely* range of 2 °C to 4.5 °C [17]. There are lots of other values, but a preponderance seem to center on an increase of about 1 °C for a doubling of CO_2 levels from its pre-industrial value of about Co ≈ 280 ppm. Numbers much higher than this include feedback loops, but without feedbacks, 0.5 °C to 1.5 °C is a fairly well accepted number for temperature rise.

While the shape of the curve in fig. 3 is generally correct, other more sophisticated approximations show the initial curve less steep, and the asymptote less pronounced. Nevertheless, it is generally accepted by most of the climate scientists that, in the absence of feedbacks, future increases in atmospheric CO_2 will have less effect on world temperature than past increases, and that there is a cap (~1.5 °C in fig. 3) on the total potential warming [16]. However, recent record of global temperature and related concentration of CO_2 in the atmosphere show that temperature rise trend in case without the feedback effect is underestimated if compared to records already proven by measurements. This fact opens two important questions for the continued scientific debate. Positive feedback effect may be well overestimated if doubling of CO_2 is projected to cause 3 °C temperature rise [18]. Moreover, the time lag of CO_2 uptake by the ocean of at least 20 years to a century should always be taken into account whenever concentration of GHG and temperature are mutually correlated.

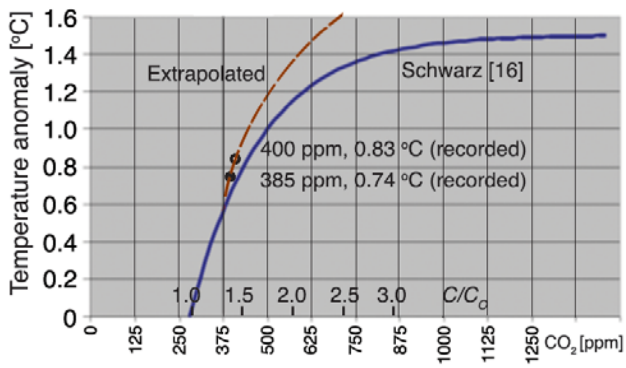

Figure 3. Arrhenius' greenhouse law without feedback effect

Milanković's cycles

A theory ascribing climatic changes due to variation in the Earth's orbit, known as Milanković's cycles, is developed by Milutin Milanković [19]. The basic premise of his theory is that, as the Earth travels through the space, three separate cyclical movements combine to produce variations in the amount of solar energy that falls on the Earth. The Earth's orbit around Sun changes in the shape (eccentricity, *e*) from nearly a circle to an elliptical orbit and back again in about 96,000 years. The greater the eccentricity of the orbit, the greater the variation in solar energy received at the top of the atmosphere between the Earth's closest and farthest approach to the Sun. Presently the Earth is closer to the Sun in January and farther away in July, but the difference in distance is small (~ 3%), although it is responsible for nearly 7% increase in the solar energy received at the top of the atmosphere [3].

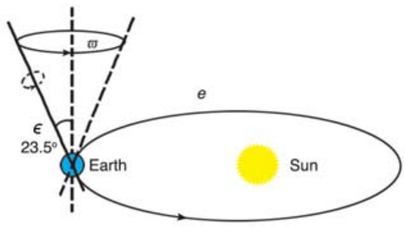

Figure 4. Changes in Earth's movement

Table 1. Milanković's cycles

Orbital change	Notation	Period, years
Excentricity	*e*	96,000
Precession	ϖ	23,000
Obliquity	∈	41,000

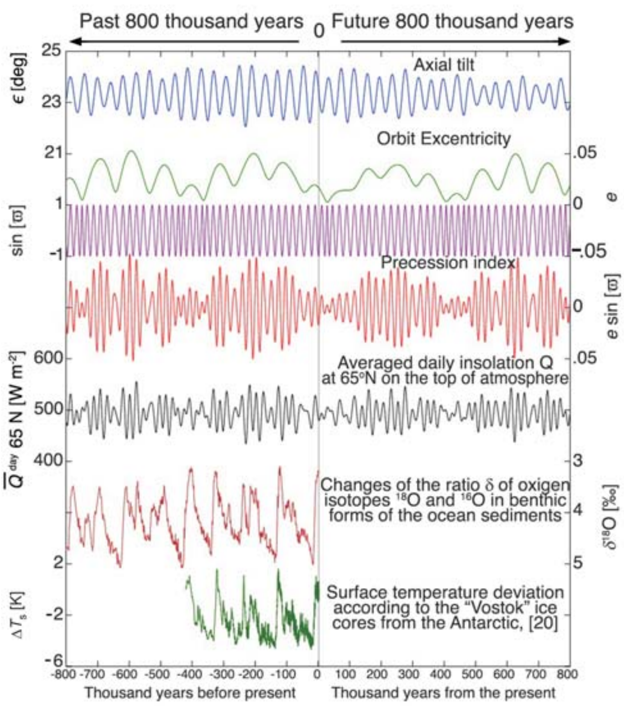

Figure 5. Milanković's cycles and their proofs

The Earth's axis of rotation moves and traces out the path of the cone in space. This change (precession, or wobbling) occurs in a cycle of about 23,000 years, tab. 1. In about 11,500 years, due to the precesion, the Earth will be closer to the Sun in July and seasonal variations in the northern hemisphere should be greater than present (opposite would be true for the southern hemisphere [2]). Changes in the tilt (obliquity) of the Earth's axis takes about 41,000 years to complete this cycle during which the tilt varies from about 22.1° to 24.5° (presently, the Earth orbital tilt is 23.5°, fig.4). The smaller the tilt the less seasonal variation there is between summer and winter.

Many studies found strong evidence that variation in climate during the past several hundred thousands years were closely associated with Milanković's cycles. Two are made evident in fig. 5 [20].

Averaged daily insolation Q at 65 °N on the top of Earth's atmosphere, calculated from the three Milanković's cycles is found coincident with the cyclical variations of surface temperature derived from the *Vostok* ice cores from the Antarctic, as well as with temperature dependent changes of concentration of the oxigen isotopes ^{16}O and ^{18}O derived from the benthic forams in ocean sediments. The *Vostok* ice-core records, spanning 420,000 years, suggest that GHG played an important role as amplifiers of the original weak, orbitally driven changes in the amount of the averaged daily insolation [21].

Climate models and their imperfections

Computer based climate models

The scientists today look into the climate change with more and more sophisticated techniques and methods of calculations. They use the computer-based climate models and analogies with historical or paleoclimatological records, which are the only two ways presently available to estimate how will climate change following the rise of the greenhouse effect. The numerical models of global climate are basic tools used for understanding and predicting climate change. They comprise a set of computer programs that solves well-understood equations describing how pressure changes cause winds to blow, how energy is absorbed, temperature changes, moisture evaporates from surface and precipitation falls.

Modern climate models are becoming increasingly accurate based on better understanding of the basic scientific principles and observations of the climate change. By creating computer simulations of how different components of the climate system behave and interact, scientists have been able to reproduce the overall course of the climate in the past. Using this understanding of the climate system, scientists are then able to project what is likely to happen in the future, based on various assumptions about natural phenomena and human activities.

It is important to note that computer models cannot exactly predict the future, since there are many unknowns concerning what might happen. Scientists make different assumptions about important factors such as how the world's population may increase, what policies might be introduced to deal with climate change and how much CO_2 and other GHG humans will emit into the atmosphere. The resulting projection of the future climate for each scenario gives various possibilities for the temperature within a defined range. While climate models are now able to reproduce past and present changes in the global climate rather well, they are not, as yet, sufficiently well-developed to project accurately all the detail of the impacts at regional or local levels. They do, however, give a guide to the direction and magnitude of future climate change, and their reliability also continues to be improved through the use of new techniques and technologies [22].

Current climate models predict that Earth's average temperature will keep rising over the next 100 years or so. There may be a year or years where Earth's average temperature is steady or even falls, but the overall trend is expected to be rising. Earth's average temperature is expected to rise even if the amount of GHG in the atmosphere decreases, but the rise would be less than if emissions remain the same or increase. Model calculations, based on the predicted ranges of future emissions and climate sensitivities show an increase in global mean surface temperature relative to 1990 of about 3-5 °C by 2100, with significant variation by region, with greater surface warming of the land than of the sea in winter, a maximum surface warming in high northern latitudes in winter and little surface warming over the Arctic in summer, as well as an enhanced global mean hydrological cycle, and increased precipitation and soil moisture in high latitudes in winter [9]. These changes are expected to lead to prospects for more severe droughts and/or floods in some places and less severe droughts and floods in other places, as well as an increase of sea-level by several tens of centimeters by the end of the next century, primarily due to the thermal expansion of the oceans and the melting of glaciers and ice sheets. As a result of climate change, the scientists expect long-term shifts in average climate conditions and/or a change in the frequency of extreme climate events, that will have significant direct and indirect impacts on the lands, oceans and resources, as well as on the economy and the quality of life for current and future generations.

In support to the IPCC studies, scientists use climate models to find the future pathways for adaptation and mitigation as complementary strategies for reducing and managing the risks of climate change [17]. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development. IPCC is confident that *without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, wide-spread and irreversible impacts globally* [6]. Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change.

The IPCC claims that limiting climate change would require substantial and sustained reductions in GHG emissions which, together with adaptation, can limit climate change risks. Namely, the climate change is expected to amplify the existing risks and create new risks for natural and human systems. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases [21]. Also, risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. Nevertheless, the IPCC is convinced that there are multiple mitigation pathways to prevent climate change beyond repair, aiming to limit warming to below 2 °C relative to pre-industrial levels [20]. These pathways, however, would require substantial emissions reductions over the next few decades and even near zero emissions of CO_2 and other long-lived GHG by the end of this century. However, implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation.

Model outcome uncertainty, also referred to as prediction error, arises from the propagation of the uncertainties through the model simulation and is evidenced by the simulated outcomes. Model prediction error can be evaluated against known analytical solutions, comparisons with other simulations, and/or comparison with observation. IPCC describes three approaches for indicating confidence in a particular result and/or the likelihood that a particular conclusion is correct [6]:

- a qualitative level-of-understanding scale describes the level of scientific understanding in terms of the amount of evidence available and the degree of agreement among experts. There can be limited, medium, or much evidence, and agreement can be low, medium, or high,
- a quantitative confidence scale estimates the level of confidence for a scientific finding and ranges from *very high confidence* (9 in 10 chance) to *very low confidence* (less than 1 in 10 chance), and
- a quantitative likelihood scale represents *a probabilistic assessment of some well-defined outcome having occurred or occurring in the future*. The scale ranges from *virtually certain* (greater than 99% probability) to *exceptionally unlikely* (less than 1% probability).

Uncertainty should be distinguished from risk because the risk involves a known probability, whereas an uncertainty arises when such probabilities are not available. This distinction is useful because the IPCC explicitly assigns probabilities to its main climate predictions, making the situation one of risk, rather than uncertainty [2]. Furthermore, these probabilities are of considerable magnitude. Given that many of the effects assigned high probabilities are associated with significant costs, they would seem to justify some kinds of action. The idea to deny the anthropogenic cause of climate change is perhaps that the IPCC's probability statements are not reliable, and as such should therefore be ignored. However, to refuse to act because of uncertainty is either to refuse to accept the global warming problem as it is, or else to endorse the principle that to *do nothing* is the appropriate response to the uncertainty [1].

Climate model imperfections

Climate model imperfection is a general term used here to describe a limited ability of scientists to simulate climate and is categorized in terms of model inadequacy and model uncertainty. Model inadequacy reflects a limited understanding of the climate system, inadequacies of numerical solutions employed in computer models, and the fact that no model can be structurally identical to the actual system. Model structural form in modeling of the physical system (*e. g.* dynamical equations, initial and boundary conditions) include the selection of subsystems to simulate (*e. g.* stratospheric chemistry, ice sheet dynamics). In addition to insufficient understanding of the system, uncertainties in model structural form are introduced as a pragmatic compromise between numerical stability and fidelity to the underlying theories, credibility of results, and available computational resources [1].

Some scientists argue that future IPCC efforts need to be more thorough about describing sources and types of uncertainty, making the uncertainty analysis as transparent as possible. Scientists argue that a concerted effort by the IPCC is needed to identify better ways of framing the climate change problem. They put particular focus on the climate model complexity that arises from the nonlinearity of the equations with high dimensionality (many degrees of freedom) and the linking of multiple subsystems. Indeed, computer simulations of the complex climate system can be used to represent aspects of climate that are extremely difficult to observe, experiment with theories in a new way by enabling hitherto infeasible calculations, understand a system of equations that would otherwise be impenetrable, and to explore the system to identify unexpected outcomes. Yet, their outputs must be taken with extreme care.

Climate models uncertainty is associated with uncertainty in model parameters, but also with uncertainty in the initial and boundary conditions. Uncertainties in parameter values include uncertain constants and other parameters that are largely contained in boundary layer turbulence and cloud microphysics, and parameters involved to compensate for the absence of neglected factors. To avoid uncertainty in model parameters and initial conditions, Curry and Webster suggest that rather than conducting a single simulation, multiple simulations must be made [23]. Uncertainty in initial conditions arises from simulations of nonlinear and chaotic dynamical systems. If the initial conditions are not known exactly, then the forecast trajectory will diverge from the actual trajectory, and it cannot be assumed that small perturbations have small effects.

Evidently, there are substantial uncertainties surrounding both the direct empirical evidence for warming and the theoretical understanding of the overall climate system. But these uncertainties impact both ways. In particular, it is also possible that global warming will turn out to be much worse than anyone has yet anticipated [24]. More importantly, the really vital issue does not concern the presence of scientific uncertainty, but rather how humanity will decide what to do under such circumstances.

Many scientists argue that even before the industrial revolution, when humans began emitting CO_2 into the atmosphere on a large scale, the Earth experienced warmer or colder periods, the changes such as periods known as the *Medieval Warm Period*, when less sea ice and larger areas of cultivated land were reported. However, in contrast to these climate phases, an increase of 0.74 °C in average global temperatures over the last century is larger than can be accounted for by natural factors alone [2].

Scientific controversies on climate change

Controversial topics

The scientific disputes concern the high level of complexity of the global climate system, in particular certain mechanisms that might be in play to moderate global warming effect. The issue here is whether there might be negative feedbacks that either reduce or negate the effects of higher levels of GHG, or even reduce the amount of them present in the atmosphere. There are positive feedbacks in the climate system as well, because an Earth covered with more snow reflects more of the Sun's energy into space, causing additional cooling. Current climate models suggest that most related factors will likely exhibit positive feedbacks (water vapor, snow, and ice), http://www.jstor.org/stable/10.1086/382247 – fn40, while others have both positive and negative feedbacks, whose net effect is still unclear (*e. g.*, clouds, ocean currents) [21]. But this scientific uncertainty does not by itself justify a sceptical position about action on climate change. There may be no more reason to assume large negative feedbacks than that the warming effect will be much worse than anticipated due to unexpectedly large positive feedbacks. Hayward [25] argues that *The models the IPCC uses for projecting a 3°C to 4°C increase in temperature all assume large positive (that is, temperature-magnifying) feedbacks from a doubling of carbon dioxide in the atmosphere* and that *changes in ocean currents, cloud formation, and wind patterns in the upper atmosphere may explain the retreat of glaciers and sea ice better than GHG*. He concludes that *The IPCC downplays theories of variations in solar activity, such as sunspot activity and gamma ray bursts, although there is robust scientific literature on that issue*, and that *even the sceptic community is divided about whether solar activity is a primary cause of recent climate variation*.

The conclusions about feedback are open to doubt because considerable uncertainties remain about the performance of the models. In particular, they are not completely reliable against past data, which is to be expected because the climate, as a highly complex system, is not very well understood yet. Also, the current models tend to assume that atmospheric feedbacks scale linearly with surface warming, and they do not adequately account for possible threshold effects and may underestimate the potential risks from global warming. Finally, there is a great deal of uncertainty about the distribution of climate change [24]. The George C. Marshall Institute states that *Natural flows of* CO_2 *in and out of the Earth's surface average about 20 times the human contribution* and that *Predictions of future climate come from computer models which are very incomplete approximations of the behavior of the real climate system* so that *The predictions of future climatic changes are hypotheses, not scientific facts* and concludes that *Whatever the threat of climate change to humanity, it is most likely to be natural, not man-made* [26].

The major scientific debate concerns the global temperature rise and the anthropogenic impacts that might be the cause of it. Systematic global temperature records exist from 1860 and satellite-based measurements are available only from 1979. The direct evidence for recent warming comes from satellites, but many scientists suggest that the satellite measurements neither match the surface readings nor provide evidence for warming, and there is no well-defined baseline from which to measure change [24]. While it is true that the last couple of decades have been the warmest in human history, it is also true that the long-term climate record displays significant short-term variability and that, even accounting for this, *climate seems to have been remarkably stable since the end of the last Ice Age about 10,000 years ago, as compared with the preceding 100,000 years* [21].

It appears that the global temperatures have fluctuated considerably over the long-term record, and that these fluctuations have been naturally caused. Therefore, the scientists are right when they assert that the observational temperature record is a weak data set and that *the long-term history of the climate is such that even if the data were more robust, we would be rash to conclude that humans are causing it solely on this basis* [27]. Even though it might be true that the empirical evidence is consistent with there being no anthropogenic warming, it is also true that it provides just the kind of record one would expect if there were a real global warming problem. This paradox is caused by the fact that scientific position with respect to climate change may simply be impossible to confirm empirically. Yet, the temperature record is not the only evidence for warming because there is also a strong theoretical grounds for concern, such as well understood physical and chemical mechanisms which give rise to a potential global warming effect.

Moreover, a new scientific study concludes that the climate change may essentially be irreversible. It explains that *As CO_2 emissions continue to rise, the world will experience more and more long-term environmental disruption and the damage will persist even when, and if, emissions are brought under control* [6]. That is the case for some of the gases that contribute to climate change, such as CH_4 and N_2O, but it is not true for the most abundant CO_2, and turning off the CO_2 emissions will not stop global warming. Contrary to common belief that *if we stopped emitting CO_2 the climate would go back to normal in 100 years or 200 years*, Solomon and others show that this is not right, because such an *irreversible change will last for more than a thousand years* [28]. They explain that this is because the oceans are currently soaking up a lot of the excess heat and a lot of the CO_2 put into the air. This heat will eventually start coming out of the ocean, which will take place for many hundreds of years, and even some decades more if emissions continue with business as usual [9]. The idea that changes will be irreversible has consequences for how politicians should deal with climate change. The scientists claim that humanity need to proceed with more caution right now, *sooner rather than later* [22].

The increase in global temperature is consistent with what science predicts that should be expected when the levels of CO_2 and other GHG in the atmosphere increase in the way that they have. Contrary to the common scientific standpoint, some scientists argue that rises in the levels of CO_2 in the atmosphere are the result of increased temperatures, not the opposite. The Center for the Study of Carbon Dioxide and Global Change [29] declared in their position statement that *considering the seven greatest temperature transitions of the past half-million years (three glacial terminations and four glacial inceptions) we note that increases and decreases in atmospheric CO_2 concentration not only did not precede the changes in air temperature, but followed them, and by hundreds to thousands of years*.

Indeed, it is true that the fluctuations in temperatures that caused the ice ages were initiated by changes in the Earth's orbit around the Sun which, in turn, drove changes in levels of CO_2 in the atmosphere. This fact is backed up by data from ice cores which show that rises in temperature came first, and were then followed by rises in levels of CO_2 during several hundred years later [30]. The reasons for this, although not yet fully understood, are partly because the oceans emit CO_2 as they warm up and absorb it when they cool down and also because soil releases greenhouse gases as it warms up. These increased levels of GHG in the atmosphere then further enhanced warming, creating a positive feedback. In contrast to this natural process, IPCC claims that the recent steep increase in the level of CO_2 is not the result of natural, but human factors because the majority of this CO_2 has come from the burning of fossil fuels [31]. The IPCC further concludes that warming caused by GHG from human sources could lead to the release of more GHG into the atmosphere by stimulating natural processes and creating a *positive feedback* effect [18].

The scientists expect that both the lower atmosphere (the troposphere, where most GHG are found) and the surface of the Earth should warm as a result of increased levels of GHG in the atmosphere, while the lower stratosphere should cool. However, initial estimates of temperatures in the lowest part of the Earth's atmosphere, based on measurements taken by satellites and weather balloons did not show the temperature rises at the Earth's surface. This was the reason for some scientists to argue that observations of temperatures taken by weather balloons and satellites do not support the theory of global warming [32]. These discrepancies have been found to be related to problems with how the data was gathered and analysed and have now largely been resolved. For example, satellites were found to be slowing and dropping in orbit slightly, leading to inconsistencies in their measurements. Also, variations between the instruments on board of different satellites also led to discrepancies (the same problem has been found with weather balloons). Furthermore, some errors in the original analyses of the satellite data showed less warming in the troposphere. However, once adjustments are made to take account of these and other issues, the warming in the troposphere is shown to be broadly consistent with the temperature trends seen at the Earth's surface.

In addition, the lower stratosphere has been shown to be cooling and this corresponds with the understanding of what effect global warming should have on that part of the atmosphere. However, some of this cooling is not related to the increased levels of GHG but due to the depletion of the ozone layer. This reduction of ozone also has an effects on other parts of the atmosphere. It is fair to note that in tropical regions there are still some discrepancies between what computer models give regarding temperatures at the surface and in the troposphere and what actually is [5]. However, these disagreements are within the bounds of the likely remaining errors in the observations and uncertainties in the models.

Some climate change scientists argue that there is a strong link between increased temperatures on Earth and the cycling processes on the Sun. Variation in solar output appears to be linked to sunspots, the huge magnetic storms that show up as cooler (darker) regions on the Sun's surface, which occur in cycles, with the number and size reaching a maximum approximately every 11 years [21]. Changes in the Sun's activity influence the Earth's climate through small but significant variations in its intensity (when more active, with a greater number of sunspots on its surface, the Sun emits more light and heat). However, while there is evidence of a link between solar activity and some of the warming in the early 20^{th} century, measurements from satellites show that there has been very little change in underlying solar activity in the last 30 years (there is even evidence of a detectable decline [10]), which cannot explain recent rises in the global temperatures. Therefore, magnitude and pattern of temperature changes can only be understood by taking into account both natural and human factors.

In their attempt to deny the role of man in climate change, some scientists argue that climate is greatly affected by cosmic rays, fast moving particles which come from space and release electric charge in the atmosphere. Laboratory experiments indicate that cosmic rays could play a role in the development of tiny particles that could play a part in the formation of clouds, which generally have a cooling effect by reflecting the Sun's rays back into space. It is believed that this process would act to enhance the influences of the Sun on the climate. However, when the Sun is more active, its magnetic field is stronger and this deflects cosmic rays away from the Earth. In fact a more active Sun would lead to fewer cosmic rays reaching the Earth, resulting in fewer clouds and therefore a warmer Earth. Even if cosmic rays were shown to have a more substantial impact, *the level of solar activity has changed so little over the last few decades and, therefore, it could not explain the recent rises in temperature* [18].

Under one of its mid-range estimates, the IPCC has projected a global average temperature increase this century of 2 °C to 3 °C [17]. This would mean that the Earth will experience a larger climate change than it has experienced for at least 10,000 years and that the impact and pace of this change would be difficult for many people and ecosystems to adapt to. Although some parts of the world could initially benefit from climate change because increased levels of CO_2 in the atmosphere would have a fertilizing effect on plants, it is likely that, as climate change progresses, negative effects would begin to dominate almost everywhere [17]. Contrary to these estimates of the IPCC, many scientists claim that the scale of the negative effects of climate change is overstated by IPCC and that there is no need for urgent action to prevent climate change.

Cross-discipline debate

Many scientific disciplines are involved in the analyses on global warming and climate change. However, some scientists claim that the climate has always been changed due to natural phenomena, while the others explain recent changes exclusively to the human activities. Hence, a great deal of publications about climate change, even in the same discipline, are either attributed to anthropogenic impacts, often illustrated by catastrophes somewhere in the world, or to absolute negation of any impact of human emissions of GHG on climate, often based on denial of the scientific background of the first ones. Yet, both are using available scientific methods and certain facts to support their standpoints.

The climate science is thus brought in focus of a heated debate on the causes of climate change. With still too many existing scientific uncertainties, and the complexity of climate system, the debate is continuing over what actions, if any, governments should take to prevent global warming. Over several years of debate it become evident that individuals from both groups tend to use the methods of the political debate to arrive to their conclusions on a complex and difficult scientific field such as climate science. Scientists in different scientific disciplines may know how much work and study is needed to understand climate science, and, as debaters, they should be expected to speak the same language and start from the same assumptions, but mainly they are not.

The IPCC declares that there is a consensus amongst their multidisciplinary scientific teams that human emissions of CO_2 are the main driver of climate change. IPCC [6] firmly states that *Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history*, that *Warming of the climate system is unequivocal*, that *since the 1950s, many of the observed changes are unprecedented over decades to millennia*, that *The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen*, *etc*. Contrary to the IPCC, many scientists deny the anthropogenic impact on climate change. They argue that these statements are not true at all, blaming the IPCC as alarmist. They conclude that *the world is no warmer today than it was earlier and that even a cooling trend has begun, although CO_2 levels are at record high levels* [32]. They add that *climate on Earth has always been and always will be changing, and no action should be taken to prevent it because natural forces have a larger impact on the climate than human CO_2.*

For example, Lindzen [33] admits that CO_2 could contribute to future warming, but *what the public fails to grasp is that the claims neither constitute support for alarm nor establish* *man's responsibility for the small amount of warming that has occurred*, and that *model results must be wrong* so that *catastrophes couldn't happen even if the models were right as justifying costly policies to try to prevent global warming*. Christy [34] states that *It is a simple fact that* CO_2 *is plant food and the world around us evolved when levels of* CO_2 *were five to ten times what they are today*, so that *The extra* CO_2 *we are putting into the atmosphere not only invigorates the biosphere, but also enhances the yields of our food crops* and concludes that *This is a tremendous benefit to nature and us*.

Also, Moore [35] claims that *When modern life evolved over 500 million years ago,* CO_2 *was more than 10 times higher than today, yet life flourished at this time; then an Ice Age occurred 450 million years ago when* CO_2 *was 10 times higher than today*. He admits that *There is some correlation, but little evidence, to support a direct causal relationship between* CO_2 *and global temperature through the millennia*, but *The fact that had already been both higher temperatures and ice ages at times when* CO_2 *emissions were 10 times higher than they are today, fundamentally contradicts the certainty that human-caused* CO_2 *emissions are the main cause of global warming*.

There is particularly a lot of geological evidence used for claims that CO_2 has been a much larger fraction of the Earth's atmosphere than it is today, and records to show that life flourished on land and in the oceans during ancient times. For example, Schmitt [36] states that the current levels of CO_2 in the Earth's atmosphere of 400 ppm are low by the standards of geological and plant evolutionary history (*levels were 3,000 ppm, or more, until about 65 million years ago*) and that *The cessation of observed global warming for the past decade or so has shown how exaggerated NASA's and most other computer predictions of human-caused warming have been, and how little correlation warming has with concentrations of atmospheric* CO_2, and concludes that *For most plants, and for the animals and humans that use them, more* CO_2, *far from being a pollutant in need of reduction, would be a benefit*. Also, when detailed 500,000-year record of ^{18}O variations found in vein calcite core in Nevada have been used to challenge the Milanković's theory concerning the occurrence of Quaternary glaciations [37], Winograd and Landwehr [38] have not only dismissed the relevance of this record for determining the timing of global climatic fluctuations, but concluded that it *asserts that the record provides support for the Milanković's theory*.

Another geologist, Easterbrook [39], argues that increase of anthropogenic CO_2 in the atmosphere was not the cause of the warming (*it was a continuation of natural cycles that occurred over the past 500 years*), and that *Global warming of the past century (0.8 °C) is virtually insignificant when compared to the magnitude of at least 10 global climate changes in the past 15,000 years*, but *None of these sudden global climate changes could possibly have been caused by human* CO_2 *input to the atmosphere because they all took place long before anthropogenic* CO_2 *emissions began* [40].

From the available satellite evidence Spencer [8] concludes that *the climate system is much less sensitive to GHG emissions than the IPCC climate models suggest that it is*. *If that is true, then mankind's* CO_2 *emissions are not strong enough to have caused the global warming seen over the last 100 years*. Ball [41] argues that *Claims that recent severe weather and flooding in the US are proof of human* CO_2 *impacts on global climate are scientific nonsense* and that *Unless people understand the basic science they will continue the fraud and pressure politicians into even more damaging energy and environmental policies*. An expert in meteorology (Gray [42]) denies any the anthropogenic impact on climate and adds that *A high percentage of meteorologists and/or climate scientists do not agree that the climate changes we have seen are mostly man-made*, so that *Thousands of us think the larger part of the climate changes observed* *over the last century are of natural origin*. He believes that *most of the changes that have been observed are due to multi-decadal and multi-century changes in deep global ocean currents* and that *The small changes in climate we have seen so far and the changes we will likely see in the coming decades are not potentially dangerous. It has been noted that vegetation growth is enhanced by higher CO_2 levels*. He is sure that *The global climate models will never be able to replicate the complex global atmosphere/ocean environment and its continuing changes* and therefore *We should all call out faulty science that humans are largely responsible for climate change* [42].

An expert in physics, Soon [43] claims that changes in the amount of solar energy hitting the Earth at climatically sensitive latitudes and zones exceed the global radiative forcing of CO_2 and CH_4 by several fold, but that the popular notion of CO_2 and CH_4 radiative forcing as the predominant amplifier of glacial-interglacial phase transitions cannot be confirmed. His basic hypothesis is that *long-term climate change is driven by insolation changes, from both orbital variations and intrinsic solar magnetic luminosity variations* and that this implies natural warming and cooling variations. He claims that *There is no quantitative evidence that varying levels of minor GHGs like CO_2 and CH_4 have accounted for even as much as half of the reconstructed glacial-interglacial temperature changes or, more importantly, for the large variations in global ice volume on both land and sea over the past 650,000 years*. However, a highly reputable and old scientific institution, the UK's national academy of science (The Royal Society) declares that *gases found trapped in cores of polar ice show that the levels of CO_2 in the atmosphere are now 35% greater than they have been for at least the last 650,000 years*, [44]. From the radioactivity and chemical composition of these gases the Royal Society concludes that *this is mainly due to the burning of fossil fuels, as well as the production of cement and the widespread burning of the world's forests*.

Conclusions

Scientific community mostly agrees that there is no simple method to deal with the climate change. Rather, very complex multi-disciplinary methods should be applied. To expect reliable outcomes, the climate scientists need to share the basic assumptions on how the conclusions of climate science are obtained and validated through the other relevant scientific fields. The fundamental point is to admit that scientific fields such as climate science use different methods for gathering data and managing knowledge than those scientific fields based on well designed laboratory experiments, which obviously is not possible in the case of the climate science. Otherwise, the scientific debate becomes political, and the methods used for political debates are completely different from the scientific ones.

In spite of its sophistication, when used to solve this dilemma, a global climate model is still only an approximation of the reality, because even the most powerful supercomputers available today cannot handle all the details needed to give a complete description of the climate system, nor do scientists fully understand all of the processes that affect climate. For a given concentration of GHG, the future radiation could be predicted with precision, but the resulting impact on climate may even be more uncertain because a significant fraction of warming might have been masked by many other factors, such as increased levels of sulfates and other aerosols, which reflect incoming solar radiation and alter the reflective properties of clouds, for example.

There is no scientific controversy over the claims that human activities since the industrial revolution have significantly increased the atmospheric concentration of GHG and that a higher concentration of GHG molecules in the upper atmosphere would cause more heat to be retained by the Earth and less radiated out into the solar system, so that, other things being equal, such an increase could cause global temperatures to rise. Hence, the basic circumstances are such that a greenhouse effect is to be expected. Also, the basic heat-trapping property of additional GHG emissions is essentially undisputed. However, there still remain considerable scientific controversy about whether, how and when the Earth's climate will respond to enhanced concentration of GHG. The lag time between emission of these gases and their impact is of the order of decades to centuries, so too is the time needed to reverse any effects. This implies that the policy decisions in the near term will have long-term consequences.

It is often argued that the uncertainty of the scientist's predictions on climate change is a reason for not acting at present, and that it is necessary to wait for further research to be concluded. Despite the uncertainty in measurements and in theory, difficult decision should have to be made on the basis of the available knowledge. Majority of the scientific community warns that humanity need to proceed with more caution on anthropogenic climate change sooner rather than later.

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