THE ROYAL SOCIETY

CLIMATE CHANGE controversies

a simple guide

excellence in science

The Royal Society has produced this overview of the current state of scientific understanding of climate change to help non-experts better understand some of the debates in this complex area of science.

This is not intended to provide exhaustive answers to every contentious argument that has been put forward by those who seek to distort and undermine the science of climate change and deny the seriousness of the potential consequences of global warming. Instead, the Society – as the UK's national academy of science – responds here to eight key arguments that are currently in circulation by setting out, in simple terms, where the weight of scientific evidence lies.

Misleading argument 1:
The Earth's climate is always changing and this is nothing to do with humans.

Misleading argument 2:
Carbon dioxide only makes up a small part of the atmosphere and so cannot be responsible for global warming.

Misleading argument 3:
Rises in the levels of carbon dioxide in the atmosphere are the result of increased temperatures, not the other way round.

Misleading argument 4:
Observations of temperatures taken by weather balloons and satellites do not support the theory of global warming.

Misleading argument 5:
Computer models which predict the future climate are unreliable and based on a series of assumptions.

Misleading argument 6:
It's all to do with the Sun – for example, there is a strong link between increased temperatures on Earth and the number of sunspots on the Sun.

Misleading argument 7:
The climate is actually affected by cosmic rays.

Misleading argument 8:
The scale of the negative effects of climate change is often overstated and there is no need for urgent action.

Misleading argument 1

The Earth's climate is always changing and this is nothing to do with humans. Even before the industrial revolution, when humans began pumping carbon dioxide into the atmosphere on a large scale, the earth experienced warmer periods.

What does the science say?

It is true that the world has experienced warmer or colder periods in the past without any interference from humans. The ice ages are well-known examples of global changes to the climate. There have also been regional changes such as periods known as the 'Medieval Warm Period', when grapes were grown extensively in England, and the 'Little Ice Age', when the River Thames sometimes froze over. However, in contrast to these climate phases, the increase of three-quarters of a degree centigrade (0.74°C) in average global temperatures that we have seen over the last century is larger than can be accounted for by natural factors alone.

The Earth's climate is complex and influenced by many things – particularly changes in the Earth's orbit in relation to the Sun, which has driven the cycles of ice ages in the past. Volcanic eruptions and variations in the energy being emitted from the Sun have also had an effect. But even when we take all these factors into account, we cannot explain the temperature rises that we have seen over the last 100 years both on land and in the oceans – for example, eleven of the last twelve years have been the hottest since records started in 1850.

So what is causing this increase in average global temperature? The natural greenhouse gas effect keeps the Earth around 30°C warmer than it would otherwise be and, without it, the Earth would be extremely cold.

It works because greenhouse gases such as carbon dioxide, methane, but mostly water vapour, act like a blanket around the Earth. These gases allow the Sun's rays to reach the Earth's surface but hinder the heat they create from escaping back into space. Indeed, the ability of carbon dioxide and other greenhouse gases to trap heat in this way has been understood for nearly 200 years and is regarded as firmly established science.

Any increases in the levels of greenhouse gases in the atmosphere mean that more heat is trapped and global temperatures increase – an effect known as 'global warming'. We know from looking at gases found trapped in cores of polar ice that the levels of carbon dioxide in the atmosphere are now 35 per cent greater than they have been for at least the last 650,000 years. From the radioactivity and chemical composition of the gas we know 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. The increase in global temperature is consistent with what science tells us we should expect when the levels of carbon dioxide and other greenhouse gases in the atmosphere increase in the way that they have.

It has been alleged that the increased level of carbon dioxide in the atmosphere is due to emissions from volcanoes, but these account for less than one per cent of the emissions due to human activities.

Misleading argument 2

Carbon dioxide only makes up a small part of the atmosphere and so cannot be responsible for global warming.

What does the science say?

Carbon dioxide only makes up a small amount of the atmosphere, but even in tiny concentrations it has a large influence on our climate.

The properties of greenhouse gases such as carbon dioxide mean that they strongly absorb heat – a fact that can be easily demonstrated in a simple laboratory experiment. While there are larger concentrations of other gases in the atmosphere, such as nitrogen, because they do not have these heat trapping qualities they have no effect on warming the climate whatsoever.

Water vapour is the most significant greenhouse gas. It occurs naturally, although global warming caused by human activities will indirectly affect how much is in the atmosphere through, for example, increased evaporation from oceans and rivers. This will, in turn, cause either cooling or warming depending on what form – such as different types of clouds – the water vapour occurs in.

Humans have been adding to the effect of water vapour and other naturally occurring greenhouse gases by pumping greenhouse gases such as carbon dioxide into the atmosphere through, for example, the burning of fossil fuels and deforestation. Before industrialization carbon dioxide made up about 0.03 per cent of the atmosphere – or 280ppm (parts per million). Today, due to human influence it is about 380ppm. Even these tiny quantities have resulted in an increase in global temperatures of 0.75°C (see misleading argument 1).

Misleading argument 3

Rises in the levels of carbon dioxide in the atmosphere are the result of increased temperatures, not the other way round.

What does the science say?

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 carbon dioxide in the atmosphere. This 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 carbon dioxide up to several hundred years later. The reasons for this, although not yet fully understood, are partly because the oceans emit carbon dioxide 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 greenhouse gases in the atmosphere then further enhanced warming, creating a 'positive feedback'.

In contrast to this natural process, we know that the recent steep increase in the level of carbon dioxide – some 30 per cent in the last 100 years – is not the result of natural factors. This is because, by chemical analysis, we can tell that the majority of this carbon dioxide has come from the burning of fossil fuels. And, as set out in 'misleading argument 1', carbon dioxide from human sources is almost certainly responsible for most of the warming over the last 50 years. There is much evidence that backs up this explanation and none that conflicts with it.

Warming caused by greenhouse gases from human sources could lead to the release of more greenhouse gases into the atmosphere by stimulating natural processes and creating a 'positive feedback', as described above.

Misleading argument 4

Observations of temperatures taken by weather balloons and satellites do not support the theory of global warming.

What does the science say?

It is true that in the early 1990s initial estimates of temperatures in the lowest part of the earth's atmosphere, based on measurements taken by satellites and weather balloons, did not mirror the temperature rises seen at the earth's surface. However these discrepancies have been found to be related to problems with how the data was gathered and analysed and have now largely been resolved.

Our understanding of global warming leads us to expect that both the lower atmosphere – the troposphere where most greenhouse gases are found – and the surface of the earth should warm as a result of increased levels of greenhouse gases in the atmosphere. At the same time, the lower stratosphere – the part of the atmosphere above the greenhouse gas 'blanket' – should cool.

Some have argued that climate change, as a result of human activities, isn't happening because early measurements taken from satellites and weather balloons seemed to show that virtually no warming was happening in the troposphere. However, this has been found to be due to errors in the data. Satellites were found, for example, to be slowing and dropping in orbit slightly, leading to inconsistencies in their measurements. Variations between the instruments onboard different satellites also led to discrepancies – a problem that has also been found with weather balloons. Furthermore, a mathematical error in one of the original analyses of satellite data meant that it 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 we see at the earth's surface.

In addition, the lower stratosphere has been shown to be cooling and this corresponds with our understanding of what effect global warming should have on this part of the atmosphere. However, some of this cooling is not related to increased levels of greenhouse gases but due to a different impact that humans have had on the atmosphere – the depletion of the ozone layer. Ozone warms the stratosphere by trapping incoming energy from the sun. This reduction of ozone also has 'knock on' effects on other parts of the atmosphere, underlining the importance of taking all factors into account when looking at what is happening to our climate.

It is fair to note that in tropical regions of the world there are still some discrepancies between what computer models lead us to expect regarding temperatures at the surface and in the troposphere and what we actually see. However, these disagreements are within the bounds of the likely remaining errors in the observations and uncertainties in the models.

Misleading argument 5

Computer models which predict the future climate are unreliable and based on a series of assumptions.

What does the science say?

Modern climate models have become increasingly accurate in reproducing how the real climate 'works'. They are based on our understanding of basic scientific principles, observations of the climate and our understanding of how it functions.

By creating computer simulations of how different components of the climate system – clouds, the Sun, oceans, the living world, pollutants in the atmosphere and so on – behave and interact, scientists have been able to reproduce the overall course of the climate in the last century. 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 human activities.

It is important to note that computer models cannot exactly predict the future, since there are so many unknowns concerning what might happen. Scientists model a range of future possible climates using different scenarios of what the world will 'look like'. Each scenario makes 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 carbon dioxide and other greenhouse gases humans will pump into the atmosphere. The resulting projection of the future climate for each scenario, gives various possibilities for the temperature but 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 we might see at regional or local levels. They do, however, give us a reliable guide to the direction of future climate change. The reliability also continues to be improved through the use of new techniques and technologies.

Misleading argument 6

It's all to do with the Sun - for example, there is a strong link between increased temperatures on Earth and the number of sunspots on the Sun.

What does the science say?

Change in solar activity is one of the many factors that influence the climate but cannot, on its own, account for all the changes in global average temperature we have seen in the 20th Century.

Changes in the Sun's activity influence the Earth's climate through small but significant variations in its intensity. When it is in a more 'active' phase – as indicated by a greater number of sunspots on its surface – it emits more light and heat. While there is evidence of a link between solar activity and some of the warming in the early 20th 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 – and so this cannot account for the recent rises we have seen in global temperatures.

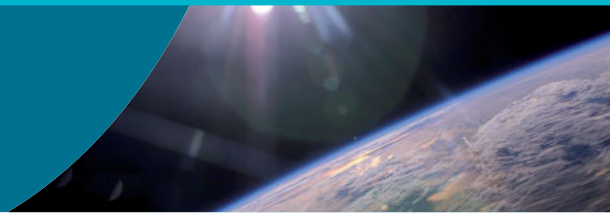
The magnitude and pattern of changes to temperatures can only be understood by taking all of the relevant factors – both natural and human – into account. For example, major volcanic eruptions produce a cooling effect because they blast ash and other particles into the atmosphere where they persist for a few years and reduce the amount of the Sun's energy that reaches the Earth's surface. Also, burning fossil fuels produces particles called sulphate aerosols which tend to cool the climate in the same way.

Over the first part of the 20th Century higher levels of solar activity combined with increases in human generated carbon dioxide to raise temperatures. Between 1940 and 1970 the carbon dioxide effect was probably offset by increasing amounts of sulphate aerosols in the atmosphere, and a slight downturn in solar activity, as well as enhanced volcanic activity.

During this period global temperatures dropped. However, in the latter part of the 20th Century temperatures rose well above the levels of the 1940s. Strong measures taken to reduce sulphate pollution in some regions of the world meant that industrial aerosols began to provide less compensation for an increasing warming caused by carbon dioxide. The rising temperature during this period has been partly abated by occasional volcanic eruptions.

Misleading argument 7

The climate is actually affected by cosmic rays.



What does the science say?

Any effect that cosmic rays could have on the climate is not yet very well understood but, if there is one, it is likely to be small. Cosmic rays are fast moving particles which come from space, and release electric charge in the atmosphere.

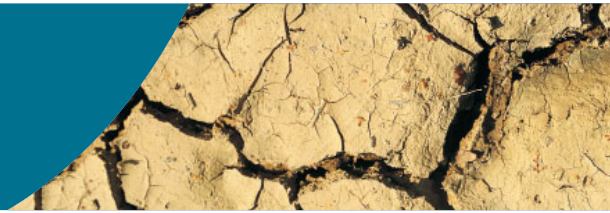
Experiments done in a laboratory hint that cosmic rays could play a role in the development of tiny particles that could in turn play a part in the formation of clouds. If this happens in the same way in the atmosphere – which isn't proven – it might lead to more clouds, which generally have a cooling effect by reflecting the Sun's rays back into space. Whether the whole chain of processes actually occurs in the atmosphere is speculative, but some of the individual steps are plausible.

It has been proposed that this process would act to enhance the influences of the Sun on the climate. We know that when the Sun is more active its magnetic field is stronger and this deflects cosmic rays away from the Earth. So the argument is that a more active Sun would lead to fewer cosmic rays reaching the Earth, resulting in fewer clouds and therefore a warmer Earth.

However, observations of clouds and galactic cosmic rays show that, at most, the possible link between cosmic rays and clouds only produces a small effect. 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 the process could not explain the recent rises in temperature that we have seen.

Misleading argument 8

The scale of the negative effects of climate change is often overstated and there is no need for urgent action.



What does the science say?

Under one of its mid-range estimates(*), the Intergovernmental Panel on Climate Change (IPCC) – the world's leading authority on climate change – has projected a global average temperature increase this century of 2 to 3 °C. This would mean that the Earth will experience a larger climate change than it has experienced for at least 10,000 years. The impact and pace of this change would be difficult for many people and ecosystems to adapt to.

In the short term, some parts of the world could initially benefit from climate change. For example, more northerly regions of the world may experience longer growing seasons for crops and crop yields may increase because increased levels of carbon dioxide in the atmosphere would have a fertilizing effect on plants.

However the IPCC has pointed out that as climate change progresses it is likely that negative effects would begin to dominate almost everywhere.

Increasing temperatures are likely, for example, to increase the frequency and severity of weather events such as heat waves, storms and flooding.

Furthermore there are real concerns that, in the long term, rising levels of greenhouse gases in the atmosphere could set in motion large-scale and potentially abrupt changes in our planet's natural systems and some of these could be irreversible. Increasing temperatures could, for example, lead to the melting of large ice sheets with major consequences for low lying areas throughout the world.

And the impacts of climate change will fall disproportionately upon developing countries and the poor – those who can least afford to adapt. Thus a changing climate will exacerbate inequalities in, for example, health and access to adequate food and clean water.

(*) See misleading argument 5 on computer model scenarios

Our scientific understanding of climate change is sufficiently sound to make us highly confident that greenhouse gas emissions are causing global warming. Science moves forward by challenge and debate and this will continue. However, none of the current criticisms of climate science, nor the alternative explanations of global warming are well enough founded to make not taking any action the wise choice. The science clearly points to the need for nations to take urgent steps to cut greenhouse gas emissions into the atmosphere, as much and as fast as possible, to reduce the more severe aspects of climate change. We must also prepare for the impacts of climate change, some of which are already inevitable.

This document was compiled with the help of the Royal Society Climate Change Advisory Group and other leading experts.

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- Inspire an interest in the joy, wonder and fulfillment of scientific discovery

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