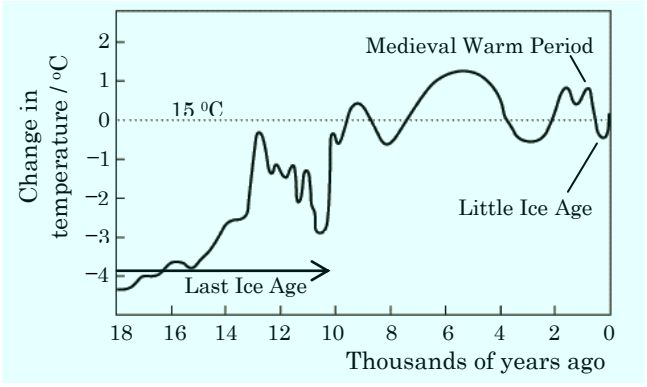
to infrared radiation than H_2O. Changes in the concentration of CO_2 in the atmosphere through human activities therefore make a significant contribution to the greenhouse effect. CO_2 emissions are believed to be the major culprit in the enhanced greenhouse effect blamed, in part, for global warming (see below). Chlorofluorocarbons, or CFCs, are extremely potent greenhouse gases but are present in tiny concentrations in the atmosphere. A list of greenhouse gases and their individual contributions to an enhanced greenhouse effect is given in Table E2 on page 14.

The Greenhouse Effect and Global Warming

Ice core samples, fossilised remains and glacial deposits all provide evidence that the Earth has had periods of climate change throughout its history (Figure E10). The last ice age finished around 10,000 years ago – relatively recently in terms of geological time. Even since then, the average global temperature has varied, at times by as much as 1 °C. For example, between the fourteenth and nineteenth centuries there was a "Little Ice Age", during which time people could skate across the frozen River Thames in London (the first Thames frost fair was held in 1607 and the last in 1814). The Little Ice Age followed a period of higher temperatures called the Medieval Warm Period.

Figure E10 Changes in Earth's Temperature over Time

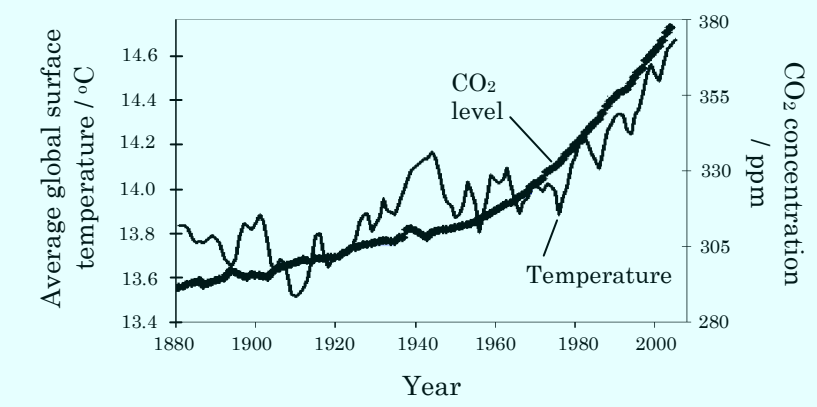


Climate change has occurred in the history of the Earth because of changes in solar activity, variations in the Earth's orbit around the Sun and changes to ocean currents. Intense periods or episodes of volcanic activity can catapult immense amounts of dust into the atmosphere, causing global cooling; the same effect can be caused by large asteroids strikes, one of which is almost certainly to have led to the extinction of the dinosaurs some 65 million years ago. Relatively small changes in temperature, both locally and globally, can have catastrophic effects on the Earth's ecosystems.

The average temperature of the Earth is buffered by various negative feedback mechanisms. For example, if the temperature of the Earth were to rise, this would result in higher rates of evaporation of water and increased cloud cover. Increased cloud thickness would *reduce* the amount of incoming solar radiation (although this does depend on the nature of the clouds formed), creating a cooling effect. Similarly, according to black body radiation, a body emits infrared radiation in proportion to the fourth power of its thermodynamic temperature (the temperature measured in kelvin). Therefore, as the Earth becomes warmer, it radiates considerably more heat.

Although we can see that the Earth has gone through repeated changes in climate, scientists are very concerned by the current rapid rise in global temperatures. The average surface temperature has risen by approximately 0.75 °C over the last century. Most scientists attribute this trend, which is commonly known as global warming, to **human activities resulting in an enhanced greenhouse effect**. All the major greenhouse gases have increased in concentration in the atmosphere since the beginning of the Industrial Revolution in the eighteenth century. For example, the concentration of CO_2 in the atmosphere has increased by around one-third since the start of the eighteenth century and the concentration of CH_4 has more than doubled over the same period. The increase in CO_2 levels due to human activities is believed to be the major contributor to global warming (see Table E2). Certainly, there is a strong relationship between atmospheric CO_2 levels and global temperature rise (Figure E11), although this does not necessarily indicate a direct causal link. The climate is a hugely complex system and influenced by many factors in addition to greenhouse gas concentrations. Some scientists believe that the rise in CO_2 is insufficient to drive the currently observed rise in global temperature, suggesting alternative factors like increases in solar activity; other global warming sceptics suggest that the current increase in temperature is simply part of another natural climate cycle.

Figure E11 Earth's Temperature and Atmospheric Carbon Dioxide Levels



About two-thirds of the extra CO_2 now found in our atmosphere have been produced from the combustion of fossil fuels like coal, oil and natural gas. The remainder is derived from deforestation and the conversion of land for intensive agriculture. Destruction of forests removes one of the natural sinks for CO_2 in the atmosphere, thus compounding the problem (a **positive feedback** mechanism). Scientists also believe that there are a number of natural positive feedback mechanisms within the environment which result in an enhanced greenhouse effect and higher and higher temperatures. For example, the oceans are another important sink for CO_2. The capacity of the world's oceans to remove CO_2 from the atmosphere decreases with temperature. Therefore, as the oceans warm up because of global warming, less CO_2 is stored by the oceans and more is released into the atmosphere. Glaciers and ice sheets serve an important function in reflecting solar radiation back into space. The oceans have a lower solar reflectivity (albedo) than ice. So as glaciers and ice sheets melt, less solar radiation is reflected from the Earth's surface. This causes more warming and the cycle continues. The thawing of permafrost (frozen soil) in arctic regions such as the vast Siberian peat bogs releases much more methane, CH_4, into the atmosphere. More and more CH_4 is also being released into the air directly and indirectly through human activities, such as from bacterial decay in landfill sites, cattle farming and biomass burning. The impact of positive feedback mechanisms is examined in http://www.5min.com/Video/How-Climate-Feedbacks-Worsen-Global-Warming-516923291.

Study Hint:
The mechanisms involved in the measured rise in the Earth's temperature, the contribution of man to these mechanisms, and the impact of global warming on life on the planet are the subject of probably the most important scientific debate of the last thirty years. There certainly is a lot – some might say everything – at stake. It is not surprising, therefore, that the subject continues to be beset by controversy, exaggerations and denials; the term "global warming" is highly emotive. There is a consensus in the scientific community that man's activities are making a noticeable impact on the global climate. But this consensus is by no means universal. The essential problem is that the Earth's climate is a hugely complex and, to a large extent, poorly characterised system. This makes it extremely difficult to link any climatic events or characteristics to a single cause. Passionate but uninformed addresses by politicians, administrators and environmentalists do little to help the debate.

As always, it is necessary to separate facts from conjecture and then work out exactly what those facts mean. There are a number of fundamental questions that we need to ask:

- Are the recent rises in global temperature part of a natural post-glacial climatic cycle or are they unnatural and influenced by human activities?
- Are global temperature rises due to an *enhanced* greenhouse effect? Is there another explanation?
- If an enhanced greenhouse effect is in operation, how much have man's activities contributed to this?
- Are changes to the way we live necessary? What can we do to limit or even reverse the impact we may have on the environment and will this help?

It is not the aim of this text to try and answer these questions for you but instead provide you with at least some of the facts so that you can have your own informed debate. Interested students may like to read the following comprehensive report from the Intergovernmental Panel on Climate Change: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

Whatever the cause, the simple fact is that the Earth is currently warming. But getting accurate data on the extent of present and future warming is problematic. Climate model projections in the IPCC report indicate that global surface temperature will rise by a further 1.1–6.4 °C this century. This is a large range, which reflects a large uncertainty in the models. Climate models are inevitably simplifications because of limitations in available computer power and our knowledge of the climate system. Nonetheless, as the controversy rages about the precise origin and extent of global warming, even small increases in the planet's surface temperature have tremendous implications for the environment and for the way we live.

Impact of Global Warming

While global warming may be, as the name suggests, a global issue, the impact of rising temperatures may have local effects; moreover, these effects may be completely different in different parts of the world (for example, more rainfall in one area and less rainfall in another). We can only make generalisations about the current and future impact of global warming. Some of the most important consequences are given below.

Sea level rises

We have seen that the oceans are an integral part of the carbon cycle. Warming of the oceans releases more CO_2 into the atmosphere. Global warming models predict a rise in the level of the Earth's oceans due to two main mechanisms:

- **Thermal expansion** of the oceans: as water warms up, it occupies a greater volume.
- Additional water entering the oceans because of **ice-cap and glacier melting**.

Estimates of sea level rise in the next century vary from around 10–80 cm, although much larger rises have been predicted in some studies. The degree of sea level rise varies between different oceans; some areas like off the west coast of North and South America have actually seen sea level falls over the last twenty years or so. Because of variations in atmospheric pressure and ocean currents, the oceans of the planet are not flat. There may be up to 2 m difference in the height of oceans across the globe.

An overall rise in sea level could have the following effects:

- Increased coastal erosion and loss of coastal habitats
- Changes to coastal water quality, affecting habitation and agriculture
- More flooding of coastal areas, especially during storm surges
- Inundation of low-lying regions of the world, such as Bangladesh, and tropical islands such as the Maldives and the Polynesian islands
- Adverse effects on tourism, recreation and transportation.

Warming of the oceans will almost certainly have an impact in other ways. For example, temperature change can cause significant alterations to ocean water circulation. We are only beginning to appreciate the influence of ocean currents on local and global weather. For example, episodes of the El Niño and La Niña ocean currents in the Pacific Ocean change rainfall patterns around the Pacific Rim. El Niño brings generally warm and wet weather to South America, often resulting in calamitous flooding, while bringing drier conditions to Australia and Southeast Asia, causing bush fires which result in a decrease in air quality. El Niño even impacts on the climate as far away as Southern and Eastern Africa. Some scientists believe that the increased intensity and frequency of El Niño and La Niña events in recent decades is due to warmer ocean temperatures resulting from global warming.

Glacier melting

As well as contributing to rises in sea level, the melting of the planet's glaciers can have a more direct impact on the environment and our lives on the planet. The glaciers of the Himalayas and the Hindu Kush, for example, are the principle sources of water for the major rivers of Central and Southern Asia. Rivers like the Ganges, Brahmaputra and Indus provide hundreds of millions of people with a supply of freshwater and also water for agricultural irrigation. Severe **freshwater and crop shortages** may occur in the future if the glaciers continue to retreat.

Locally, glacial retreat can cause loss of habitats, more frequent landslides, drought in those regions that rely on reliable glacial melt as a freshwater source, and even flooding when lakes fed by glacial melt overflow. http://video.nationalgeographic.com/video/environment/global-warming-environment/glacier-melt/ shows how a shrinking glacier in the Alps provides evidence for rising temperatures and highlights some of the local threats this poses.

Weather patterns

Asides from influencing ocean currents, global warming can affect the weather in other ways. One major concern is that global warming is increasing the occurrence of **severe weather events**. The incidence and strength of hurricanes in the Northern Hemisphere and tropical cyclones in the Southern Hemisphere appears to have been rising in recent years, with 2005 being the most active Atlantic hurricane season on record. The origins of hurricanes and tropical cyclones are not fully understood but it is believed that rising sea temperatures are an important contributor to more frequent and stronger storms. Recent extreme weather events around the world are documented in http://video.nationalgeographic.com/video/environment/global-warming-environment/glacier-melt/.

Instead of rising temperatures, some scientists suggest that Northern Europe could actually get colder. They suggest that as more of the arctic ice melts, more cold freshwater will be sent southwards. This movement of water could cut off the Gulf Stream, the warm ocean current which keeps countries like the UK warmer than might be predicted from their northerly latitude.

Through the complex and interrelated mechanisms that determine our weather, a rise in global temperatures could bring **longer and more extreme spells of dry weather or of rain**, depending on where you are in the world. Some regions of the world may experience more frequent droughts and there may be increasing desertification; other regions may experience more precipitation, increasing the risk of flooding. Changes to the average temperature and to rainfall patterns will impact on the **yield and distribution of commercial crops**, especially if supplies of freshwater diminish. Some areas have actually seen some benefits from higher temperatures, such as being able to grow crops in regions in which it was previously too cold, or by extending the growing season. Barley is being grown in Iceland for the first time in centuries and dairy farming is now possible in some parts of Greenland. However, the overall effect of global warming on agriculture is likely to be negative, particularly in Africa.

Social and economic effects

A major concern is that higher global temperatures may **increase the range of certain pests and disease-carrying organisms**. Changes in rainfall patterns, greater precipitation and humidity in the atmosphere, as well as many new areas of floodwater, could lead to an increase in disease-carrying pests such as ticks, mosquitoes and rats, which live in warmer climates and whose breeding grounds are often in damp areas. We may see, for example, the spread of malaria further into Europe. Many regions of the world rely on cold winters to eliminate disease-carrying insects and viruses. In the absence of cold winters, more areas may experience year-round illnesses. The actual effects are difficult to predict accurately because disease-carrying insects and ticks are very sensitive to the types of vegetation changes expected through global warming.

Extreme weather events are also likely to increase the threat from disease. Severe weather events like hurricanes and typhoons can cause damage to freshwater supplies and wastewater systems, creating an environment suitable for pathogens and resulting in diseases like typhoid and cholera.

The prevalence of disease, the shortage of freshwater and food, and the migration of people away from areas vulnerable to climate change will all have a significant impact on local and global economies. Some economists suggest that the changes agreed by governments under the Kyoto Protocol, designed to reduce greenhouse gas emissions, will cause the global economy to shrink, at least in the short term.