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Global warming

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If the quantity of carbonic acid increases in geometric progression,
the augmentation of the temperature will increase nearly in arithmetic progression.
SVANTE ARRHENIUS, 'GREENHOUSE LAW'

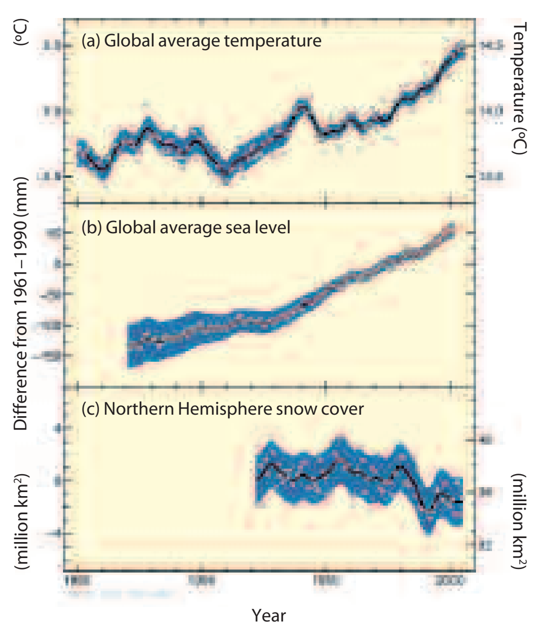
If you were to try to count all the molecules that make up the air we breathe, you would probably reach over a thousand before you came across a molecule of the colourless and odourless gas called carbon dioxide (CO_2). So if it is present only at such a low concentration, how can it possibly affect the climate of the entire planet? We also know that CO_2 must have been naturally present in our atmosphere throughout the history of the Earth, and in addition is essential to all plants. So why should we worry about releasing more CO_2 into the atmosphere by burning carbon-containing 'fossil fuels' such as oil, gas and coal?

In the beginning

In 1896, the Swedish scientist Svante Arrhenius put forward a radical new theory to explain the ice ages that had so prominently sculpted the landscape of northern Europe – he proposed that changes in the concentration of carbon dioxide in the atmosphere altered the surface temperature of the Earth and caused ice sheets to wax and wane. He went on to suggest that industrial activities and the burning of coal might drive a new warming of the Earth. Ironically, Arrhenius considered this prospect rather a good thing because of the harsh winters in Sweden, and even wondered whether coal should be burned more quickly to accelerate the warming.

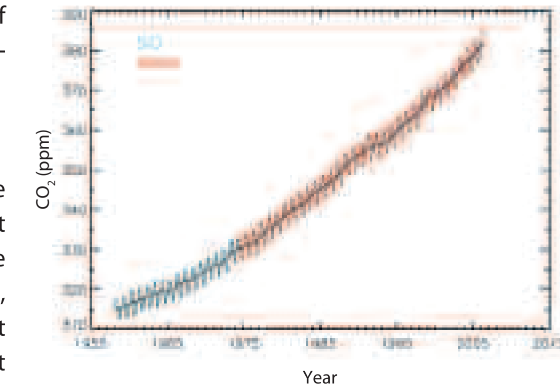
At that time, most scientists were not ready to accept a critical role for CO_2 in the climate. It is only in recent years that we have accumulated enough information about climate changes to allow scientists to make the landmark pronouncement in 2007 that: 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.'

The second missing piece of the puzzle concerned the fate of CO_2 released from the burning of coal (and other concentrated forms of 'fossil' carbon such as oil and natural gas). Like most atmospheric gases, CO_2 is soluble in water and it was once widely assumed that the oceans would quickly mop up all industrial emissions released into the atmosphere. Now, thanks to pioneering measurements made in remote parts of the world, we have unequivocal evidence that CO_2 released from fossil fuel combustion is actually accumulating in the atmosphere, year-on-year.



Changes in temperature, sea level and northern hemisphere snow cover, 1850–2000. From IPCC Climate Change 2007: The Physical Science Basis, Summary for Policymakers, 2007 caption to be written, caption to be written, caption to be written, caption to be written

But how are these two observations – of increases in both global temperatures and atmospheric carbon dioxide concentrations – linked?



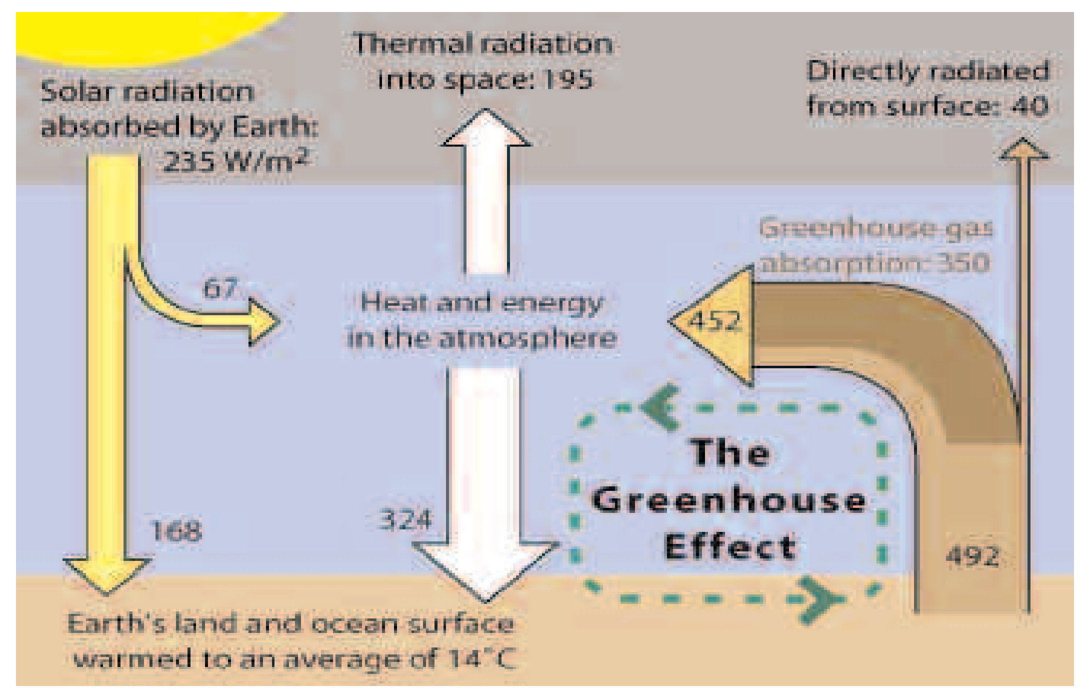
Keeling curve caption to be written, caption to be written, caption to be written, caption to be written

CO_2 – the greenhouse gas

To unravel the mysterious role of CO_2 in climate we must first look at what happens to sunlight reaching the Earth. Snow and clouds, which are fairly reflective, are said to have a high 'albedo', absorbing only 20–60% of the visible light that strikes them and reflecting the rest back the way it came. In contrast, most of the surface of the planet – leaves, rocks, soils and the ocean – has a low albedo and absorbs as much as 70–95% of sunlight.

Clearly, there has to be a loss of energy that balances the gain from visible light, otherwise the Earth would overheat. This is invisible 'infra-red' radiation – the warmth you feel from a distance from a hot water radiator even though you can see nothing if you turn off the lights. The Earth balances the absorbed sunlight by continually radiating energy to space in the form of invisible infra-red radiation. The emitted infra-red radiation has a range of different wavelengths called a spectrum, just as sunlight has a spectrum of different wavelengths corresponding to the different colours of the rainbow. This has significance in the action of greenhouse gases.

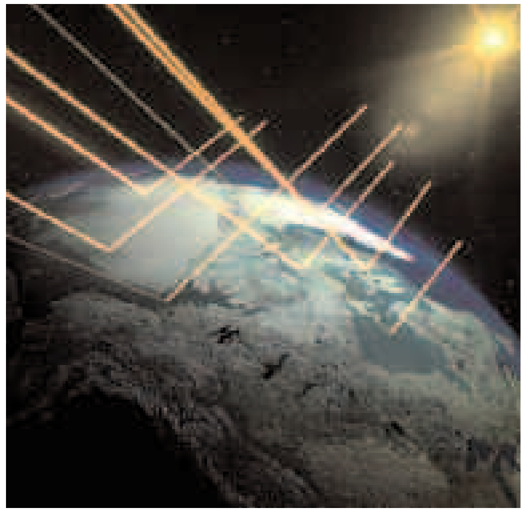
The CO_2 molecule is important because it has a special property – it traps certain wavelengths of the infra-red radiation spectrum that would otherwise escape into space and sends some of it back down to the surface. In fact, CO_2 is extremely good at this. Water vapour is another good absorber of infra-red radiation, as is methane (CH_4), which is released from decaying vegetation in swamps and from cows as they digest grass (scientists even have a polite technical term for cow burps and farts – 'enteric fermentation'), as well as



Left *Greenhouse effect diagram caption to be written, caption to be written, caption to be written, caption to be written*

Opposite *An oil refinery at Grangemouth, Scotland, caption to be written, caption to be written, caption to be written, caption to be written*

Series of images showing how polar ice reflects light from the sun. As this ice begins to melt, less sunlight gets reflected into space. It is instead absorbed into the oceans and land, raising the overall temperature, and fuelling further melting caption to be written, caption to be written, caption to be written, caption to be written



nitrous oxide (N_2O), which can also partly be blamed on cows and other livestock.

Much of the infra-red spectrum is blocked by water vapour, and the atmosphere finds it difficult to lose heat at these particular frequencies. However, there is an important 'window' region through which most infra-red radiation escapes to space. This is where the concentration of CO_2 in the atmosphere has a particularly important effect on climate, because one of the frequencies it absorbs most effectively at is immediately next to this 'window' – adding more CO_2 molecules to the atmosphere means that the band of the spectrum that CO_2 absorbs gets broader, and the width of the window consequently narrows.

The presence of CO_2 in the atmosphere, along with water vapour and methane, means that the Earth's surface is warmer than it would be if there were no greenhouse gases at all in the atmosphere. In fact, computer models of the Earth's climate system (see p. 000) predict that if the Earth had no atmosphere, the average annual surface temperature would be a chilly –19°C (–2.2°F) rather than the global average of around 14°C (57.2°F)we have today.

The past importance of CO_2 is hinted at in events some 300 million years ago when much of the coal on Earth was being formed. The CO_2 taken out of the atmosphere by plants and locked up into peat and coal deposits when they died and were buried should have resulted in colder temperatures. We see evidence for a great ice age at this time, suggesting that the Greenhouse Effect has indeed been an important controller of climate in the past (see p. 000).

Fast-forward to the future

The Greenhouse Effect then can be seen as a helpful natural phenomenon. Moreover, if there has been more CO_2 in the atmosphere in the geologic past, why is there a 'problem' with rising concentrations in the atmosphere now?

One thing that Svante Arrhenius got wrong was his estimate that global warming would take 3,000 years to occur. In fact, all the ancient CO_2 that was removed by plants on land and in the ocean, and which accumulated over tens of millions of years in geologic formations, is now being released by us in just a few short centuries.

Cattle grazing at methane fuel plant. The power from this power plant is generated from the methane of the manure of the cattle grazing in the foreground. El Centro, California caption to be written, caption to be written, caption to be written, caption to be written

Can ecosystems adapt to perhaps one of the fastest changes in climate that has ever taken place on Earth? And can society modify farming practices in response to fluctuating temperatures and rainfall and move cities away from low-lying coastal areas quickly enough to avoid rising sea-levels? These are questions we must make decisions about. Fundamentally, however, we should ask ourselves whether it would not be preferable to act first rather than react, and ensure that climate did not change to such a potentially disastrous degree.