Global Warming

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The starting point in any discussion on global climate change is to appreciate the fact that the concentration of the greenhouse gas - carbon dioxide - in our atmosphere has reached a record high relative to more than the past half million years in Earth's history, and has done so at an exceptionally fast rate. We know this because continuous direct measurements have been made since 1960, and we have data from ice core records in the polar regions that tell us the natural range of atmospheric composition for the past 650 000 years at least. In pre-industrial times, the amount of carbon dioxide in the atmosphere was around 280 ppm (parts per million). By 2005 it had reached 380 ppm a rise of 35%. We have to go back many millions of years, long before the emergence of homo sapiens, to find a time when carbon dioxide levels were naturally higher. Bear in mind that our Earth was a very different place then. As the continents were joined together in different configurations and ocean circulation was completely different to today we cannot use that time period to make comparisons with the present day. There was no ice in the Polar Regions, and sea levels and global temperatures very much higher than today. Of course, if our climate system simply responds to natural variations and is not influenced in any way by human activities, then we have no option but to take whatever comes, be that the next ice age or a greenhouse world with no polar ice caps. If, as a huge amount of scientific evidence suggests, our activities are influencing the global climate system leading to warming, then we need to be concerned and to take action now.

Carbon dioxide is not the only greenhouse gas and a similar pattern can be seen with other greenhouse gases like methane and nitrous oxide (Figure 1). However, for the purposes of this article I will focus on carbon dioxide because it is one of the two most important greenhouse gases in our atmosphere the other being water vapour, and because human activities have only a small direct influence on the amount of atmospheric water vapour. So, why are carbon dioxide concentrations in our atmosphere increasing?

Is the increase in carbon dioxide in our atmosphere due to natural causes or human influences?

Having stated that the concentration of greenhouse gases in our atmosphere has increased raises the important and relevant question as to whether this increase is due to natural causes as has happened in the past or to human activity like burning fossil fuel, making cement, deforestation or modern intense agricultural practices. If you drive around one of our cities one would not be surprised if this increase was due to our obsession with the motor car. Well, continuing to focus on carbon dioxide, we can tell by the character of the carbon in the atmosphere that the increase is caused by human activities, in that the ratio of heavy to light carbon atoms has changed in a way that can be attributed to the addition of carbon derived from burning fossil fuel. Furthermore, it is estimated that the annual fossil carbon dioxide emissions increased from an average of 6.4 per year in the 1990's to an average of 7.2 giga tonnes of carbon dioxide per year in 2000 to 2005. So, not only do we know that our emissions are increasing but we can measure resulting changes in atmospheric compositions. Unlikely as it may seem, human activities are affecting and have affected the composition of our atmosphere. This is not the first time that we have seen human activity having an affect on Earth's atmosphere. We now know that the release of chlorofluorocarbons (CFC's) mainly in the Northern Hemisphere has resulted in the destruction of stratospheric ozone and the resulting hole in the ozone layer detectable over Antarctica in early summer.

This may all be correct, I hear you say, but what affect does an increase in greenhouse gases have on our climate, is it or will it ultimately lead to global warming? To answer this question, we need to understand a little about the greenhouse effect and how climate systems work.

What is the Greenhouse effect?

The greenhouse effect that we hear so much about modifies the amount of the Sun's energy that escapes the atmosphere (Figure 2). It is caused by water vapour and gases like carbon dioxide and methane in the atmosphere warming the Earths surface and lower atmosphere by absorbing the suns heat and stopping it radiating back into space. Without the natural greenhouse effect the Earth's surface would be well below the freezing point of water. With the greenhouse effect the average temperature is about 14 degrees Centigrade. It follows that if we add to the concentration of greenhouse gases in our atmosphere, we intensify the blanketing effect, the amount of heat escaping will be lessened and surface temperatures will rise. Each year we pour about 26 billion tonnes of carbon dioxide into the atmosphere. Fortunately not all of this is added to that greenhouse layer; approximately half of the carbon dioxide released by human activities is absorbed by the sea (although this process seems to be slowing down as the oceans become more acidic) and by land plants. The remaining carbon dioxide stays in the atmosphere meaning more heat is retained and surface temperatures go up.

Consequently, atmospheric concentrations are a balance between what has been emitted through natural processes and human activities, and what has been removed. It would be great if the natural system could process or hide away the extra carbon that we are producing by the oceans and land plants absorbing more. Unfortunately, at the moment this is not happening and atmospheric concentrations of greenhouse gases from human emissions are increasing.

Climate, a complex interactive system

Before discussing whether or not temperatures are increasing, I would like to explain how complicated climate really is and therefore how difficult it is to understand what is happening and for scientists to predict what may happen in the future. Climate is part of a very complex interactive system called the Earth System which is affected by many natural processes and increasingly influenced by human activities. Consequently there is valuable debate (and argument!) and scientific research in progress which aims to improve confidence in predictions of future climate. Figure 3 illustrates some of the processes and exchanges that are taking place. Solar radiation which powers the whole climate system is slowly changing. There is an11 year solar cycle with varied sun spot activity which influences the intensity of the suns radiation. Also the orbit of Earth around the sun leads to changes in climate which themselves influence atmospheric concentrations of greenhouse gases. Volcanic activity can also have a significant effect, leading initially to climate cooling through the release of airborne solid or liquid particles called aerosols as witnessed by the violent eruption of Mount Pinatubo in the Philippines in June 1991. The eruption caused world temperatures to fall by an average of 1 degree Centigrade. Aerosols are also released by humans having an opposite but not equal cooling effect to our greenhouse gas emissions. Our resulting climate is a balance between all of these natural and human factors. For some times in the past, the balance was strongly influenced by solar radiation, as indicated in the ice core record, in other times in the more distant past, intense periods of volcanic activity have resulted in increased greenhouse gas concentrations in the atmosphere and a warm greenhouse World with no ice in the polar regions.

So what is happening now and how is that balance playing out? At the moment, the system is not coping with our emissions and the concentration of green house gases in the atmosphere, as I have shown above, is increasing rapidly. This may of course change in the future. But this brings us to what appears to be the key questions, is our climate warming and will it do so increasingly in the immediate future? Whether it does or not, our activities have influenced the Earth System and this should be sufficient cause for concern.

Is climate warming?

To answer this question, let's return to instrumental records. Is temperature increasing? This is not a simple question, hopefully you are getting the idea by now that the World we live in is not a simple system, the distribution of heat across our globe is irregular, we hear about parts of our world that are warmer than ever before and parts that have cooled. However, instrumental records over the past 157 years show that surface temperatures have risen globally with regional variations. More alarming, an increasing rate of warming has taken place over the past 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. Expressed as a global average, surface temperatures have increased by about 0.74 degrees C over the past 100 years (see Figure 4). Of course, there is no single thermometer measuring global temperature and it relies on many measurements across the globe. Some measurements, such as those that are taken in cities and urban areas that may be artificially high due to local effects (often referred to as the urban heat island effect) have been factored out of climate change calculations and not taken into account in the global average. If you look closely at the graph in Figure 4 you will see that the increase is not a straight line, there are some decreases as well but the overall trend is up. It is perfectly understandable that we will get this sort of response involving cooling periods. It comes back to the point that I made earlier, the response is a balance of many natural and human influences. One part of the system may take precedence for a period of time; it is the overall trend that is significant and for the past 150 years or so it is very definitely a warming trend.

And finally, I believe we can see the effects of this increase in temperature in other aspects of our Earth System such as rising sea level, melting glaciers, retreating sea ice in the Artic, diminishing snow cover (Figure 4) in the Northern Hemisphere and many changes in the distribution and behaviour of plants and animals. However, we cannot be certain in every individual example of change that it is due to increased greenhouse gas concentrations from human activities. A case in point here is the Antarctic, a part of the globe with which I am most familiar. With the exception of the Antarctic Peninsula which is one of the global hot spots, most of Antarctica has not warmed; in fact it may have cooled and is often used as an example to counter global warming arguments. The latest research suggests that the climate changes we see in Antarctica are most likely due to the thinning of the ozone layer keeping most of Antarctica cold but warming the Peninsula. Ozone is itself a greenhouse gas. This is a further example of how complicated the system is, and it also goes to show what effect humans have had through the release of CFC’s.

A warming World

For me, it is the correspondence in time between the increase in greenhouse gas concentrations in our atmosphere since the industrial revolution and the measured increases in average global temperatures and the effects that we see particularly in the Arctic region. If you combine this with our understanding of physical processes like the greenhouse effect it provides the most compelling support for global climate change and more specifically global warming. Climate change is inevitable from what we know about how the Earth System functions but the extent and speed of global warming is by no means certain. There is no doubt whatsoever that carbon dioxide is a greenhouse gas that produces warming affects, and that human activity is increasing carbon dioxide levels in the atmosphere.

Our understanding has improved to the extent that we can now have very high confidence that the average global effect of human activities since 1750 has been one of warming.

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Figure 1. Changes in atmospheric greenhouse gas concentrations.

Figure 2. Schematic view of the components of the climate system, their processes and interactions.

Figure 3. A schematic view of the components of the climate system, their processes and interactions.

Figure 4. Changes in global average surface temperature, global average sea level and Northern Hemisphere snow cover relative to averages for the period 1961 to 1990.