CLIMATE CHANGE – PAST AND PRESENT

Earth's earliest atmosphere was very dense and highly toxic, with only a small trace of oxygen. The skies were dull yellow-orange, volcanic activity was widespread and temperatures were very high, similar to Venus' surface today. Over time, temperatures fell, and the water vapour in the atmosphere condensed to form shallow oceans; hot springs were common and there was much more volcanic activity than today.

The earliest evidence of life was found in rocks dated at around 3.8 billion years old. In 1966 Maarten de Wit and Frances Westall found fossilised remains of simple bacteria. The rocks containing these fossils were formed from volcanic rocks near hot springs. It is estimated that bacteria evolved the ability to photosynthesise (the use of light energy to convert carbon dioxide and water vapour to food and oxygen) some 3 billion years ago. Geological evidence suggests that some 2.1 billion years ago the concentration of oxygen in the atmosphere began to increase markedly, as these photosynthesising bacteria spread across the world's oceans. At about this time, the skies were turning blue and the ozone layer was forming. About a billion years ago the oxygen content of the atmosphere was approaching the present-day level of 21%. Thus life itself had radically altered a highly toxic atmosphere to one similar to that of today where life as we know it could evolve; the beginnings of climate as we know it.

Since life began, the climate on Earth has fluctuated considerably, with relatively stable periods between the extremes. Over the last billion years there have been four or five mass extinctions where it is believed that between 60% and 90% of all species became extinct owing to naturally occurring climatic extremes. The latest of these was about 65 million years ago (mya) where considerable volcanic activity in western India combined with the impact of a large meteor in Mexico triggered a cooling of the climate. Large quantities of dust, ash and toxic gases were released into the atmosphere, filtering out heat and light from the Sun. Many marine creatures and larger land animals, including the dinosaurs, became extinct. It is believed that the extinction of the dinosaurs enabled the evolution of large mammals, leading to humankind. Climate change due to natural causes has been present throughout prehistory and will continue into the future. Fortunately for humankind, the climate over the past 8,000 years or so has been relatively stable.

Physicists regard the atmosphere as a non-linear system in that a small change in one part can have a disproportional effect on the whole, which can lead to catastrophic changes in climate. The causes of climate change are extremely complex and profoundly interactive, and are due largely to long term changes in the atmosphere. Variations in Earth's orbital and axial dynamics, meteor impacts and volcanic activity can result in large and occasionally rapid swings in the climate. The possibility of sunspots and related solar activity affecting climate is under investigation.

The behaviour of the atmosphere is largely controlled by insolation (the energy received from the Sun) which varies to some degree with roughly periodic changes in Earth's orbit, axial tilt and orientation. The connection between changes in the geometry of Earth's orbit and climate change over time, primarily ice ages, was first established by James Croll in 1864. In the 1920's, Milutin Milankovitch developed Croll's ideas, calculated variations in insolation over time and produced a set of curves known as Milankovitch cycles. These plot variations in Earth's orbital and axial dynamics caused largely by the gravitational influence of Jupiter and Saturn. It is believed that the Moon's gravitational field limits these planets' effect on Earth's axial movements over time, thus limiting climatic extremes to a degree. In the 1970's scientists around the world compared the climate changes revealed by the oxygen isotope record in deep sea core samples extracted from the sea bed with variations in insolation calculated by Milankovitch. It was determined that Milankovitch cycles were responsible for much of the climatic variation over the ages.

A continuous record of climate change during the last 100 million years or so is provided by fossil shells obtained from deep sea cores. Those fossil shells made of calcium carbonate contain oxygen-16, and the far less common isotope oxygen-18. Experiments have shown that the ratio of O-16 to O-18 is dependent on water temperature, thus enabling the temperature of the water in which the fossil lived to be determined. Some of these fossils originated in the top 50 metres of the ocean and sank to the ocean floor, whereas others are from bottom-dwelling creatures, enabling temperatures at the ocean surface and bottom to be established. Earth's magnetic field reverses roughly every million years; these reversals are recorded in the sediment layers of the core sample. The deep ocean temperatures have fallen from about 20^{O} C about 100 million years ago (mya) to near freezing today; this fall being particularly marked about 30 mya. This coincides with the first glacial deposits found in deep sea sediments around Antarctica, suggesting the appearance of an ice sheet on Antarctica. Land temperatures also fell considerably during this time. The record in deep sea cores suggests that about 2.5 mya the climate began to cool markedly and ice sheets became extensive in the southern hemisphere. Over the last 250,000 years there have been numerous advances and retreats of the ice sheets, which correlate with falls and rises in sea level.

A more detailed account of climate change, over the past few hundred thousand years, has been obtained from ice cores taken in Greenland. The ratio of O-16 to O-18 can be used to determine atmospheric temperature. Fresh layers of snow accumulate year by year on the ice sheet and are gradually compressed into ice. The ice can be dated by counting back these layers; on occasion volcanic fallout (from known volcanoes) trapped in the ice acts as markers. The ice cores show that the average annual temperature in Greenland has oscillated violently in the past. During the past 10,000 years the temperature has varied frequently, but not by much. However, prior to this time there were rapid and dramatic swings in temperature every few thousand years and the temperature minima were much lower until about 100,000 years ago.

Russian scientists have extracted a record of levels of carbon dioxide and methane over Antarctica during the last 150,000 years from ice cores. Minute bubbles trapped in the ice are believed to be samples of the atmosphere at the time when a particular layer in the ice core was formed, and can be analysed for gas composition. It was found that carbon dioxide and methane levels fluctuate through time and that these fluctuations correlate with changes in the atmospheric temperatures calculated from the O-16 to O-18 ratio in the ice.

Geologists have assembled the evidence from both deep sea and ice cores to produce graphs of the cyclic growth and decay of the ice sheets. Today we are in an interglacial period where the ice sheets are relatively small, sea levels are high and polar temperatures relatively high. The previous interglacial period, which was warmer (hence elephant and other warm-climate fossils discovered in Hertfordshire) ended about 115,000 years ago. By 18,000 years ago a glacial maximum had been reached, and the ice sheets extended about as far south as London and New York. During ice ages the temperature gradient between the equator and the poles becomes greater, the mean equatorial temperatures falling perhaps 2 or 3^{O} C and polar temperatures falling some 5 to 10 times as much. Further evidence for ice sheets developing so far south is in characteristic scratch-marks made in rocks by rock fragments trapped in the bottom of glaciers abrading them as the glacier advances. In addition when glaciers melt, rocks trapped throughout the glacier are deposited (drift), and the drift can be dated and analysed.

Continental drift, resulting in changing land-mass distribution and changing ocean currents over the Earth are other factors that cause climate change. The Earth's crust, together with the very outermost, more rigid part of the mantle (the lithosphere) is split into a number of tectonic plates. It is believed that convection currents within the Earth's inner mantle drive the movement of the tectonic plates. This results in continents drifting apart or colliding, and oceans expanding or contracting. Geological evidence for continental drift is found in the matching of rock types and formations, and mountain ranges across continental edges. In addition fossils of the same species from the Carboniferous and Triassic periods are spread across today's continents. Continental drift is today measured by laser ranging, which suggests that Europe and America are moving apart by some 20mm annually.

Dust particles from volcanic eruptions swept into the upper atmosphere can enhance global cooling by reflecting solar radiation back into space, and also absorbing it. High mountain ranges can influence the workings of the atmosphere in their vicinity by altering the flow of air. There is a tendency for ice ages to coincide with periods in Earth's history when continents are clustered near the poles. For example, during the Precambrian ice age about 600 mya, and that around 280 mya, large "supercontinents" were near the south pole. Land masses provide a surface for snow to settle on, the snow reflecting more solar radiation than the oceans, so resulting in more cooling. In addition ice sheets on land can spread further.

There are complex flows of ocean currents which operate at the surface and at different depths whose directions are often different within the same ocean. These can affect climate; and continental drift influences ocean currents, causing climate change. The joining of North and South America some 6 to 5 mya blocked the equatorial connection between the Atlantic and Pacific oceans and changed the pattern of ocean currents. The Gulf Stream surface current which warms the U.K. and western Europe would have intensified or even been initiated at around this time. The flow of such a current is influenced by the salinity, temperature and direction of flow of surface, intermediate and deep ocean currents (thermohaline circulation). When the ice sheets melted at the end of the last glacial maximum about 13,000 years ago, huge quantities of cold fresh water entered the sea, disrupting the global thermohaline circulation and inducing much colder conditions. Eventually, when the influx of meltwater declined, the salinity of the oceans increased sufficiently to retrigger the thermohaline circulation. This resulted in a dramatic average atmospheric temperature rise in Greenland of some 7^{O} C over the following 50 years. This implies an average global temperature change of about 4^{O} C over the same period, far greater than global temperature rise today, which is estimated at between 0.5^{O} C and 2^{O}C over the next 50 years.

The "greenhouse gases", including carbon dioxide (CO_2), methane and water vapour, have a considerable effect on the temperature at the Earth's surface. The Sun's short-wave heat radiation travels unimpeded through clear atmosphere and about 10% of the received heat is radiated back from Earth. However, the wavelength of the reflected heat is longer, as the Earth is cooler than the Sun. This longer wavelength heat is largely absorbed by the atmosphere, thus heating it. Some of this heat is re-radiated back to Earth; some is lost to space but there is a net heating effect. Computer climate models suggest that without these gases the average temperature at the Earth's surface would be -6^{O} C or less rather than the current +14^{O} C.

Dry air at sea level contains 78.1% nitrogen, 20.95% oxygen, 0.9% argon and 0.05% CO_2 and other trace gases. Evidence from ice cores shows that over the four most recent ice ages the proportion of CO_2 changed from about 180 parts per million by volume (ppmv) to 280 – 300 ppmv, and methane from 320 - 350 parts per billion by volume (ppbv) to 650 – 770 ppbv. Some 150 years ago the atmospheric CO_2 level was some 280ppmv; currently it is about 360ppmv and that of methane is 1700ppbv. Thus the quantity of CO_2 is slightly higher than previous maxima over the last 400,000 years and that of methane over twice the maximum amount over the same period.

Life on Earth is based on carbon, which is present in all living organisms. They transfer CO_2 to and from the atmosphere by respiration and decomposition. This is part of the carbon cycle, which is closely linked with the other cycles of the Earth, such as the water and nitrogen cycles. If living organisms are buried after death, there will be a net loss of CO_2 from the atmosphere; if the organic remains are burnt (coal for example), the CO_2 will be returned. Volcanic activity and forest fires can produce large quantities of CO_2. Rock weathering and plants "pumping" CO_2 into the soil (where the air spaces are far richer in CO_2 than the atmosphere) act as balancing influences. During the 150 years or so of industrial development, CO_2 levels have risen by over 20%. Some of this sharp increase may be due to natural causes but the greater proportion by far is believed to result from the burning of fossil fuels. However, because the behaviour of the atmosphere is linked to so many aspects of the surface of the Earth (insolation, volcanic activity, etc) it is difficult to establish cause and effect. Although there is direct correlation between global temperatures and the proportion of CO_2 in the atmosphere over time, it has been suggested that global warming, caused by other factors, itself may cause an increase of CO_2, rather than increasing levels of CO_2 causing global warming. However, CO_2 does influence climate, plant growth and the production of oxygen. Strictly speaking CO_2 is not a pollutant but is an essential gas in the life process, but too much is not desirable.

Chloroflourocarbons (CFC's) are the product of various industrial processes and are (or were in some instances) used in refrigerators, air conditioners and aerosol cans. Apart from damaging the ozone layer which reduces the amount of ultra-violet light from reaching the Earth's surface, they are most potent greenhouse gases. A single CFC molecule within the atmosphere has a greenhouse effect some 5,000 to 10,000 times greater than a single molecule of CO_2. Because of the clampdown on the use of CFC's in spray cans, 'fridges, etc the holes in the ozone layer are shrinking.

Methane is produced when organic materials decompose without the presence of oxygen. Leakage from coal mines, oil and gas fields, effusions from livestock, rice cultivation and sewage farms all add methane to the atmosphere. Methane is many times more effective per molecule than CO_2 as a greenhouse gas. Another potential source of methane is the loss of the permafrost in the huge areas of the Russian steppes. Increasing amounts of methane are bubbling up from the many lakes there as the winters become less severe.

Sulphur dioxide is a greenhouse gas and is also the principal cause of acid rain, which has caused widespread damage to trees. This, coupled with deforestation is effectively removing a potential source of CO_2 absorption from the atmosphere. The tropical rainforests release vast quantities of water vapour which forms clouds and provides rainfall. Where deforestation has occurred the rains tend to fail and the land turns to scrub or desert, such as the Harrapan Desert in western Pakistan.

The study of Earth and her ecosystems has been largely from the separate viewpoints of a number of specialised scientific disciplines, or a "bottom up" approach. A systems or "top down" approach which regards the Earth, including all life, as a whole, single system would complement the bottom up view. This could well broaden our understanding of life and environment. To some extent it is recognised that there are living, interdependent systems within the overall environment, known as ecosystems.

James Hutton advocated a top down approach in the 18th century. Late in the 20th century James Lovelock, who also favours a top down approach, proposed that the evolution of living organisms is tightly coupled to the evolution of their environment.

In spite of all that has been learned about climate change, our understanding of it is still very limited. It would be most unwise to jeopardise the atmosphere, and the most vigorous efforts need to be applied to minimising emissions. Reducing the burning of fossil fuels in particular and today's excessive energy usage in general will reduce emissions of CO_2 (and as an added benefit, pollutants such as sulphur dioxide) which will result in a cleaner atmosphere. All species have a small impact on the environment but "fit in", such that they find their own niche and form part of the food chain as part of a working and healthy ecosystem. It is the degree to which a species (including humans) impacts the environment that is important – too much can lead to environmental disruption.

The impact of human activity on the environment is now so great that ecosystems around Earth are being damaged or even destroyed. Because of the interdependence of ecosystems with the atmosphere, land and oceans, and to a greater or lesser extent with each other, there is risk of systemic failure in the future.

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