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Greenhouse Gases and Their Importance to Life

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1. Introduction

Greenhouse gases are those in the atmosphere that are essentially opaque to long-wave radiation but virtually transparent to short-wave radiation (Simpson, 1928; Johnson, 1954). They filter out the long-wave component of solar radiation reaching the outer surface of the atmosphere but permit the short-wave radiation to warm the surface of the Earth. Since the re-radiation from that surface is predominantly long-wave, they prevent this energy from escaping. As a result, Arrhenius (1896) proposed that carbon dioxide emitted by combustion in large industrial centres could raise the near-surface atmospheric temperature. In recent years, this warming of the local microenvironment has been found in the heart of many major cities situated away from the Tropics and is called “the urban heat-island effect”. During the last decade, this same process has been claimed to be resulting in “global warming”, i.e., resulting in rising temperatures across the entire earth. This has set off a frenzy of concern, fed in part by overexposure in the media. In many recent research papers, the data has tended to be interpreted as though atmospheric carbon dioxide concentrations were the only possible cause of climatic change. It is true that carbon dioxide is a greenhouse gas, but even the most extreme estimates of the ability of potential man-made carbon dioxide increases in the next century suggest a warming of mean annual air temperature (MAAT) of under 4°C, with most recent models suggesting an increase of less than 2°C. This confirms that the gas is only a minor factor in climatic change (Table 1). In comparison, changes in ocean currents have resulted in a decrease in MAAT over Northern Ellesmere Island of about 30°C in the last 2.5Ma.

2. Evolution of the atmosphere

The earth is believed to be 4.5 to over 5 billion years old, and its exact means of formation is still being debated. Initially, the bulk of its surface may have been covered by water (Carver and Vardavas, 1994; 1995), indicating that the mean annual air temperature (MAAT) was below 100 °C. Assuming that the equatorial regions were under water, the MAAT would have been higher than now since water absorbs about five times as much solar radiation as soil or rock (Pavlov, 1999; Harris, 2002). Gases are believed to have been vented from volcanoes and probably determined the composition of the atmosphere. These gases included large quantities of water vapour that condensed to form lakes and streams on the land areas, but would ultimately join the oceans. The hydrogen sulphide and sulphur dioxide would have dissolved in the water to form sulphuric acid. This would have

Order	Potential change in temperature (°C)	Control.
1 st	c. 30°C.	1. Difference in heat absorption by sea and land as controlled by position of continents and oceans.
2 nd	c. 15°C.	2. Changes in the geometry of the solar system. 3. Changes in ocean currents and thermohaline circulations.
3 rd .	5-10°C.	4. Milankovich cycles.
4 th .	<5°C.	5. Fluctuations in CO ₂ and greenhouse gases. 6. Large-scale volcanic eruptions. 7. Elevation of large tracts of land, e.g., Tibet. 8. El Niño and La Niña. 9. Short-term cycles, e. g., 2 and 7 years. 10. Variations in solar output. 11. Agriculture, deforestation and urbanization.

Table 1. The main suggested controls of climatic change arranged into four orders based on the potential temperature change that they can cause (after Harris, 2005).

reacted with the minerals in the rocks to form metal sulphides and sulphates, whereas the carbon dioxide that dissolved in the water was far less potent. Over time, it would have built up in the atmosphere and oceans to levels far exceeding what is found today, though it is believed that this was partially offset by chemical weathering of rocks. The relatively inert nitrogen would also have slowly built up over time. Any hydrogen or helium which may have been present in the primaeval atmosphere would have slowly escaped into space due to their low molecular weights and the correspondingly weak pull on the molecules by the Earth's gravity.

About 3Ma, there appears to have been a phase of expansion of the land areas, especially around the South Pole to form a continent called Pangaea. By that time, the MAAT around the earth appears to have been similar to that today, because we find glacial deposits intercalated in the rocks of that and subsequent ages (Crowell, 1999). Periods of increased solar radiation are postulated to have occurred (Carver and Vardavas, 1995) but there is no evidence that the sea boiled, in spite of the high carbon dioxide levels in the atmosphere. Sedimentary rocks are common in these old rocks, although they have often been metamorphosed into marbles, schists, etc.. In practice, there are numerous natural sinks or storage places for carbon dioxide including the oceans (Roll, 1965), vegetation, soils, etc.. Excess carbon dioxide in warm, shallow seas can result in precipitation of calcium carbonate deposits such as chalk or fine-grained limestones, as is occurring today around the Bahamas. Meanwhile the concentration of nitrogen would be becoming dominant in the atmosphere.

About 3 billion years ago, calcareous algal reefs are found in some sediments together with graphite, believed to be derived from metamorphism of organic matter. It appears that the reef-forming organisms used carbon dioxide dissolved in the water to both build the reefs and to produce energy and oxygen by photosynthesis. They used carbon dioxide and water to produce organic structures while emitting oxygen into sea. There is always a dynamic equilibrium in both carbon dioxide and oxygen levels in water bodies and the adjacent atmosphere, so the atmospheric levels of carbon dioxide would be decreasing while oxygen would be increasing. In the atmosphere, the mixing of gases is fairly efficient, but in the oceans, the dissolved gases may vary considerably from place to place, depending on the topography, gravity, and currents. There can be appreciable latitudinal variations in the oceans (Grasby and Beauchamp, 2008). Even today, parts of the Baltic Sea are anoxic. This implies that indications of carbon dioxide levels in sediments deposited in water bodies cannot safely be used as indicators of contemporary atmospheric concentrations.

At first, the oxygen produced by the reef organisms would have been mainly used in the oxidation of other minerals, but over time, the composition of the atmosphere would have changed. The algal reefs continued to occur as the main evidence of life until there was an explosion of new life forms in the oceans about 600ka, at the beginning of the Cambrian period. Many early Cambrian fossils exhibit large gill-like structures, clearly adapted to making the most of the low oxygen levels in the oceans. By this time, more advanced aquatic plant life was also present.

Shortly afterwards, the first simple plants appeared on land and flourished, soon producing the large and spectacular forests that were to characterize the middle Palaeozoic era, and they paved the way for the survival of the first animals on land. The fern, *Glossopteris*, even colonized the land around the margins of the vast ice cap covering the South Pole at this time.

In photosynthesis, six molecules of carbon dioxide yield six molecules of oxygen plus one molecule of glucose. The organic compounds in the structures of the plant decompose when the plant dies. In the humid tropical climates, this becomes carbon preserved today in the form of coal. For every 12 kilos of carbon being fixed as glucose by photosynthesis, 32 kilos of oxygen would have been released into the atmosphere. The great volumes of the coal deposits of the Palaeozoic era indicate that initially, there was a great concentration of carbon dioxide in the atmosphere. The extensive tropical forests of the latter part of the Palaeozoic era must have resulted in a vast change in the proportions of atmospheric oxygen and carbon dioxide. This would also mean that the weathering of rocks would have changed to processes similar to those occurring today in comparable climatic regimes. Runoff would have been reduced by the accumulation of a litter layer and substantial quantities of water would have been returned to the atmosphere by evapotranspiration.

The GEOCARB III CO₂ model of Berner and Kothavala (2001) indicates the change in relative proportions of carbon dioxide and oxygen, but suggests that the atmospheric carbon dioxide concentration increased from under 1% by volume in early Permian times to a maximum in the early Cretaceous Period. Since then, it has been steadily decreasing. The volcanic outpourings of magma in the Permo-Triassic period would have been accompanied by degassing, with increasing levels of carbon dioxide, but there was significant formation of coal deposits along the Rocky Mountains under a wet tropical climate at this time to drop the levels towards those seen today (0.03% by volume).

Berner (1990) suggests that the atmospheric oxygen levels rose from about 26% by volume in the Lower Mississippian to a maximum around 35% in the Stephanian (Upper

Carboniferous), before declining to around 15% at the Permian-Triassic boundary. Since then, they have increased with minor fluctuations to the present level (21%).

The ice cap persisted over the South Pole, and when Laurasia separated from Gondwanaland, the carbon dioxide content of the atmosphere was still at least eight times the present-day levels (Retalack, 2001). In spite of this, there was no obvious world-wide climatic change, nor was there when the excess carbon dioxide was re-absorbed into the natural sinks or largely used up in forming the Mesozoic coal deposits, e.g., at the Crows Nest Pass and Banff. If carbon dioxide levels controlled the MAAT the way that has been claimed by proponents of global warming, why were there not considerable changes in the MAAT as the concentration of carbon dioxide dwindled at various times in the past?

3. Greenhouse gases in the atmosphere

The dominant greenhouse gas in the atmosphere is water vapour. For every three parts of carbon dioxide, there are 500-750 parts of water vapour. The latter fluctuates continuously within these limits, depending on the ambient temperature and the relative humidity. Any excess is condensed into water droplets or ice crystals (clouds) which can lead to precipitation (rain, hail, sleet or snow). The clouds also act as layers of greenhouse substances in the atmosphere, modifying diurnal heating and cooling. Given the vast discrepancy in abundance between the concentrations of water vapour and carbon dioxide, it is surprising that so little attention has been paid to the role of water vapour. It would seem likely that the continuous and substantial changes in water vapour would dominate the relatively puny changes in carbon dioxide. Both gases are key elements for the survival of life as we know it since both are required for photosynthesis in green plants. The latter represents the starting point in our food chain, and the carbon dioxide emitted by living animals helps provide the continuous supply needed by plants. The latter return the favour by emitting oxygen which is needed by the animals. This relationship is especially well demonstrated on coral reefs. Note that water is essential for all forms of life as we know it, and as the human population grows, it will become increasingly a limiting factor in our lives.

4. Sources of atmospheric moisture

There are three main sources of atmospheric moisture. The first is evaporation from water bodies, primarily oceans. This source represents about 70% of the surface of the Earth and does not change significantly on the time scale affecting Mankind. A second source is evaporation from bare ground, but this is a relatively minor component, even though it tends to be increasing due to desertification. However the third main source is evapo-transpiration from vegetation. This returns enormous quantities of water to the atmosphere in the case of mature forests, which have tremendous areas of leaf surfaces with stomata. This represents a very important element in the hydrologic cycle, while the trees act as an umbrella, keeping the bulk of the solar radiation from heating the ground. Instead, there is a relatively cool, humid micro-environment beneath a closed forest canopy. Furthermore, the organic surface layer on top of the mineral soil acts like a sponge, storing water and reducing runoff. This water ensures that the humidity remains high beneath the upper canopy between precipitation events and provides the moisture for the evapo-transpiration to continue long after the precipitation has ceased. This ensures that this water is recycled back into the atmosphere instead of mainly draining away as runoff down stream courses to the oceans.

5. Humans, population growth and the loss of mature forests

As human populations increase, they need more places to live, with more food, and there is increasing commercial use of the forests. This results in clearing more land to try to grow more food and provide employment opportunities. The logging industry, together with the slash and burn expansion of agriculture in forested regions greatly affects the global availability of atmospheric moisture due to its reduction in evapo-transpiration in the deforested areas. Since the middle of the last century, 85% of the forests have been logged to provide arable land in Costa Rica, resulting in a decrease in precipitation by 30% in some areas of the country. Since the country is in the subtropical trade wind belt with no obvious barriers to the rain-bearing winds, it would appear that deforestation is the culprit. Replanting of forests is a step in the right direction, but it takes decades to replace the original forest with an equivalent leaf-cover to the original forest in the tropics, and several centuries in the case of forests at higher latitudes. Since fresh water is becoming a scarce commodity in many parts of the world while populations and demands are increasing, this problem needs serious consideration.

Desertification is an ever increasing problem. When Sir Henry Rawlins sailed his gunboat up the Tigris River in 1845, the villagers around the Arch of Ctesiphon requested him to send a shore party to kill a man-eating lion that was dwelling in the jungle around the Arch. He obliged, and then continued up the river, dodging plane tree logs that were floating down to the sea. The last lion is reputed to have been killed at Balad Ruz in 1890. By 1957, the Arch stood alone in the desert (Figure 1). Gone were both the jungle and the villagers. The only remaining forest in Iraq at that time was some scrub Oak in the mountains along the Iranian and Turkish borders.



Fig. 1. The Arch of the Ctesiphon in 1956.

There is a similar trend all along the Silk Road to China. Towns that once saw the hustle and bustle of the trade route in the Middle Ages now lie abandoned to the wind and sand dunes. The same thing has happened in North Africa. In Roman Times, this was the granary of the south, while France and England represented the granary of the north.

6. Contemporary desiccation in western Canada

In western Canada, the glaciers along the crest of the Eastern Cordillera in the National Parks are retreating at an alarming rate (Bolch et al., 2010), though there is far less loss of mass in the case of the glaciers along the Coastal Ranges. The values of mean annual air temperature at stations along the Eastern Cordillera are not currently changing (Harris, 2009), but the glaciers are retreating at an ever-increasing rate. There is no farming or agriculture in the vicinity, nor any large towns. The problem is that the precipitation has decreased markedly since 1910 A.D. There were terrible accidents along the Canadian Pacific Railroad through the Rogers Pass about that time due to enormous avalanches which killed many workers. Today, many of the former deadly avalanche slopes have become reforested with young trees, though many problematic slopes remain. In a study of the increase in size of the avalanche tracks in the Vermilion Pass, Winterbottom (1974) demonstrated that the avalanches were more than double the size of the present-day tracks in the recent past, based on the evidence of the mixed up materials (soil layers, logs, roots, rock, organic matter) in the soil profile. Again, the high precipitation area around the Sunshine Ski Area in Banff National Park has double the number of vascular plant species of the lower precipitation areas to the north and south (Harris, 2007; 2008). It is therefore acting as a refugium for species that require higher precipitation and had migrated into the region after deglaciation but before the present reduction in precipitation. What could be the cause?

To the west is the Central Plateau, some 300km wide, and west of there are the Coast Ranges. These receive their precipitation from the westerly maritime Pacific air masses that have crossed the Pacific Ocean. The precipitation on the Coast Ranges has not changed much. However extensive clear-cut logging along the coast is starting to change that. In the interior on the Plateau, clear-cut logging has essentially decimated large areas of virgin forest, and even relatively puny second and third growth forest is being harvested. The result is that there is now relatively little evapo-transpiration putting moisture back into the air before it continues eastwards to climb over the Eastern Cordillera. This seems to be the cause of the problem of declining precipitation in the source areas of the glaciers along the Eastern Cordillera. Obviously, too many jobs in British Columbia depend on the forests, but the amount of precipitation falling in the mountains determines the flow of the rivers (Fraser, Columbia, Bow, and Athabasca) which originate from the Divide near the Columbia Icefields. The dying glaciers result in lower base river levels as well as reduced precipitation on the mountain slopes, which, in turn, mean that less water is available for use in the dry Prairie Provinces. The current B.C. policy of sacking up to 200 Government forestry officers who are supposed to ensure that there is no over-cutting and that there is replanting of the cut-over areas will not help the problem. Franklin (2001) is among those who have documented the fact that the rate of cutting cannot be sustained at present levels if the forest industry is to survive in B.C. The recent devastation by the pine bark beetle has been used as an excuse for increasing the clear-cutting during the last two years. It would therefore appear that there is a major problem developing as a result of the major exploitation of the forests in the central interior of B.C. What can be done to reduce this?

7. Carbon dioxide levels and tree growth

The striking feature of the Palaeozoic forests was the enormous size of the Horsetails and Coniferous trees. The present-day species of *Equisetum* do not grow taller than about 2 m while most of the modern species of *Pinus* are also nowhere near as big. The Palaeozoic forests were growing in an atmosphere containing far more carbon dioxide than the trees have available today. Is this an indicator of a partial solution to speeding up re-forestation? Recently, it has been demonstrated in experiments that increasing the carbon dioxide content around poplar seedlings doubles their rate of growth. Assuming that there is replanting of the forests (which is not always being carried out in western Canada), allowing carbon dioxide levels in the atmosphere to rise could have considerable economic importance in increasing the rate of re-growth of forests after harvesting of timber. The latter is not going to stop, but any means of increasing the rate of regrowth of the forests will have an important economic effect, both to the lumber industry and in minimizing the reduction in water supplies to the east.

This leads to the question, is it appropriate to sequester carbon dioxide underground when it could aid reforestation and potentially significantly increase precipitation down-wind of these forests? Increasing the amount of carbon dioxide has a relatively minor effect on atmospheric temperatures compared with other known factors (see table 1, after Harris, 2005), indeed, any such minor increase in temperature would also increase the rate of reforestation. On the other hand, it could make a significant difference to the hydrologic cycle, provide more water in the rivers for use by on the dry Prairie Provinces to the east, and reduce the rate of desertification. The Forest Products industry would gain through more rapid regeneration of the forests, the Prairie Provinces would face a reduced water shortage in the future, and the Energy Industries would not have to spend large sums of money on a very expensive new technology. Thus there appears to be a trade-off between stopping a very minor influence on the temperature of the Earth and taking measures to curb desertification in drought-prone areas such as the Prairies. At the moment, this trade-off is being ignored.

As usual in nature, there is a downside. Research carried out at UC Davis indicates that the increased plant growth is followed by decreased ability of the plants to assimilate nitrogen from the soil. This element is needed to manufacture proteins, so there is a reduction in nutritional value of crops unless a suitable fertilizer is applied to the soil. However, the increase in the number of animals including humans is resulting in greater amounts of nitrogen being returned to the environment, thus potentially mitigating this problem.

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This book is intended to introduce the reader to examples of the range of practical problems posed by "Global Warming". It includes 11 chapters split into 5 sections. Section 1 outlines the recent changes in the Indian Monsoon, the importance of greenhouse gases to life, and the relative importance of changes in solar radiation in causing the changes. Section 2 discusses the changes to natural hazards such as floods, retreating glaciers and potential sea level changes. Section 3 examines planning cities and transportation systems in the light of the changes, while section 4 looks at alternative energy sources. Section 5 estimates the changes to the carbon pool in the alpine meadows of the Qinghai-Tibet Plateau. The 11 authors come from 9 different countries, so the examples are taken from a truly international set of problems.

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