The Past is the Key to the Present: Greenhouse and Icehouse over Time

Professor Ian Plimer, School of Earth Sciences, The University of Melbourne

Summary

For 80% of time, planet Earth has been a warm wet greenhouse planet. Polar icecaps are rare, plants have only be on Earth for 10% of time and 99.99% of all life that has ever existed is extinct. Global atmospheric CO_2 and CH_4 have been variable over time and have decreased over time whereas O_2 has been in the atmosphere for 50% of time, has greatly fluctuated and has increased over time. There have been 5 major and numerous minor mass extinctions of complex life, extinction opens new environments for colonisation and, because former terrestrial animals have become extinct, we humans now have a habitat. Sea levels have risen and fallen thousands of time by up to 400 metres, land levels constantly rise and fall and massive rapid climate changes derived from supernovae, solar flaring, sunspots, meteorites, comets, uplift of mountain ranges, pulling apart of oceans, stitching together of land masses, drifting continents, orbital changes, changes in the shape of Earth, ice armadas, changes in ocean currents and volcanoes. There is no evidence that life has changed climates. The major components of the atmosphere have been added by volcanicity and other components are added by life, principally from the organisms that have ruled and continue to rule the world (bacteria). The messages written in stone show that the lithosphere, biosphere, atmosphere and biosphere are constantly interacting on our dynamic evolving planet. There is no evidence to suggest that the future of planet Earth will be significantly different from its past. However, planet Earth is not a spaceship and the great environmental changes in the past have been related to rocky and icy visitors from space.

In the long ago

Planet Earth condensed 4550 million years ago (Ma) from recycled stardust. Since that time, the continents have been enlarging, Earth materials have been constantly recycled and the Earth and all associated systems have been dynamically evolving. The Earth has not stopped being an evolving dynamic system just because humans now live on the continents.

During the first 800 Ma of planetary history, Earth was bombarded by large asteroids, one of which broke off a mass that condensed to form the Moon. Volcanic activity was degassing Earth. The main gases emitted from volcanoes were and still are the greenhouse gases H_2O, CO_2 (carbon dioxide) and CH_4 (methane) mixed with minor helium, nitrogen compounds, sulphur compounds and acids and rare gases such as chlorofluorocarbons. The main greenhouse gas on Earth is H_2O. These volcanic gases accumulated to form a primitive O_2-

deficient greenhouse gas atmosphere. Early accumulations of water in oceans were vapourised by large asteroid impacts. The intensity and frequency of impacting has decreased over time and now some 40,000 tonnes of extraterrestrial material is added to Earth each year.

As soon as there was liquid water on Earth, there was life. This early bacterial life thrived, the O_2-deficient atmosphere was hot and CO_2- and CH_4-rich. Rain was extremely acid. Early Earth was very warm and wet however there is some evidence to suggest that there were minor periods of local glaciation. The origin of these climate variations is unknown. Bacteria slowly diversified and, by the time the Earth was middle aged, one group of bacteria had emitted such large quantities of O_2, that the atmosphere contained minor O_2. Some of this excess O_2 was trapped in rocks by weathering, most dissolved in the oceans resulting in the precipitation of iron oxides. It is these iron oxides that form the great iron ore fields of planet Earth (e.g. Hamersley Basin). Life, the atmosphere, the oceans and the rocks interacted, a process that has been occurring for at least 2500 Ma on our dynamic evolving planet.

For at least the last 2500 Ma, the continents have been pulled apart and stitched back together. Every time the continents are pulled apart, huge quantities of volcanic H_2O, CO_2 and CH_4 are released into the atmosphere and greenhouse conditions prevail. When continents stitch together, mountain ranges form. Mountains are stripped of soils, new soils form and remove CO_2 from the atmosphere, these soils are stripped from the land and the CO_2 becomes locked in sediments on the ocean floor. When atmospheric CO2 is low, glaciation occurs. Large climate cycles can be related to plate tectonics.

The origin of the greatest climate change on Earth is an enigma. Between 750 and 600 Ma, there were two major glacial events and numerous smaller events. Sea level changed by up to 400 metres and interglacial sea temperatures were 40℃. Furthermore, glaciation was at the sea level and equatorial. Bacterial life survived, which is no surprise, because we now know that bacteria live in O_2-poor or O_2-rich conditions in acid and alkaline hot springs, deep in the Earth in cracks in rocks, in volcanic rocks in mid ocean ridges, in clouds, in ice and on every environment on Earth. Bacteria always have been the dominant biomass of Earth and yet their role in interaction with the atmosphere is unknown. Bacteria some 400,000 years old have been resurrected from in the Greenland ice sheet for 400,000 years and from salty liquid inclusions of water in the 250 Ma salt beds of Texas. After glaciation, the atmosphere had some 20% CO_2 and bacteria thrived and diversified in the warm oceans. Multicellular life appeared, diversified and used the CO_2 to make shells and skeletons. This explosion of life from 580 to 520 Ma gave us all of the major life forms currently present on Earth.

Plants appeared at 470 Ma, there were numerous minor mass extinctions and there was a major mass extinction of multicellular life at 430 Ma. The origin of this mass extinction is not known. Vacated ecologies were quickly filled and life continued diversifying. More minor mass extinctions followed and there was another major mass extinction at 368 Ma resulting from the extraterrestrial

impacting of Sweden. Intense global volcanism was trigged by this impacting. Between 368 and 248 Ma, massive coal deposits formed, there was a major 50 million year period of glaciation and the atmosphere was blessed with a very high CO_2 and O_2 content. Life continued to diversify. Minor mass extinctions continued and, at 248 Ma, the biggest major mass extinction on Earth took place. Some 96% of species became extinct, evidence for impacting is weak and the smoking gun is volcanicity in Siberia. Massive volcanic activity over a very short period of time exhaled huge volumes of CO_2 into the atmosphere inducing a greenhouse and this was counterbalanced by the release of sulphur compounds that reflected heat and light. The resultant climate was cooler and acid rain may have destroyed large tracts of vegetation thereby creating a collapse of terrestrial environments. Life diversified quickly to fill the vacated ecologies.

Another major mass extinction took place at 214 Ma. A swarm of asteroids hit the Northern Hemisphere, a continental mass was fragmented, large volumes of lava were released and the Atlantic Ocean formed. The planet was still a warm wet greenhouse planet with the normal cycles of rising and falling sea levels, rising and falling land levels and changing climates. The record written in stone by fossils in the period 520Ma to the present shows that the planet is a warm, wet, greenhouse, volcanic planet with the normal cycles of rising and falling sea levels, rising and falling land levels and changing climates.

The day before yesterday

Some 120 million years ago, Australia was at the South Pole enjoying a temperate climate. There were minor glaciers in the highlands, volcanoes were active and dinosaurs adapted to the long periods of darkness by evolving enlarged optic nerves. Global sea level was more than 100 metres higher than at present, the sea surface temperature was 10-15º C higher than now and many continents were covered by shallow tropical seas. Planet Earth was a warm wet greenhouse paradise and thick vegetation covered the land masses. Atmospheric CO_2 was about 1% when the world's major coal deposits formed 368 to 248 million years ago.

From 250 to 120 million years ago, the global CO_2 content varied greatly and increased to a peak 6% CO_2 120 million years ago. This derived from intense volcanic activity associated with continental fragmentation. Thick vegetation covered the land masses. The atmospheric oxygen content greatly increased to 35% at 300 Ma, decreased and then increased to 27% at 150 Ma. It is currently 21%. During times of high atmospheric O_2 content, there was spontaneous combustion of the atmosphere, global bushfires and increased erosion. Australia started to pull away from Antarctica at about 100 Ma. It drifted northwards at cm/year, the Tasman Sea opened and the Indian Ocean opened with India starting to drift away from Western Australia.

The opening of the Tasman Sea produced the rise of the Great Dividing Range, the diversion of the major river systems and changes to the climate of eastern Australia. A minor mass extinction of life 90 million years ago was the result of

volcanoes in the Indian and Pacific Oceans belching out CO2 and other gases into the oceans and atmosphere. The oceans became acidic, some 26% of advanced life became extinct and there was a runaway greenhouse until volcanism waned. Volcanic emissions of CO_2 are common. In 1984 and 1986, burps of CO2 the volcanic crater lakes of Monoun and Nyos respectively killed thousands and added CO2 to the atmosphere. Near Mt Gambier, volcanic CO2 is commercially extracted from rocks, one small hot spring on Milos contributes to 1% of the planet's volcanic CO_2 and huge quantities CO_2, the planet's second most common volcanic gas, constantly leak from unseen submarine volcanoes.

An extraterrestrial visitor at 65 Ma induced another major mass extinction of life, a huge volcanic event and the release of CO_2, CH_4 and sulphur gases into the atmosphere. Ancient soils, vegetation and rock chemistry show that conditions were tropical.

Another minor mass extinction at 55 Ma was caused by a Caribbean volcano. There was a rise in sea temperatures by up to 8℃ for 100,000 years, atmospheric CO_2 was 10 times that of today, the oceans became acid, the oceans lost dissolved O_2 and the ocean floors released CH_4 into the atmosphere. During the greenhouse, plankton sucked up the atmospheric CO_2, mammals thrived and life filled the vacated ecologies. Atmospheric CO_2 decreased from 3500 to 700 ppm within a million years, stayed low until 47 Ma and went up and down to about the present level (365 ppm) at 40 Ma.

India collided with Asia at 50 Ma. Uplift produced the Tibetan Plateau which started to scrub CO_2 out of the atmosphere. The Tibetan plateau is still rising and CO_2 is still being scrubbed out of the atmosphere. The Drake Passage opened as South America drifted from Antarctica, a circum polar current developed and Antarctica refrigerated. Changes in submarine topography along the Tasman Rise, the closing of the Mediterranean Sea, the onset of polar glaciation and the flow of polar bottom waters formed climate zones, a feature that had not previously existed during the previous long periods of warm wet tropical climates. There were a numerous of minor mass extinctions, comet and meteorite impacts and sea level changes. For example, the Murray Basin became a large sea, retreated and then advanced again only to start its final retreat at 5 Ma.

Warm currents in the Indian Ocean were deflected and drifted through the Great Australian Bight and up the Pacific coast of Australia. Southern Australia from 17 to 14.5 Ma was again tropical with mid-latitude temperatures 6℃ warmer than today. Atmospheric CO_2 was 180-290 ppm. This greenhouse occurred when atmospheric CO2 was 30-50% lower than today! Land changes closed the Straights of Gibraltar at 7 Ma, the Mediterranean Sea again dried and because there was less salt in the oceans, parts of the oceans froze. Both the ice and salt reflected sunlight and the planet cooled further. By 5 Ma, Earth was so cool that very slight orbital wobbles now had a bearing on climate and every 100,000 years was characterized by 90,000 years of glaciation and 10,000 years of interglacial. We are currently in one of those interglacial periods. Cooling changed forests to grasslands and primate extinction and diversification to

upright bipeds took place. By 2.67 Ma, central American volcanoes had closed the seaway between the Pacific and Atlantic Oceans, explosive volcanoes in Kamchatka had added dust to the atmosphere, dust reflected sunlight and the planet cooled further. The Northern Hemisphere polar ice cap formed.

The penultimate interglacial was 120,000 years ago. *Homo erectus*, *Homo neanderthalensis* and *Homo sapiens* coexisted, sea level was 6 metres higher than at present and the planet was far warmer and wetter than now. We live in unusual times when only one species of *Homo* is on Earth. During this greenhouse, there was more vegetation than today and atmospheric CO_2 was 78% of that today. After warming, the atmospheric CO_2 and CH_4 content increased suggesting that atmospheric temperature rise drives an increase in atmospheric carbon dioxide and methane contents. Orbital-driven cooling commenced, the eruption of Toba (Indonesia) produced dust that reflected sunlight, sea level dropped and glaciation commenced. During the history of the latest glaciation, armadas of ice were released into the sea every 7,000 years resulting from the physical failure of thick ice sheets. These had a profound effect on climate. Small cool periods occurred every 1,100 to 1,300 years.

The zenith of the last glaciation was 18,000 years ago. Sea level was 130 metres lower than today, temperature was 10-15°C lower than today and there were very strong cold winds. The northern hemisphere was covered by ice to 38 ºN with more northern areas such as Scandinavia was covered by 3 km of ice. The loading of the polar areas with ice changed the shape of the planet, the planet's rotation changed and as a result ocean currents distributing heat across the Earth were changed. Humans lived very short lives around the edge of ice sheets. Australia was scoured by anti-cyclonic winds that deposited sand dunes and carried sea salt spray to be trapped in the inland basins. Tasmania and parts of the south eastern highlands of Australia were covered in ice and sea level was so low that Aboriginals walked to Tasmania from mainland Australia. Rainforest disappeared with the Amazon Basin consisting of grasslands and copses of trees.

Yesterday

The northern polar ice sheet started to melt 14,700 years ago. There were very rapid and major temperature fluctuations, sea level rose and fell and the total sea level rise over the last 14,700 years has been at least 130 metres. Land masses previously covered with ice started to rise. For example, Scandinavia is still rising and has risen more than 340 metres over the last 14,700 years. As a counterbalance, the Netherlands, south eastern England, Schleswig-Holstein and Denmark are sinking. The breaching of dams of melt waters filled the oceans with cold surface waters 12,000-11,000 and 8,500-8,000 years ago resulting in changed climates, an increase in sea level and changes to ocean currents. After these intensely cool periods, temperatures rose by 5-10°C in the space of a few decades. Sea level rise resulted in the breaching of the Mediterranean into the Black Sea Basin some 7,600 years ago and is probably the origin of the Sumarian, Babylonian and biblical stories of a great flood.

One of the consequences of a massive sea level rise over the last 14,700 years is that the West Antarctic Ice Sheet was no longer unpinned by the land. Two thirds of the West Antarctic Ice Sheet collapsed into the oceans and sea level rose 12 metres. The final third of the West Antarctic Ice Sheet has yet to collapse to produce a 6 metre sea level rise as part of the dynamic post-glacial climate on Earth. Climate changes induced by changes in ocean currents cooled North Africa, grasslands changed to a desert, humans migrated and the great Mesopotamian cities were established.

Sea levels were 1-3 metres higher in a greenhouse 6,000 years ago. There was 20% more rainfall. Cold dry periods, glacier expansion and crop failures between 5,800 and 4,900 years ago resulted in deforestation, flooding, silting of irrigation channels, salinisation and the collapse of the Sumerian city states. Long periods of El Nino-induced drought resulted in the abandonment of Middle Eastern, Indian and North American towns. In 1470 BC (?), Thira exploded and threw 30 cubic kilometers of dust into the atmosphere. The tsunami, ash blanket and destruction of Thira greatly weakened the dominant Minoans. This led to the rise of the Mycaeneans and Greeks. One volcano changed the course of western history.

Global cooling from 1,300 to 500 BC gave rise to the advance of glaciers, migration, invasion and famine. Global warming commenced again at 500 BC, there was an excess of food and great empires such as the Ashoka, Ch'hin and the Romans grew. Contemporary records and Roman clothing shows that conditions were some 5°C warmer than today.

In 535 AD Krakatoa exploded, as did Rabaul in 536 AD. The Earth passed through cometary dust in 536 AD. The dusty atmosphere reflected heat and darkness prevailed and, as a result, the climate cooled and there was famine and warfare. Changes in ocean currents resulted in the Medieval Warm Period from 900 to 1300 AD. The first to feel the change were the Vikings who were able to navigate the northern waters, colonized Newfoundland, colonized Greenland and established extensive trade routes as far south as the modern Gulf States. On Greenland, crops were grown and there were cattle. This would not be possible today. The warmer wetter climate of Europe produced excess crops and wealth which resulted in the building of castles, cathedrals and monastries. As with previous greenhouse events, there was great prosperity.

In 1280 AD, volcanic eruptions on Iceland and a change in ocean currents started the Little Ice Age which finished in 1920. The North Sea froze in 1303 and 1306-1307, there was massive famine in 1315 and the plague pandemic attacked the weakened population in 1347-1349. There was massive depopulation and it took Europe 250 years to reach the population of 1280 AD. During the Little Ice Age, there were warmer periods associated with sunspot activity. During minimum sunspot activity (1440-1460, 1687-1703 and 1808-1821), the intensely cold conditions were recorded by the Dutch masters and King Henry VIII was able to roast oxen on the frozen Thames. There were food shortages. Short cold periods occurred after the eruptions of Tambora (1815)

and Krakatoa (1883) respectively. In fact, 1816 was known as the 'year without a summer'. This was the time when Turner painted stormy oceans and skies full of volcanic dust, Mary Shelley wrote *Frankenstein* and Byron wrote *Darkness*.

Today

The twentieth Century and early 21st Century AD are times of natural post-glacial rebound. Ice sheets, a rare phenomenon in the history of time, still exist. Sea level is relatively low, as are global temperatures and atmospheric CO_2. Between 1920 and 1945, there was a period of warming (0.37°C) and another that commenced in 1976 (0.32°C). In 1976-1977, global temperatures in the lower atmosphere jumped 0.3°C, sea surface temperature in the equatorial Pacific jumped 0.6°C, sea surface temperature during upwelling increased 1.5 to 3°C but there was reduced upwelling, the heat content of the upper 300 metres of the world's oceans increased, there was increased wave activity in the North Sea and the length of the day changed. The stepwise increase in temperature in 1976-1977 shows that there was a major re-ordering of the ocean heat transport coinciding with an orbital change expressed as a change in the length of the day. Maybe global warming of the 20th Century is just a measure of the variability on a dynamic evolving planet?

To put such measurements into perspective over the history of time, changes in atmospheric temperature in the 20th Century can only be considered small and slow. A 24 year global coverage of satellite atmosphere temperatures shows only modest warming in the Northern Hemisphere and a slight cooling in the Southern Hemisphere. Temperature measurements from balloons agree with the satellite measurements for the period of overlap. Because greenhouse warming is a phenomenon of the atmosphere, significant changes should have been recorded. They have not.

Conclusions

Science is married to evidence and bathes in modest uncertainty. The nature of science is skepticism and science encourages argument and dissent. Scientific evidence is derived from reproducible observation, measurement, experiment and calculation. Evidence in geology is interdisciplinary, terrestrial and extra-terrestrial and shows the complex and fascinating intertwining of evolving natural processes on a dynamic planet. Scientists engage in healthy argument about the veracity of evidence. On the basis of evidence, an explanation called a scientific theory is constructed. A scientific theory is the best available explanation of evidence, it may change with new evidence and it must be coherent with the existing body of knowledge. Scientists also argue about scientific theory. Scientific theories are testable and once the scientific theory has been tested over time, it becomes accepted into the body of knowledge. The word belief is not used in science because belief is untestable. This process has not taken place with the construction of what is popularly called the greenhouse effect. Furthermore, science is unable to make judgments about what is good or bad.

These are judgments with vary with time and are based on contemporary politics, religion, aesthetics and culture.

Underpinning the global warming and climate change mantra is the imputation that humans live on a non-dynamic planet. On all scales of observation and measurement, sea level and climate are not constant. Change is normal and is driven by a large number of natural forces. Change can be slow or very fast. However, we see political slogans such as *Stop Climate Change* or government publications such as *Living with Climate Change* demonstrating that both the community and government believe that climate variability and change are not normal. By using the past as the key to the present, we are facing the next inevitable glaciation yet the climate, economic, political and social models of today assess the impact of a very slight warming and do not evaluate the higher risk of yet another glaciation. Geology, archaeology and history show that during glaciation, famine, war, depopulation and extinction are the norm.

In 1831, Admiral Sir James Robert George Graham had the Union Jack hoisted on a volcanic land mass that suddenly appeared near Sicily. It was called Graham Bank and was claimed by England. It was also claimed by the Kingdom of the Two Sicilies who called it Isola Ferdinandea, the French (L'Isle Julia) and other powers who variously named it Nerita, Hotham, Scicca and Corrao. In the subsequent dispute over ownership, France and the Kingdom of the Two Sicilies almost came to war and England and the Two Kingdoms of Sicily had a diplomatic row. During the intense diplomatic dispute, the island quietly slipped back underwater. In 1987, US warplanes thought the dark mass 8 metres below sea level was a Libyan submarine and attacked it with depth charges. In February 2000 when the volcano again stirred, Domenico Macalusa, a surgeon, diver and the Honorary Inspector of Sicilian Cultural Relics, took action. He persuaded Charles and Camilla, the last two surviving relatives of the Bourbon Kings of the Two Sicilies to fund the bolting of a 150 kg marble plaque to the volcano at some 20 metres below sea level. The plaque pre-empted ownership if the volcano ever again rose above sea level. It was placed underwater in September 2001, by November 2002, person or persons unknown had smashed the plaque into 12 pieces. This rock is worth nothing, is of no use as a territorial possession and is of no scientific interest and yet the French and Bourbons nearly came to war 170 years ago and the English and Italians are still in dispute. Graham Banks serves to show that whatever political decisions we humans make, the land rises and falls, sea level rises and fall and climates change as they have done since the dawn of time.