Prof. Lord Oxburgh's Question:

"In June 2017, a giant iceberg the size of Delaware broke off the Larsen C Ice Shelf in West Antarctica, creating an 80 mile long crack in the ice. How do relatively small shifts, rifts and changes lead to a long lasting effect on our planet's climate?"

It is often noted in history that profound, lasting change is achieved by the continuous efforts of small-scale actors and forces, this being even more true regarding changes in the natural environment and climate. Though we may assume climate change to be a purely human phenomenon, momentous and awesome climatic revolutions have occurred many times over the Earth's history causing global upheavals, forcing any life caught up in the change to adapt, or die. The cumulative efforts of individually insignificant actors have triggered these changes, surprising not only in their scale but in their enduring effects, lasting over tens of millions of years in some cases, while our human civilisation has only come about in the geological equivalent of the blink of an eye. The agents of change in question range in size from celestial bodies to microscopic and even molecular ones, yet they all work, or worked, to change the climate in relatively miniscule steps, creating significant climatic change as a result.

Amongst the forces causing long-lasting climate changes, incremental changes in the Earth's orbit are the most persistent, being vital to the triggering of events such as Ice Ages and interglacial periods. The effect of these changes in Earth's solar orbit on the climate are also known as the Milankovitch Cycles, named after Serbian geophysicist and astronomer Milutin Milanković. The crux of his theory was that these cyclical alterations resulted in variation in the amount of solar radiation reaching earth, thus naturally causing long-lasting changes in Earth's climate. Due to the gravitational pull of Jupiter and Saturn, the Earth's solar orbit becomes more eccentric, or elliptical, over 100,000-year cycles, causing one hemisphere to receive very mild seasons and other extreme seasonal change. This is known as orbital eccentricity. However, for a great proportion of the cycle the effects of orbital eccentricity on radiation and thus climate may be negligible in comparison to the effect of the seasons themselves, with eccentricity even considered to be a lesser factor by Milanković himself. Despite this, at maximum eccentricity solar radiation can vary 30% in a year from the furthest point, aphelion, to the closest point, perihelion.

Another cycle noted by Milanković is that of axial tilt, or obliquity. Over the course of 41,000 years the Earth's axis oscillates between 22.1^{o} and 24.5^{o}, with our current axial tilt at 23.5^{o}. Though this may seem like a quantitively minute change, Milanković argued a low obliquity, closer to 22.1^{o}, would be the main trigger for ice ages, as it would cause areas of high latitudes to experience very little sunlight, allowing for glaciation to take place. A further axial cycle is that of axial progression, which denotes the rotation of the Earth's axis 360^{o} around a point over 26,000 years, this being caused by the exertion of tidal forces by the Sun and Moon. Though this alone has little significance, when combined with the effect of apsidal progression, where the long axis of Earth's elliptical orbit progresses irregularly, what emerges is a 21,000-year cycle known as the "precession of the equinoxes". Over the course of this cycle, the seasons proceed to take place at different parts of Earth's orbit, which when combined with high eccentricity, can drastically change the climatic fortunes of an entire hemisphere, causing mild perihelion winters for the North to become cold aphelion winters. Independently, these cycles cause mild climatic variation over long periods of time, which can hardly be truly called lasting due to their cyclical nature. However, precession and eccentricity working in conjunction, for example, has been responsible for triggering ice ages in our Quaternary period, as explained by Jung-Eun Lee of Brown University. These cycles, imperceptible to the human frame while occurring on time scales so seemingly abstract our entire civilisation could snuff itself out before we see their effect on us, truly epitomise the gradual yet overwhelming forces that shape our climate.

Though the crawling power of these celestial bodies is truly fascinating, the Earth and its climate is not merely shaped by the heavens, but by its many inhabitants, as we are so perfectly demonstrating. This is seen none more clearly than in the Great Oxygen Catastrophe in the early Proterozoic eon. With the emergence of photosynthetic Cyanobacteria, oxygen levels rose dramatically, causing one of the greatest mass extinction events in Earth's history. Yet the real significance to the climate was the loss of CO_2 and CH_4 from the atmosphere, reducing the "greenhouse effect", or the insulation of heat and radiation, of the atmosphere and resulting in a "snowball earth" where glaciers stretched to the equator. This change was not reversed for hundreds of millions of years until the Cambrian explosion, during which the rise of aerobic organisms caused temperatures to normalise, by our modern standards, through their respiration and excretion of CO_2. Similar theories propose that "snowball earths" are self-defeating, as widespread sea ice prevents fresh CO_3^{2-} (carbonate) deposition in the ocean so CO_2 accumulates in the atmosphere, increasing the greenhouse effect and thus global temperature. Nevertheless, this cataclysmic climatic change arose not due to an instantaneous event, but the slow, microscopic propagation of tiny Cyanobacteria, each one contributing miniscule amounts, yet cumulatively acting to bring about a change achieved by no organism before it.

The changes brought about by life does not end there, as illustrated by the Palaeocene-Eocene Thermal Maximum (PETM), roughly 56 million years ago. As inferred from glacial ice cores, the atmosphere experienced an enormous infusion of carbon at this time. The prevailing theory is that undersea and glacial deposits of methane hydrate (clathrates) were melted, most likely due to the aforementioned Milanković cycles, causing large amounts of CH_4, a potent greenhouse gas, to be released. This was reinforced by a positive feedback loop, as the subsequent warming would melt more ice, releasing more methane, and in turn causing more warming. The result was a "greenhouse earth", in which the Artic Ocean reached temperatures associated with modern mid-latitude oceans, with fossil records showing tropical flora and fauna as far north as Greenland. Though this warming event can be deemed as a long-lasting change brought about by decades of small shifts in solar radiation and CH_4 concentration, the real micro-level changes were yet to come.

The temperate climate of the arctic at this time in fact provided perfect conditions for the Azolla freshwater fern to form sweeping blooms across the, then topical, Arctic ocean. Though the Arctic ocean may sound inhospitably saline for a freshwater fern, it is in fact predominantly far less saline than other oceans, owing to high freshwater inflow from rivers and low evaporation due to its high latitude. As this rampant bloom photosynthesised, it sequestered an unfathomable volume of CO_2, dragging it to the sea bottom as the Azolla died. The tiny, countless Azolla acted as probably the most effective CO_2 sequestration event ever seen, and is still argued as a possible fix to anthropogenic climate change by geo-engineers and their proponents, despite the damaging side-effects such a bloom would cause, such as widespread deoxygenation. The drop in CO_2 levels over this period led to the gradual reversal of the warming brought about by the PETM due to a substantially weakened greenhouse effect. Though the "Azolla Event" is described as a bloom causing it to be inferred to be rapid event, such prolonged cooling was rather brought about by innumerable single organisms over an extended period, exemplifying climate change from small shifts.

Of course, in an essay on climate change, one would be remiss to not mention the changes humans are creating and their many effects. Since the industrial revolution, the concentrations of greenhouse gases such as CO_2 and CH_4 have increased exponentially from the combustion of fossil fuels, causing a warming of the earth, amongst other trying changes. Though compared to the examples stated previously, this change in climate is occurring in a geological twinkling. Regardless, it is still the sum of seemingly infinite small-scale shifts in human action. From the discovery of fossil fuels to the enlightenment of Faraday, to each individual who pioneered, promoted and adopted fossil fuel derived innovations, the choices and changes of innumerable people continue to set in motion a long lasting and treacherously rapid climatic change.

However, anthropogenic climate change does not need to be synonymous with hockey-stick graphs, mass extinction and global warming. The previous argument can be adapted to contend that for every individual who pioneers, promotes and adopts CO_2 reduction strategies, such as afforestation and Carbon Capture and Storage (CCS), and for every person and business changes their lifestyles and practices to become more “carbon neutral”, a reversal of current trends and the creation of a steady, sustained climate is truly possible.

Though seemingly irrelevant, the history of Earth’s, at the very least, varied climate proves to be a more useful lesson than ever before. As Cyanobacteria and Azolla have clearly shown, the power to enduringly alter the climate lays in the hands of even the smallest of individuals, working together to create change on a planetary scale.