How and why Earth's climate is changing

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Accepted Version

How and why Earth's climate is changing

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We can monitor our changing climate through local measurements taken at ground-based meteorological stations, by weather balloons or aircraft sampling the atmosphere, or by ship measurements and automated buoys that sample the ocean to depth. Remote sensing by interpreting the electromagnetic fingerprints measured by satellites further provides continuous, global coverage of the planet. We also know how the Earth's climate has changed in the distant past based on indirect or 'proxy' data such as tree rings, ice cores and fossil or other ancient geochemical evidence. This tells us that the Earth's climate has always changed: throughout the billions of years of the planet's history as the atmosphere and life co-evolved, across hundreds of millions of years as continents crept across the surface, and over tens of thousands of years as predictable and periodic oscillations and wobbles in the Earth's orbit around the sun set in motion glacial cycles. These changes over vast periods of time are not readily perceptible to us and yet provide insight and context for current changes, which we know are caused by (and are increasingly damaging) human societies.

A wealth of knowledge can be gleaned from kilometre-deep cores into the ice of Antarctica, like million-year time machines that capture colossal fluctuations in Earth's climate. Fingerprints from the composition of the ice and tiny bubbles trapped within it, can tell us about swings in temperature from the last mild interglacial period about 125,000 years ago, followed by a long glacial period that was finally punctuated by our current interglacial climate about 12,000 years before present. Combining with other geochemical evidence we know that during the last glacial maximum, about 21,000 years ago, the planet's surface temperature was 5 to 6ºC colder than in pre-industrial times. Vast amounts of ocean waters were locked away in giant ice sheets over North America and Eurasia leading to sea levels around 120m lower than today.

It has long been known that cyclical changes in Earth's orbit can explain the timings of the swings between glacial and inter-glacial climates over the past few million years. These changes alter the distribution of sunlight across the surface of the planet and how much this heating contrasts between winter and summer. The orbital changes set in motion a chain of events causing ice sheets to expand and contract. But the fossilized records of the atmosphere, trapped in tiny bubbles in the ice cores, show how the concentrations of the greenhouse gases, carbon dioxide and methane, also rise and fall with temperatures in conjunction with glacial to interglacial swings. And only with the helping hand of the changing greenhouse effect and coverage of reflective ice can the magnitude of glacial climate cycles be explained.

The ice core records show how carbon dioxide has varied over the past 800,000 years, from less than 0.02% of the atmosphere (below 200 ppm) during frigid periods up to about 280 ppm during mild interglacial interludes. Yet current concentrations are 415 ppm, well outside the natural fluctuations. Until now these levels have never been experienced by anatomically modern humans, who first appeared over 200,000 years ago. It is well known that carbon dioxide emissions (mostly from fossil fuel burning but also by changes to land cover including deforestation) are causing levels to rise in the air we breathe. Although these emissions are small compared to the natural flow of carbon dioxide into and back out of the atmosphere each year, as the planet ‘breathes’ through growth and decay of vegetation over an annual cycle, they tip the balance such that concentrations inexorably rise by 2 to 3 ppm each year.

The Earth’s greenhouse effect naturally insulates the planet, keeping it habitable by reducing how effectively the planet loses the energy gained from the sun by emitting infrared heat back out to space. But this warming influence is being amplified as greenhouse gas concentrations rise. Research stemming from the 19th century determined how greenhouse gases absorb and emit infrared radiative heat; this cornerstone of climate science has developed over the years into a fundamental understanding of how the climate system works, and today satellite measurements confirm this emerging greenhouse gas fingerprint. Rather than naturally responding to and amplifying climate change, as is the case over many thousands of years across glacial cycles, today, human-caused greenhouse gas emissions are driving Earth’s climate into an uncharted, much warmer future.

The average temperature of the planet has already risen more than 1ºC since industrialization was well underway in the 19th century. The planet has not warmed steadily since the early 20th century – there are fluctuations as the sun varies in its intensity; or following major volcanic eruptions that temporarily block out sunlight; or as the oceans fluctuate naturally from one decade to the next. These factors explain a barely perceptible and temporary slowing of global warming at the beginning of this century. A longer pause in warming in the 1950s and 1960s is partly explained by increased particle pollution that scattered more sunlight back to space and pulled against the warming greenhouse gas influence. Yet, since the 1970s, each decade has been significantly warmer than the one before it, as the heating influence of the growing greenhouse effect has dominated.

Additional signals of climate change come from declining Arctic ice, melting glaciers, rising sea levels and increasing ocean heat. Precipitation is changing, as wind patterns shift with the chaotic fluctuations in the weather; but these weather patterns are increasingly being nudged out of kilter by the human-induced warming and the smaller but more uneven cooling effects of aerosol particle pollution. Atmospheric moisture is increasing too, amplifying the warming through its strong greenhouse effect but also intensifying heavy rainfall.

To predict how climate change will unfold requires understanding of past changes. State-of-the-art physical understanding of the atmosphere, ocean and land is applied across millions of grid boxes that make up a three-dimensional jigsaw model planet, represented by millions of lines of computer code. These global climate simulations are virtual laboratories with which to test hypotheses and answer ‘what if’ questions such as: how much of the observed warming can be explained by greenhouse gas increases alone; would the flooding event have occurred if ocean temperature had been at pre-industrial levels?

Different climate simulation models have been developed over many decades at multiple science centres across the world. These are our primary tools for making projections of the future, applying plausible scenarios of socioeconomic development leading to continued high greenhouse emissions or the drastic cuts in greenhouse gas emissions needed to stabilize climate. These future projections show that without rapid, sustained and widespread cuts in emissions across all sectors of society, warming of the planet will continue beyond levels considered dangerous. Carbon dioxide levels are already about 50% higher than pre-industrial levels; at levels 100% higher than (or double) the pre-industrial levels a global-mean warming of about 3ºC is a reasonable expectation in the long term based upon the latest science. This is a staggering change in climate, considering it is about half as big as the global temperature change that took Earth from glacial conditions 21,000 years ago, when ice sheets covered northern landmasses, to today's mild climate.

The science shows that warming is greater over land areas and in particular over the Arctic where melting of bright, reflective sea ice uncovers dark oceans, causing more sunlight to heat the surface and amplify warming. Intense and sustained rainfall events with associated flooding are already becoming more severe as the air hangs heavier with moisture that fuels the storms. Conversely, when weather patterns generate heatwaves and drought these also become more severe as the temperatures climb further and the atmospheric thirst for water increases. Sea levels will continue to rise far into the future as the oceans steadily take up heat and expand, and land ice melts, adding more water to the sea.

Our extensive scientific knowledge about how and why climate is changing empowers humans to make informed decisions that will limit ongoing climate change and its effects on societies. There is therefore a window of opportunity to limit climate change by drastically cutting greenhouse gas emissions and to plan for adaptations that reduce the impact of future climate change that cannot be avoided.

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