THE LAST GENERATION

FRED PEARCE

TRANSWORLD
BOOKS

ABOUT THE BOOK

Since the last ice age, almost 13,000 years ago, human beings have prospered in a stable, predictable climate. But our generation is the last to be so blessed. In THE LAST GENERATION Fred Pearce lays bare the terrifying prognosis for our planet. Climate change from now on will not be gradual – nature doesn't do gradual change. In the past, Europe's climate has switched from Arctic to tropical in three to five years. It can happen again. So forget what environmentalists have told you about nature being a helpless victim of human excess. The truth is the opposite. She is a wild and resourceful beast given to fits of rage. And now that we are provoking her beyond endurance, she is starting to seek her revenge.

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THE LAST GENERATION

How Nature Will Take Her Revenge for Climate Change

FRED PEARCE

‘We are on the precipice of climate system tipping points beyond which there is no redemption.’

James Hansen, Director, NASA Goddard Institute for Space Studies, New York, December 2005

ACKNOWLEDGEMENTS

Where to start? In my twenty years of reporting on climate change for *New Scientist* magazine and others, innumerable scientists (and not a few editors and fellow journalists) have helped me get things mostly right. To all of them, thanks. I hope this book brings their work together in a form that many of them will find enlightening.

My greatest debt is to the synthesizers within the scientific community – the people who have tried to see the whole picture and to put their work into what seems to me to be an ever-more-frightening context. Their names recur throughout this book. But those who have especially helped me in person include Jim Hansen, Paul Crutzen, Jim Lovelock, Wally Broecker, Peter Cox, Peter Wadhams, Mike Mann, Richard Lindzen, Will Steffen, Richard Alley, Lonnie Thompson, Terry Hughes, Jack Rieley, Sergei Kirpotin, Euan Nisbet, Peter Liss, Torben Christensen, Crispin Tickell, Richard Betts, Myles Allen, Meinrat Andreae, Tim Lenton, Chris Rapley, Peter deMenocal, Joe Farman, Gavin Schmidt, Keith Briffa, John Houghton, Dan Schrag, Bert Bolin, Jesse Ausubel, Drew Shindell, Stefan Rahmstorf, Mark Cane, Arie Issar, Hans Joachim Schellnhuber and the late Charles Keeling and Gerard Bond.

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Ny-Alesund; and to the many people who have helped turn a germ of an idea into a completed book, including my agent Jessica Woollard and editors Susanna Wadeson and Sarah Emsley.

CHRONOLOGY OF CLIMATE CHANGE

5 billion years ago Birth of planet Earth

600 million years ago Last occurrence of ‘Snowball Earth’, followed by warm era

400 million years ago Start of long-term cooling

65 million years ago Short-term climate conflagration after meteorite hit

55 million years ago Methane ‘megafart’ from ocean depths causes another short-term conflagration

50 million years ago Cooling continues as greenhouse gas levels in air start to diminish

25 million years ago First modern ice sheet starts to form on Antarctica

3 million years ago First ice sheet formation in the Arctic ushers in era of regular ice ages

100,000 years ago Start of most recent ice age

16,000 years ago Most recent ice age begins stuttering retreat

14,500 years ago Sudden warming causes sea levels to rise 20 metres in 400 years

12,800 years ago Last great ‘cold snap’ of the ice age, known as the Younger Dryas era, is triggered by emptying glacial lake in North America; continues for around 1,300 years before very abrupt end

8,200 years ago Abrupt and mysterious return to ice age conditions for several hundred years, followed by stable Holocene warm era

8,000 years ago Storegga landslip in North Sea, probably triggered by methane clathrate releases that also bolster the warm era

5,500 years ago Sudden drying of Sahara

4,200 years ago Another bout of aridification, concentrated on the Middle East; widespread collapse of civilizations

1,200 to 900 years ago Medieval warm period in northern hemisphere; megadroughts in North America

700 to 150 years ago Little ice age in northern hemisphere, peaking in 1690s

1896 Svante Arrhenius calculates how rising carbon dioxide levels will raise global temperatures

1938 Guy Callendar provides first evidence of rising carbon dioxide levels in the atmosphere, but findings ignored

1958 Charles Keeling begins continuous monitoring programme that reveals rapidly rising carbon dioxide levels in the atmosphere

1970s Beginning of strong global warming that has persisted ever since, almost certainly attributable to fast-rising carbon dioxide emissions; accompanied by shift in state of key climate oscillations such as El Niño and the Arctic Oscillation, and increased melting of Greenland ice sheet

Early 1980s Shock discovery of Antarctic ozone hole brings new fears of human influence on global atmosphere

1988 Global warming becomes front-page news after Jim Hansen’s presentations in Washington, DC, during US heatwave

1992 Governments of the world attending Earth Summit promise to prevent ‘dangerous climate change’ but fail to act decisively

1998 Warmest year on record, and probably for thousands of years, accompanied by strong El Niño and exceptionally ‘wild weather’, especially in the tropics; major carbon releases from burning peat swamps in Borneo

2001 Government of Tuvalu in the South Pacific signs deal for New Zealand to take refugees as its islands disappear beneath rising sea levels

2003 European heatwave with more than 30,000 dead – later described as the first extreme-weather event attributable to global warming; reports of a third of the world being now at risk of drought – twice the amount in the 1970s

2005 Evidence of potential positive feedbacks accumulates with exceptional hurricane season in the Atlantic, reports of melting Siberian permafrost, possible slowing of ocean conveyor, escalating loss of Arctic sea ice and faster glacier flow on Greenland

THE CAST

Richard Alley, Penn State University, Pennsylvania – glaciologist and leading analyst of Greenland ice cores. He revealed how in the past huge global climate changes have occurred over less than a decade and is one of the most articulate interpreters of climate science.

Svante Arrhenius, Swedish chemist. In the 1890s, he was the first to calculate the likely climatic impact of rising concentrations of carbon dioxide in the atmosphere and thus invented the notion of 'global warming'. Modern supercomputers have hardly improved on his original calculation.

Gerard Bond, formerly of Lamont-Doherty Earth Observatory, Columbia University, New York – geologist, one of the first analysts of deep-sea cores and, until his death in 2005, advocate of the case that regular pulses in solar activity drive cycles of climate change on Earth, such as the little ice age and the medieval warm period.

Wally Broecker, Lamont-Doherty Earth Observatory, Columbia University, New York – oceanographer and one of the most influential and controversial US climate scientists for half a century; discoverer of the ocean conveyor, a global thousand-year circulation system that begins off Greenland and ends in the Gulf Stream that keeps Europe warm.

Peter Cox, UK Centre for Hydrology and Ecology, Winfrith – innovative young climate modeller of the likely impacts of aerosols in keeping the planet cool and the risks of land plants turning from a ‘sink’ to a ‘source’ for carbon dioxide later this century.

James Croll – nineteenth-century Scottish artisan and self-taught academic. Through many years of study, he uncovered the astronomical causes of the ice ages, which were later attributed to the Serbian mathematician Milutin Milankovitch.

Paul Crutzen, Max Planck Institute for Chemistry, Mainz, Germany – atmospheric chemist who won the Nobel Prize for Chemistry in 1995 for his work predicting destruction of the ozone layer. He pioneered thinking in stratospheric chemistry, the role of man-made aerosols in shading the planet and the ‘nuclear winter’; and he coined the term Anthropocene.

Joe Farman, formerly of British Antarctic Survey, Cambridge. His discovery of the ozone hole over Antarctica was a triumph for the dogged collection of seemingly useless data.

Jim Hansen, director of NASA’s Goddard Institute for Space Studies, New York – President George W. Bush’s top climate modeller. His unimpeachable scientific credentials have kept him in his post (at the time of this book going to press), despite his outspoken warnings that the world is close to dangerous climate change, which have clearly irked the Bush administration.

Charles Keeling, formerly of Scripps Institution of Oceanography, La Jolla, California. He made continuous measurements of atmospheric concentrations of carbon dioxide on top of Mauna Loa in Hawaii from 1958 until his death in 2005. The resulting 'Keeling curve', the most famous graph in climate science, shows a regular annual rise superimposed on a season cycle as the Earth 'breathes'.

Sergei Kirpotin, Tomsk State University, Russia – ecologist who told the world about the 'meltdown' of the permafrost of the West Siberian peatlands, raising fears of massive methane releases to the atmosphere.

Michael Mann, director of Earth System Science Center, Penn State University, Pennsylvania – climate modeller and creator of the 'hockey stick' graph, a reconstruction of past temperatures showing recent warming to be unique in the last two millennia. Though he is the butt of criticism from climate sceptics, he gives as good as he gets. He is the co-founder of the RealClimate website.

Peter deMenocal, Lamont-Doherty Earth Observatory, Columbia University, New York – climate historian who has charted megadroughts, the sudden drying of the Sahara and other major climate shifts of the past 10,000 years, and their role in the collapse of ancient cultures.

John Mercer, formerly of Ohio State University, Columbus – glaciologist who first proposed that the West Antarctic ice sheet has an Achilles' heel and that a 'major disaster' there may be imminent. He also pioneered research on tropical glaciers.

Drew Shindell, NASA's Goddard Institute for Space Studies, New York – ozone layer expert and climate modeller. He is doing ground-breaking research on unexpected links between the upper and the lower atmosphere, revealing how the stratosphere can amplify small changes in surface temperature.

Lonnie Thompson, Byrd Polar Research Institute, Ohio State University, Columbus – geologist who has probably spent more time above 6,000 metres than any lowlander alive, all in the pursuit of ice cores from tropical glaciers that are rewriting the planet’s climate history.

Peter Wadhams, head of polar ocean physics at the University of Cambridge. He rode British military submarines to provide the first data on thinning Arctic sea ice and discovered the mysterious ‘chimneys’ off Greenland that are the start of the global ocean conveyor.

PREFACE: THE CHIMNEY

The Greenland Sea occupies a basin between Greenland, Norway, Iceland and the Arctic islands of Svalbard. It is an ante-chamber between the Atlantic and the Arctic Oceans: the place where Arctic ice flowing south meets the warm tropical waters of the Gulf Stream heading north. Two hundred years ago, the sea was a magnet for sailors intent on making their fortunes by harpooning its great schools of bowhead whales. For a few decades, men such as the Yorkshire whaling captain and amateur Arctic scientist William Scoresby sailed north each spring as the ice broke up and dodged the ice floes to hunt the whales that congregated to devour the spring burst of plankton. Scoresby was the star of the ice floes, landing a world record thirty-six whales at Whitby harbour after one trip in 1798. He was the nimblest navigator round a great ice spur in the sea known as the Odden tongue, where the whales gathered.

Scoresby was too clever for his own good, and boom turned to bust when all the whales were gone. What was once the world's most prolific and profitable whaling ground is still empty of bowheads. But just as the unique mix of warm tropical waters and Arctic ice was the key to the Greenland Sea's whaling bonanza, so it is also the key to another hidden secret of these distant waters.

They call it 'the chimney'. Only a handful of people have ever seen it. It is a giant whirlpool in the ocean, 10 kilometres in diameter, constantly circling anticlockwise and siphoning water from the surface to the sea bed 3 kilometres below. That water will not return to the surface for a thousand years. The chimney, once one of a family, pursues its lonely task in the middle of one of the coldest and most remote seas on Earth. And its swirling waters may be the switch that can turn the heat engine of the world's climate system on and off. If anything could trigger the climatic conflagration shown in the Hollywood movie *The Day After Tomorrow*, it would be the chimney.

The existence of a series of these chimneys was discovered by a second British adventurer, Cambridge ocean physicist Peter Wadhams. In the 1990s, he began hitching rides in Royal Navy submarines beneath the Arctic ice. Like Scoresby, he too was fascinated by his journeys to the Odden tongue – not for its long-departed whales, but because of the bizarre giant whirlpools he found there. He concluded that they were the final destination for the most northerly flow of the Gulf Stream. The waters of this great ocean current that drives north through the tropical Atlantic, bringing warmth to Europe, are chilled by the Arctic winds in the Greenland Sea and start to freeze round the Odden tongue. The water that was left became ever denser and heavier until it was entrained by the chimneys and plunged to the ocean floor.

This was a dramatic discovery. The chimneys were, Wadhams realized, the critical starting point of a global ocean circulation system that oceanographers had long hypothesized but had never seen in action. It travelled the world's oceans, passing south of Africa, round Antarctica and through the Indian and Pacific Oceans, before gradually resurfacing and sniffing the air again as it returned to the Atlantic, joined the Gulf Stream and returned north once again to complete a circulation dubbed by oceanographers the 'ocean conveyor'.

But, even as he gazed on these dynamos of the ocean circulation, Wadhams knew that they were in trouble. For the Arctic ice was disappearing. Sonar data he had collected from the naval submarines revealed that the entire ice sheet that once covered the Arctic was thinning and breaking up. By the end of the 1990s, the Odden ice tongue was gone. The Gulf Stream water still came north, but it never got cold enough to form ice. The ice tongue has never returned.

‘In 1997, the last year that the Odden tongue formed, we found four chimneys in a single season and calculate there could have been as many as twelve,’ says Wadhams. Since then, they have been disappearing one by one. Except for one particularly vigorous specimen. Wadhams first spotted it out in the open ocean at 75 degrees north and right on the Greenwich Mean Line during a ship cruise in March 2001. By rights, without the ice, it should not have been there, he says. But it was. Hanging in there, propelled downward perhaps by the saltiness created by evaporation of the water in the wind.

He found the same chimney again later that summer, twice the following year and a final time in spring 2003, before the British government scandalously pulled the plug on his research funds. Over the two years he had tracked it, the last great chimney moved only about 30 kilometres across the ocean, like an underwater tornado that refused to go away. Wadhams measured it and probed it. He sent submersible instruments down through it to measure its motion at depth. It rotated, he said, right to the ocean floor, and such was the force of the downward motion that it could push aside a column of water a kilometre high. ‘It is amazing that it could last for more than a few days. The physics of how it did it is not understood at all,’ says Wadhams.

The great chimney had in May 2003 one dying companion, 70 kilometres to the north-west. But that chimney no longer reached the surface and was, he says, almost certainly in its death throes. That left just one remaining chimney in the Greenland Sea. ‘It may be many decades old or just a transitory phenomenon. But either way, it too may be gone by now. We just don’t know,’ Wadhams told me in late 2005. Like Scoresby’s bowheads, it may disappear unnoticed by the outside world. Or we may come to rue its passing.

INTRODUCTION

Some environmental stories don't add up. I'm an environment journalist, and sometimes the harder you look at some new scare story, the less scary it looks. The science is flaky, or someone has recklessly extrapolated from a small local event to create a global catastrophe. Ask questions, or go and look for yourself, and the story dissolves before your eyes. I like to question everything. I am, I hope in the best sense, a sceptical environmentalist. Sometimes it is bad for business. I have made enemies by questioning theories about advancing deserts, by pointing out that Africa may have more trees than it did a century ago, and by condemning the politics of demographic doomsday merchants.

But climate change is different. I have been on this beat for eighteen years now. The more I learn, the more I go and see for myself, and the more I question scientists, the more scared I get. Because this story does add up, and its message is that we are interfering with the fundamental processes that make the Earth habitable for humans. It is our own survival that is now at stake, not that of a cuddly animal or a natural habitat.

Don't take my word for it. Often in environmental science it is the young, idealistic researchers who become the impassioned advocates. But here I find it is the people who have been in the field the longest, the researchers with the best reputations for doing good science and the professors with the biggest CVs and longest lists of published papers who are the most fearful, often talking in the most dramatic language. People like President George W. Bush's top climate modeller Jim Hansen, the Nobel Prize-winner Paul Crutzen and the late Charles Keeling, begetter of the Keeling curve of rising carbon dioxide levels in the atmosphere. They have seemed to me not so much old men in a hurry as old men desperate to impart their wisdom, and their sense that climate change is something special.

Nature is fragile, environmentalists often tell us. But the lesson of this book is that that it is not so. The truth is far more worrying. She is strong and packs a serious counter-punch. Nature's revenge for man-made global warming will very probably unleash unstoppable planetary forces. And they will be sudden and violent. The history of our planet's climate shows that it does not do gradual change. Under pressure, whether from sunspots or orbital wobbles or now from the depredations of humans, it lurches – virtually overnight. We humans have spent four hundred generations building our current civilization in an era of climatic stability – a long, generally balmy spring that has endured since the last ice age. But this tranquillity looks like the exception rather than the rule in nature. And if its end is inevitable one day, we seem to be triggering its imminent and violent collapse. Our world may be blown away in the process.

The idea for this book came while I sat at a conference, organized by the British government in early 2005, on 'dangerous climate change' and how to prevent it. The scientists began by adopting neutral language. They made a distinction between Type I climate change, which is gradual and follows the graphs developed by climate modellers for the UN's Intergovernmental Panel on Climate Change (IPCC), and Type II change, which is much more abrupt and results from the crossing of hidden 'tipping points'. Type II change is not in the standard models.

During discussions, this temperate language gave way. Type II climate change became, in the words of Chris Rapley, director of the British Antarctic Survey, the work of climatic ‘monsters’ that were even now being woken.

Later in the year, Jim Hansen spoke in even starker terms at a meeting of the American Geophysical Union, saying: ‘We are on the precipice of climate system tipping points beyond which there is no redemption.’ The purpose of this book is to introduce Rapley’s monsters and Hansen’s tipping points and to ask the question: how much time have we got?

The monsters are not hard to find. As I was starting work on this book, scientists beat a path to my door to tell me about them. I had an e-mail out of the blue from a Siberian scientist alerting me to drastic environmental change in Siberia that could release billions of tonnes of greenhouse gases from the melting permafrost in the world’s biggest bog. Glaciologists, who are more used to seeing things happen with glacial slowness, told me of dramatic events in Greenland and Antarctica, where they are discovering huge river systems of meltwater beneath the ice sheets, and of events in Pine Island Bay, one of the most remote spots in Antarctica, that they discussed with a shudder. Soon, they said, we could be measuring sea level rise in metres rather than centimetres.

Along the way, I learned too about solar pulses, about the ‘ocean conveyor’, about how Indian village fires may be melting the Arctic, about a rare molecule that runs virtually the entire clean-up systems for the planet’s atmosphere, and above all about the speed and violence of past natural climate change. Some of this, I admit, has the feel of science fiction. On one plane journey, I re-read John Wyndham’s sci-fi classic *The Kraken Wakes*, and was struck by the similarities between events he describes in that and predictions for the collapse of the ice sheets of Greenland

and Antarctica. It is hard to escape the sense that primeval forces lurk deep in the ocean, in ice caps, in rainforest soils and in Arctic tundra. Hansen says that we may have only one decade, and one degree of warming, before the monsters are fully awake. The worst may not happen, of course. Nobody can yet prove that it will. But, as one leading climate scientist put it when I questioned his pessimism, how lucky do we feel?

I hope I have retained my scepticism through this journey. One of the starting points, in fact, was a reexamination of whether the climate sceptics – those who question the whole notion of climate change as a threat – might be right. Much of what they say is political hyperbole of more benefit to their paymasters in the fossil fuel lobby than to science. Few of them are climate scientists at all. But in some corners of the debate, they have done good service. They have, for instance, provided a useful corrective to the common assumption that all climate change must be man made. But my conclusion from this is the opposite of theirs. Far from allowing us to stop worrying about man-made climate change, it underlines how fickle climate can be and how vulnerable we may be to its capricious changes. As Wally Broecker, one of the high priests of abrupt planetary processes, says, ‘Climate is an angry beast, and we are poking it with sticks.’

This book is a reality check about the state of our planet. That state scares me, just as it scares many of the scientists I have talked to – sober scientists, with careers and reputations to defend, but also with hopes for their own futures and those of their children, and fears that we are the last generation to live with any kind of climatic stability. One told me quietly: ‘If we are right, there are really dire times ahead. Having a daughter who will be about my present age in 2050, and will be in the midst of it, makes the issue more poignant.’

PART ONE

WELCOME TO THE ANTHROPOCENE

1

THE PIONEERS

THE MEN WHO MEASURED THE PLANET'S BREATH

This story begins with a depressed Swedish chemist, alone in his study in the sunless Nordic winter after his marriage to his beautiful research assistant Sofia had collapsed. It was Christmas Eve. What would he do? Some might have gone out on the town and found themselves a new partner. Others would have given way to maudlin sentiment and probably a few glasses of beer. Svante Arrhenius chose neither release. Instead, on 24 December 1894, as the rest of his countrymen were celebrating, he rolled up his sleeves, settled down at his desk and began a marathon of mathematical calculation that took him more than a year.

Arrhenius, then aged thirty-five, was an obdurate fellow, recently installed as a lecturer in Stockholm but already gaining a reputation for rubbing his colleagues up the wrong way. As day-long darkness gave way to months of midnight sun, he laboured on, filling book after book with calculations of the climatic impact of changing concentrations of certain heat-trapping gases. 'It is unbelievable that so trifling a matter has cost me a full year,' he later confided to a friend. But with his wife gone, he had few distractions. And the calculations became an obsession.

What initially spurred the work was the urge to answer a popular riddle of the day: why the world cooled during the ice ages. Geologists knew by then that much of the northern hemisphere had for thousands of years been covered by sheets of ice. But there was huge debate about why this might have happened. Arrhenius reckoned that the clue lay in gases that could trap heat in the lower atmosphere, changing the atmosphere's radiation balance and altering temperatures.

He knew from work half a century before by the French mathematician Jean Baptiste Fourier and an Irish physicist called John Tyndall that some gases, including carbon dioxide, had this heat-trapping effect. Tyndall had measured the effect in the lab. Put simply it worked like this. The gases were transparent to ultraviolet radiation from the sun, but they trapped the infrared heat that the Earth's surface radiated as it was warmed by the sun. Arrhenius deduced that if the amount of these heat-trapping gases in the air was reduced for some reason, the world would grow colder. Later dubbed 'greenhouse gases' because they seemed to work like the glass in a greenhouse, these gases acted as a kind of atmospheric thermostat.

Tyndall, one of the most famous scientists of his day and a friend of Charles Darwin, had himself once noted that if heat-trapping gases were eliminated from the air for one night 'the warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost.' And that sounded to Arrhenius very much like what had happened in the ice ages. Sure enough, when he emerged from his labours, he was able to tell the world that a reduction in atmospheric carbon dioxide levels of between a third and a half would cool the planet by 4 to 5 degrees Celsius (C) – enough to cover most of north Europe, and certainly every scrap of his native Sweden, in ice.

Arrhenius had no idea if his calculations reflected what had actually happened in the ice ages. There could have been other explanations for the big freeze, such as a weakening sun. It was another eighty years before researchers analysing ancient air trapped in the ice sheets of Greenland and Antarctica found that ice-age air contained just the concentrations of carbon dioxide that Arrhenius had predicted. But as he reached the end of his calculations, Arrhenius also became intrigued by the potential of rising concentrations of greenhouse gases, and how they might trigger a worldwide warming. He had no expectation that this was going to happen, but it was the obvious counterpart to his first calculation. And he concluded that a doubling of atmospheric carbon dioxide would raise world temperatures by an average 5 to 6 degrees C. How did he do these calculations? Modern climate modellers, kitted up with some of the biggest supercomputers, are aghast at the labour involved. But in essence, his methods were remarkably close to theirs. Arrhenius started with some basic formulae on the ability of greenhouse gases to trap heat in the atmosphere. These were off the shelf from Tyndall and Fourier. That was the easy bit. The hard part was deciding how much of the solar radiation the Earth's surface absorbed, and how that proportion would alter as the Earth cooled or warmed under alterations to carbon dioxide concentrations.

The absorbing capacity of different surfaces across the globe varies from ice, which absorbs 20 per cent or less, to dark ocean, which absorbs more than 80 per cent. There are values in between for dark forest and light desert, grasslands, lakes and so on. So, armed with an atlas, he divided the surface of the planet into small squares and assessed the capacity of each segment to absorb and reflect solar radiation, and how factors like melting ice or freezing ocean would alter things as greenhouse gas concentrations rose or fell. By the end he had produced a series of temperature predictions for different latitudes and seasons determined by atmospheric concentrations of carbon dioxide.

It was a remarkable achievement. In the process he had virtually invented the theory of global warming, and with it the principles of modern climate modelling. Not only that: his calculation that a doubling of carbon dioxide levels would cause a warming of around 5 to 6 degrees C almost exactly mirrors the IPCC's most recent assessment, which puts 5.8 degrees C at the top of its likely warming range for a doubling of carbon dioxide levels.

Arrhenius presented his preliminary findings 'On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground' to the Stockholm Physical Society in December 1895 and, after further refinements, published them in the *London, Edinburgh and Dublin Philosophical Magazine and Journal of Science*. There he offered more predictions that modern computer models also reproduce. High latitudes would experience greater warming than the tropics, he said. Warming would also be more marked at night than in the day, in winter rather than summer and over land rather than sea.

But he had cracked an issue that seemed to interest no one else. The world forgot all about it. Luckily for Arrhenius, this labour was but a sideshow in his career. A few years after completing it, he found fame as the winner of the 1903 Nobel Prize for Chemistry, for entirely unrelated work on the electrical conductivity of salt solutions. Soon, too, he had a new wife and child, and other interests – he dabbled in everything from immunology to electrical engineering. He was an early investigator of the