Heat

How We Got Here

By Ian Sample
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Behind the treelined embankment that borders the campus of Stockholm University lies building 92E, a red brick villa as big as a fire station, its back turned to Roslagsvagen, the main artery linking the capital city with Norrtalje 70 km away.

What few markings there are on the building suggest nothing of its history. A sign above the entrance identifies it as Cafe Bojan, a student canteen, and a few shirtless students on a bench in the morning sun recall it as nothing more.

At the end of the 19th century, building 92E was the home and laboratory of Svante Arrhenius, a chemist who became Sweden's first Nobel prizewinner. He was destined to have a bigger impact than he could have imagined, far beyond his mainstream work. Unwittingly, he uncovered secrets of the Earth's atmosphere and in doing so triggered research into what many see as the biggest threat to modern humans. He is arguably the father of climate change science.

That title would be a surprise, even to him. The son of a land surveyor, Arrhenius thrived at school, showing a particular aptitude for arithmetic, but his diversity of thought and penchant for maverick theories dealt him a hefty blow at university. His PhD research, which he began at Uppsala University to the north of Stockholm, focused on the conductivity of electrolytes, but the ideas he put forward in his thesis baffled his professors and he was awarded the lowest possible pass grade. At once, any hopes of staying on at Uppsala were destroyed, and Arrhenius embarked on a tour of European laboratories before landing a job in Stockholm several years later.

Arrhenius became interested in a debate occupying the scientific community, namely the cause of the ice ages. Could it be, he wondered, that vast swings in the levels of atmospheric CO_2, lasting tens of millions of years, were the trigger?

The link between CO_2 and the Earth's temperature had been made years beforehand. It was the French scientist Joseph Fourier who first realised that certain atmospheric gases shrouded the planet like a bell jar, transparent to sunlight, but absorbing to infrared rays. It means the atmosphere is heated from above and below: first, by sunlight as it shines through and second by the infrared the Earth emits as it cools overnight.

Arrhenius set himself the task of working out just how much water and CO_2 in the atmosphere warmed the planet. From others' work, he knew that CO_2 was only part of the process. While CO_2 and other gases trapped infrared radiation and so heated the atmosphere, warmer air holds more water vapour, itself the most potent contributor to the greenhouse effect. So, if atmospheric CO_2 levels increased, water vapour would ensure the warming effect was seriously magnified.

What followed was a year doing what Arrhenius described as "tedious calculations." His starting point was a set of readings taken by US astronomer Samuel Langley, who had tried to work out how much heat the Earth received from the full moon. Arrhenius used the data with figures of global temperatures to work out how much of the incoming radiation was absorbed by CO_2 and water vapour, and so heated the atmosphere.

Between 10,000 and 100,000 calculations later, Arrhenius had some rough, but useful, results that he published in 1896. If CO_2 levels halved, he concluded, the Earth's surface temperature would fall by 4–5°C. There was a flipside to his calculations: doubling CO_2 levels would trigger a rise of about 5–6°C.

Beyond the argument over ice ages it wasn't lost on Arrhenius that human activity, in the form of widespread burning of coal, was pumping atmospheric CO_2 above the natural levels that help make the Earth habitable. Almost as a passing comment, he estimated that coal burning would drive a steady rise in CO_2 levels of about 50% in 3,000 years, a prospect he found entirely rosey. At a lecture that same year, he declared: "We would then have some right to indulge in the pleasant belief that our descendants, albeit after many generations, might live under a milder sky and in less barren surroundings than is our lot at present."

As the first to put hard figures on the greenhouse effect, it's unsurprising Arrhenius's estimates weren't spot on. He thought it would take millenia to see a 50% rise in CO_2—but modern measurements show a 30% rise during the 20th century alone. He thought a doubling of CO_2 would raise temperatures by 5–6°C. Scientists now say 2–3°C is more likely.

Over the next decades, his work was criticised, backed up and criticised again. Many disregarded his conclusions, pointing to his simplification of the climate and how he failed to account for changes in cloud cover and humidity. The oceans would absorb any extra CO_2 pumped into the atmosphere, and any remainder would be absorbed by plant life, leading to a more lush landscape, sceptics argued.

In 1938, nine years after Arrhenius had died a Nobel prizewinner for his work on ionic solutions, English engineer Guy Callendar gave the greenhouse theory a boost. An expert on steam technology, he took up meteorology as a sideline and became interested in suggestions of a warming trend. Callendar pieced together temperature measurements from the 19th century onwards and saw an appreciable rise. He went on to check CO_2 over the same period and discovered levels had increased about 10% in 100 years. The warming was probably due to the higher levels of CO_2.

The existence of an increasing greenhouse effect was hotly debated until the postwar funding of the 1950s kicked in and researchers began to get firm data. In 1956, physicist Gilbert Plass confirmed adding CO_2 to the atmosphere would increase infrared radiation absorbed, adding that industrialisation would raise the Earth's temperature by just over 1°C per century. By the end of the 1950s, Plass and other scientists in the US started warning government officials that greenhouse warming might become a serious issue in the future.

Few saw the greenhouse effect and the warming it would bring as being a problem.

Unwittingly, the US especially had already started monitoring what many believed were the direct effects of a warming world. Submarines operating in the Arctic Circle took accurate readings of the thickness of the ice sheets above them. When the Pentagon released the data nearly 40 years later, it revealed a startling melting of the ice, on average a 40% thinning of 1.3m since 1953.

In the 1960s, researchers at Scripps Institution of Oceanography in San Diego took on the testing challenge of taking a vast number of measurements of atmospheric CO_2. The aim was to establish a baseline level with which future readings in a decade or so could be compared.

Charles Keeling spent two years taking measurements in Antarctica and above the Mauna Loa volcano in Hawaii but reported that even in this short period, CO_2 levels had risen. He concluded that the oceans weren't absorbing greenhouse gases being pumped out by industry. Instead, emissions were driving levels of CO_2 higher. "It was a seminal discovery. For the first time, scientists knew that the oceans weren't going to absorb all this carbon dioxide," says Mike Hulme at the Tyndall Centre for climate change research at the University of East Anglia.

Still, few saw the greenhouse effect and the warming it would bring as being a problem. At the time, computer models were suggesting modest increases, perhaps 2°C in hundreds of years.

By the 1980s, climate change had become a megascience, attracting scientists from diverse fields, each attacking the problem from a different angle. One technique was especially useful. Deep cores of ice cut from Greenland and elsewhere held pockets of air dating back hundreds of thousands of years. By analysing the trapped air, scientists worked out CO_2 levels in the atmosphere during past ice ages. In 1987, a core cut from central Antarctica showed that in the previous 400,000 years, CO_2 had dropped to 180 parts per million (ppm) during the most extreme glacial periods and climbed as high as 280ppm in warmer times, but not once had been higher. In the outside air, CO_2 was measured at 350ppm, unprecedented for nearly half a million years.

To mainstream scientists, evidence that warming was down to human activity was becoming too big to ignore. While scientists uncovered evidence for the greenhouse effect and warming it was producing, others pointed to different processes impacting on global climate. Volcanos, for example, blast millions of tonnes of sulphur dioxide into the atmosphere that form aerosol particles which reflect sunlight back into space. The 1991 eruption of Mount Pinatubo in the Phillipines sent about 20m tonnes of the gas into the atmosphere, leading to a global cooling of around 0.5°C a year later. Scientists now believe that the warming experienced in the early 20th century can largely be explained by the lack of volcanic activity.

Variations in the sun's intensity have also been fingered as a driver of climate change. According to Joanna Haigh at Imperial College London, about a third of the warming since 1850 can be explained by solar activity. The identification of disparate contributors to warming has been seized upon by a minority who claim global warming is driven far more by nature than human activity, and the ensuing controversy is still not settled.

By 1988, the United Nations had established the Intergovernmental Panel on Climate Change to review relevant research. The panel's latest estimate points to a warming of 1.4–5.8°C by 2100, depending on what strategies, if any, are adopted to curb emissions. The 20th century saw a rise in temperature of 0.6°C, about half of which occurred since 1970.

Arguably the most concerted effort to cut global emissions has been triggered by the Kyoto Protocol. Since ratification began in 1997, more than 100 countries have adopted the protocol, which for the first time committed them to cutting emissions of six greenhouse gases.

Now, barely a week goes by without a major study on climate change. A flurry of papers started the year with warnings that the Gulf Stream would grind to a halt, ski resorts would move to higher altitudes and Antarctic glaciers were melting fast. More than 100 years after Arrhenius set out to discover why the world fell into periodic ice ages, the scientist has become a pillar of the megascience that is global warming research.

Back in Stockholm's meteorology department, Erland Kallen is musing about progress since Arrhenius first set about his calculations. "Even when I came to this field 20 years ago, I was very sceptical about global warming. There were too many uncertainties I just couldn't see how anyone could say anything sensible about it. Now, I struggle to see what other explanation there could be."

The Proof Is in the Science

BY ROGER DI SILVESTRO
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The twentieth century was the warmest of the past 1,000 years, and 19 of the 20 hottest years on record occurred after 1980. Most of this warming resulted from human activities, not nature, according to the United Nations' Intergovernmental Panel on Climate Change. Composed of 1,500 climatologists, the panel was created in 1988 by the World Meteorological Organization and the United Nations Environmental Program to evaluate climate science as a basis for setting policy. Other groups that agree with the panel's conclusion include the National Academy of Sciences, the American Meteorological Society, the American Geophysical Union and the American Association for the Advancement of Science.

The chief culprit in global warming is increased atmospheric carbon dioxide from industries and motor vehicles—at 372 parts per million, atmospheric carbon dioxide is now at the highest concentration in at least 420,000 years, as indicated by studies of gases trapped in ancient ice. This rise in density turns the atmosphere into an increasingly heavy blanket, allowing it to hold in more of the sun's heat rather than letting it radiate back into space.

So far, the global average temperature has risen 1.4 degrees F since 1750, a significant amount in terms of the world's overall average. In January, a study involving 95,000 participants from 150 countries—the world's largest climate-prediction experiment ever—concluded that greenhouse gases could raise global temperatures as much as 20 degrees F by 2100. The result: major droughts, sea-level rise and crop failures.

This prediction should raise grave concerns among policymakers, because other predictions that scientists have made in recent years about the ecological effects that rising temperatures would produce are coming true, confirming that global warming is here. Among the forecasts: warming will take place most rapidly and intensively at the poles, glaciers and ice sheets will melt, sea level will rise, precipitation patterns will change, storms and floods will become more frequent and severe, and some plants and animals will shift their ranges northward or up mountainsides to escape rising heat.

The following compendium of data, based on information from peer-reviewed scientific sources, cites forecasts that have already evolved into solid evidence for the advent of global warming.

Polar Change

The rate of warming in the Arctic was eight times faster during the past 20 years than during the previous 100 years and is occurring at nearly twice the rate of the rest of the planet. Average winter temperatures in Alaska and western Canada have risen by as much as 7 degrees F during the past 60 years.

Shrubs have been moving into the tundra, where cold temperatures historically have kept them out. Because shrubs absorb more solar heat than does tundra, they may compound the effects of global warming there.

Average temperatures in the Antarctic have increased by as much as 4.5 degrees F since the 1940s, among the fastest rates of change in the world.

Glaciers and Ice Sheets

Antarctica's 1,200-acre Larsen B ice shelf—more than 700 feet thick—collapsed in March 2002, the third large shelf in the area to do so since 1995. The calving of icebergs from ice shelves is a normal event, but complete disintegration of shelves that scientists believe may have been as much as 12,000 years old is not.

The extent of Arctic sea ice in September 2004 was more than 13 percent below average, yielding the most shrunken sea ice of the past half century. The sea ice now is melting 20 percent faster than it did two decades ago.

The lowest elevation for freezing among mid-latitude mountains, such as the U.S. Rockies and the European Alps, has shifted upward by almost 500 feet since 1970. Some 80 percent of the snowcap of Kenya's Mount Kilimanjaro has disappeared, and the 150 glaciers that studded Glacier National Park in Montana in 1910 have been reduced to fewer than 30.

Weather Events

Annual precipitation in southern New England has increased by more than 25 percent during the past century, while snowfall in northern New England has decreased by 15 percent since 1953. Snow lies on the ground in New England for seven days less per year than it did 50 years ago.

Severe droughts today affect 30 percent of the Earth's surface, compared to 10 to 15 percent 35 years ago, a change that climate scientists blame in large part on rising temperatures.

Snowfall in Australia has declined by 30 percent during the past 40 years.

Lakes in Pennsylvania freeze on average about 10 days later than they did 50 years ago and thaw about 9 days earlier.

Sea Level

Sea temperatures have risen up to 2 degrees F during the past 20 years, although the link to global warming has yet to be determined. The mean global sea level has risen as much as 7.8 inches during the past century.

Shifting Species

In Russia's Ural Mountains, the tree line has moved as much as 500 feet higher since the start of the 20th century. In Canada's Banff National Park, spruces have shifted upward by 150 to 180 feet since 1990.

Data collected for 100 flowering species in the Washington, D.C., area reveal that 89 species now are blossoming an average of 4.5 days earlier than they did in 1970. Only 11 are flowering later. In Edmonton, Alberta, a similar study found that overall spring flowering in the area occurs eight days earlier than it did 60 years ago.

The vegetative growing season of trees, shrubs and herbs in Europe has increased by 11 days since 1960.

Oak trees in England are leafing two weeks earlier than they did 40 years ago. Great white sharks and Portuguese man o'war jellyfish are moving into waters off Devon and Cornwall, previously too cold for these species.

A study of some 1,700 species completed in 2002 found that some birds and butterflies have shifted their ranges northward by 4 miles yearly since the 1960s.

An analysis of 74,000 nesting records from 65 bird species in the United Kingdom found that between 1971 and 1995, 20 of the species were laying their first eggs an average of nine days earlier.

In just 35 years, the sachem skipper butterfly has expanded its range 420 miles northward, from California into Washington. During 1998, the warmest year on record, the range expanded 75 miles.

Other U.S. species that have expanded northward include the red fox, rufous hummingbird, two subtropical dragonflies in Florida and a variety of marine species found off Monterey, California, that are following warming seas away from the equator.

"No single bit of scientific evidence makes a convincing argument that global warming is having an impact on wildlife and plants," says Doug Inkley, NWF senior science advisor, "but the cumulative evidence cannot be ignored. The question is no longer 'Is global warming happening?' The question is, what are we going to do about it?"

Strange Science

By Thomas Sieger Derr
First Things, November 2004

Global warming has achieved the status of a major threat. It inspires nightmares of a troubled future and propels apocalyptic dramas such as the summer 2004 movie *The Day After Tomorrow*. Even were the Kyoto treaty to be fully implemented, it wouldn't make a dent in the warming trend, which seems to be inexorable. Doom is upon us.

Except that maybe it isn't. You might not know it from ordinary media accounts, which report the judgments of alarmists as "settled science," but there is a skeptical side to the argument. Scientists familiar with the issues involved have written critically about the theory of global warming. The puzzle is why these commentators, well-credentialed and experienced, have been swept aside to produce a false "consensus." What is it that produces widespread agreement among both "experts" and the general public on a hypothesis which is quite likely wrong?

The consensus holds that we are experiencing unprecedented global warming and that human activity is the main culprit. The past century, we are told, has been the hottest on record, with temperatures steadily rising during the last decades. Since human population and industrial activity have risen at the same time, it stands to reason that human activity is, one way or another, the cause of this observed warming. Anything wrong with this reasoning?

Quite a lot, as it turns out. The phrase "on record" doesn't mean very much, since most records date from the latter part of the nineteenth century. Without accurate records there are still ways of discovering the temperatures of past centuries, and these methods do not confirm the theory of a steady rise. Reading tree rings helps (the rings are further apart when the temperature is warmer and the trees grow faster). Core samples from drilling in ice fields can yield even older data. Some historical reconstruction can help, too—for example, we know that the Norsemen settled Greenland (and named it "green") a millennium ago and grew crops there, in land which is today quite inhospitable to settlement, let alone to agriculture. Other evidence comes from coral growth, isotope data from sea floor sediment, and insects, all of which point to a very

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warm climate in medieval times. Abundant testimony tells us that the European climate then cooled dramatically from the thirteenth century until the eighteenth, when it began its slow rewarming.

In sum, what we learn from multiple sources is that the earth (and not just Europe) was warmer in the tenth century than it is now, that it cooled dramatically in the middle of our second millennium (this has been called the "little ice age"), and then began warming again. Temperatures were higher in medieval times (from about 800 to 1300) than they are now, and the twentieth century represented a recovery from the little ice age to something like normal. The false perception that the recent warming trend is out of the ordinary is heightened by its being measured from an extraordinarily cold starting point, without taking into account the earlier balmy medieval period, sometimes called the Medieval Climate Optimum. Data such as fossilized sea shells indicate that similar natural climate swings occurred in prehistoric times, well before the appearance of the human race.

Even the period for which we have records can be misread. While the average global surface temperature increased by about 0.5 degrees Celsius during the twentieth century, the major part of that warming occurred in the early part of the century, before the rapid rise in human population and before the consequent rise in emissions of polluting substances into the atmosphere. There was actually a noticeable cooling period after World War II, and this climate trend produced a rather different sort of alarmism—some predicted the return of an ice age. In 1974 the National Science Board, observing a thirty-year-long decline in world temperature, predicted the end of temperate times and the dawning of the next glacial age. Meteorologists, *Newsweek* reported, were "almost unanimous in the view that the trend will reduce agricultural productivity for the rest of the century." But they were wrong, as we now know (another caution about supposedly "unanimous" scientific opinion), and after 1975 we began to experience our current warming trend. Notice that these fluctuations, over the centuries and within them, do not correlate with human numbers or activity. They are evidently caused by something else.

What, then, is the cause of the current warming trend? As everyone has heard, the emission of so-called "greenhouse gasses," mostly carbon dioxide from burning fossil fuels, is supposed to be the major culprit in global warming. This is the anthropogenic hypothesis, according to which humans have caused the trouble. But such emissions correlate with human numbers and industrial development, so they could not have been the cause of warming centuries ago, nor of the nineteenth-century rewarming trend which began with a much smaller human population and before the industrial revolution. Nor is there a very good correlation between atmospheric carbon dioxide levels and past climate changes. Thus, to many scientists, the evidence that greenhouse gasses produced by humans are causing any significant warming is sketchy.