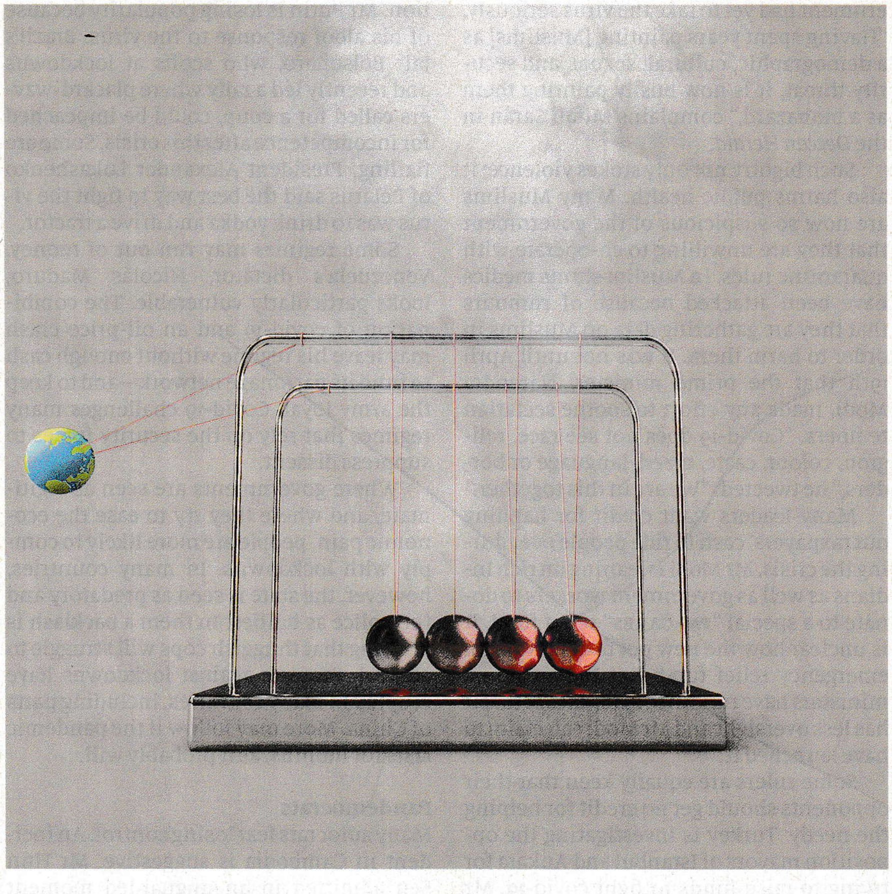

A history of action and inaction

The challenge without precedent

The first of six weekly climate briefs looks at the history and politics of attempts to tackle global warming

In June 1988 scientists, environmental activists and politicians gathered in Toronto for a "World Conference on the Changing Atmosphere". The aspect of its changing that alarmed them most was the build-up of carbon dioxide, a greenhouse gas. In the late 1950s, when systematic monitoring of the atmosphere's carbon-dioxide level began, it stood at around 315 parts per million (ppm). By that summer, it had reached 350ppm—and a heatwave was bringing record temperatures to much of North America.

The week before the Toronto conference James Hansen, a climate scientist at NASA, had pointed to the heatwave when telling the US Senate that it was time "to stop waffling...and say that the evidence is pretty strong that the greenhouse effect is here". The Toronto conference took a similar view, calling for an international effort to reduce global carbon-dioxide emissions by 20% by 2005.

A mere four years later a global compact against climate change had been signed. Even with a boost from the end of the cold war, which made global action on shared concerns seem newly possible and provided an opening for a new eschatology to replace that of nuclear Armageddon, that seemed like a remarkable political success on the part of those pressing for action.

Unfortunately, a global agreement to act is not the same thing as global action.

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Fossil fuels are the bedrock of industrial society. Even though the alternative of renewable energy has, since 1988, become far more plausible, a decisive move away from fossil carbon still means a wrenching and unprecedented shift.

To many convinced environmentalists that shift seems self-evidently worthwhile. It fits with an ideology that commits them to lives that have less impact on the natural world. But in the face of climate change, individual willingness to sacrifice the fruits of a high-energy lifestyle is not enough. People, and countries, that do not share such motivations must act, too.

The challenge of climate politics is to overcome these differences by negotiating ways forward that can gain general assent. It is a challenge that, despite those remarkable four years, has not been met. Instead of emissions in 2005 being 20% lower than they were in 1988, they were 34% higher. By 2017 they were 22% higher still.

Think global, act global

The Toronto attendees' belief that an international agreement could bring down carbon-dioxide emissions rested in part on an agreement reached a year before to limit the production of ozone-destroying chemicals, most notable among them the chlorofluorocarbons (CFCs) used in fridges and spray-cans. That Montreal protocol looked like a template in two ways.

The first was that it was global. Since the 1960s the environmental movement had increasingly taken "saving the planet" as its rhetorical focus. But practical environmental protections, such as clean-air regulations, almost all worked on a national, or at most regional, basis. Because the world's CFCs are thoroughly mixed together before they reach the stratosphere's ozone layer, the Montreal protocol had to be genuinely global, and thus balance the needs of developed and developing countries.

The second was that the Montreal protocol required remarkable faith in science. Unlike most pollution controls, which try to reduce harm already being done, it called for expensive action to deal with a problem that, despite the dramatic discovery of the Antarctic ozone hole in 1985, was not yet hurting people. It was based instead on the likelihood of future catastrophe.

Climate scientists realised that an emissions-reduction agreement on greenhouse gases would need a similarly strong consensus on their dangers. This led to the creation in late 1988 of the Intergovernmental Panel on Climate Change (IPCC). Including researchers from governments, academia, industry and non-governmental organisations, the processes of the IPCC required governments to sign off on its conclusions, so reducing their ability to ignore them.

The IPCC's first assessment of climate- ▸▸

change science, published in 1990, predicted that if greenhouse-gas emissions continued to rise unchecked, the world would warm by 0.2-0.5°C (0.4-0.9°F) every decade over the course of the 21st century, and that sea-level would rise 3-10cm a decade. Changes in the three decades since fit with the low end of both predictions.

Two years later, at an "Earth Summit" in Rio de Janeiro, the UN's members agreed on a framework convention on climate change (UNFCCC) which committed them to the "stabilisation of greenhouse-gas concentrations...at a level that would prevent dangerous anthropogenic interference with the climate system".

Despite the fact that such stabilisation implied impressive cuts in emissions, the treaty set no targets along the lines of Toronto's 20% by 2005. They were to be worked out later. In years to come those negotiations on emission cuts came to dominate discussions between the parties to the treaty, sidelining the vital question of how to help countries, especially poor ones, adapt to the now inevitable changes. To talk of such adaptation was equated with capitulating on emission cuts.

Specific emission cuts were agreed upon five years after Rio, in Kyoto. They were not global in extent, applying only to developed countries, which were responsible for most of the emissions. They were not ambitious either. And the Kyoto protocol was never ratified by America, then the largest global emitter.

The UN imprimatur gave the UNFCCC universal legitimacy. But fashioning a treaty that all could accept had meant producing one with little practical power. The UNFCCC lacked any mechanism for making countries commit to ambitious action, let alone binding them to such commitments.

If all countries had shared an urgent interest in action, those shortcomings would not have mattered. But they did not. The costs of environmental improvements tend to fall on a few groups—typically, those doing the polluting. In domestic environmental politics, progress typically relies on going some way to placate those groups while increasing the enthusiasm for action among others and the public.

If emissions had been down to just a few companies, as with CFCs, or sectors of the economy, as with the smogs tackled by clean-air acts, such trade-offs might have been possible internationally. But fossil-fuel use permeated rich economies. Those countries knew the cost of reducing them could be severe—and that the benefits would accrue mostly to people in other countries and future times.

These difficulties were exacerbated by attempts to weaken public support for climate action. Fossil-fuel companies and their political allies, understood how important a scientific consensus on future damage was to the case for action. The result was a campaign to make the science look at best dubious, and at worst fraudulent, which went beyond noting that many environmental scientists were committed environmentalists and pointing out truly open questions (the wide range of the uncertainties in the first IPCC report has been slow to narrow). In doing so it helped produce an environment in which some right-wing politicians felt able to oppose all cuts to emissions, with notable successes in America and Australia.

Future targets beat present action

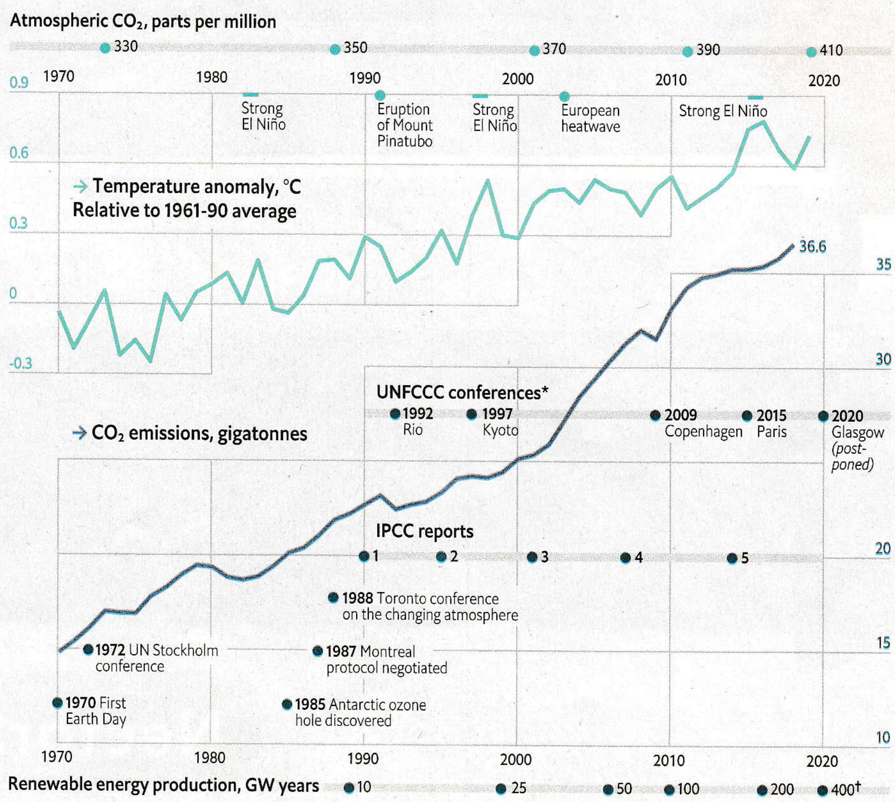
Another source of resistance to emissions reduction was the rise of China. Its GDP, measured at purchasing-power parity and in real terms, increased sevenfold in the 20 years after Rio. Its carbon-dioxide emissions more than tripled, from 2.7bn to 9.6bn tonnes. China showed no real interest in curbing this world-changing side-effect, and because it was a developing country it was not even notionally obliged to do so by the Kyoto protocol—despite the fact that, before that protocol was ten years old, China was a bigger emitter than America. Resentment over this was one of the reasons some developed countries became increasingly unhappy with their commitments. China's unwillingness to offer real action contributed to the near collapse of attempts to move beyond Kyoto at the Copenhagen summit of 2009.

Six years after Copenhagen, though, the UN process made its biggest step forward since Rio: the Paris agreement. This, at last, set a specific global target. Atmospheric greenhouse-gas levels were to be stabilised by the second half of this century at a level that would see an increase of the average global temperature over its preindustrial level well below 2°C, with strenuous efforts made to keep it down to 1.5°C. All the countries, developed and developing, that signed were required to commit to domestic actions towards that aim.

There were several reasons for the success: prior talks between America and China; skilful French diplomacy; canny negotiation by developing countries. Perhaps the most important one, though, was that the cost of renewable energy was tumbling and investments in the field booming. Reducing emissions while continuing high-energy lifestyles felt newly possible.

Perhaps it will be. But the reductions the countries offered in Paris were too small to meet the 2°C target. That insufficiency has seen a new generation of climate activists demand greater ambition at the next big UNFCCC meeting, originally to be held this year in Glasgow but now postponed because of the covid-19 pandemic. There remains no way for them to force action on people and countries who do not share their passion and commitment. ■

→ Changes, fast and slow, in the climate and its politics



Sources: Global Carbon Project; Met Office; NOAA; EIA

*United Nations Framework Convention on Climate Change †Forecast

Computing climate change

Model behaviour

The basic science of the greenhouse effect is quite straightforward. The vital work of untangling its future effects requires models which are anything but

TO IMAGINE EARTH without greenhouse gases in its atmosphere is to turn the familiar blue marble into a barren lump of rock and ice on which the average surface temperature hovers around -18°C. Such a planet would not receive less of the sunlight which is the ultimate source of all Earth's warmth. But when the energy it absorbed from the sunlight was re-emitted as infrared radiation, as the laws of physics require, it would head unimpeded back out into space.

Greenhouse gases block that swift exit. Transparent to incoming sunlight, they absorb outgoing infrared radiation, thus warming the atmosphere and, in so doing, the surface below. The result is an average surface temperature of some 15°C—warm enough for open seas and oceans and a vibrant biosphere.

In the late 19th century the discovery of the ice ages led scientists to the conclusion that climate could change on a global scale. Svante Arrhenius, a Swedish chemist, wondered if a weakened greenhouse effect might be to blame. Carbon dioxide was known to be a greenhouse gas: Eunice Foote, an American scientist, had found in the 1850s that the rate at which a sealed jar of air warmed up in sunlight depended on the level of carbon dioxide in that air. So Arrhenius—recently divorced, somewhat melancholy and in need of a project—began laboriously to calculate the effects on the climate of halving the atmosphere's level of carbon dioxide.

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Doing so required him to tackle a problem of the sort that most frustrates and most delights scientists who study the Earth system: a feedback loop through which a change in one factor affects another factor which, in turn, affects the first factor more.

Because water evaporates more slowly in cooler climes, the amount of water vapour in the atmosphere falls with the temperature. And water vapour, like carbon dioxide, is a greenhouse gas. Cooling the atmosphere dried the atmosphere which cooled the atmosphere further. Many pencils and thousands of sheets of paper into his exploration of this, Arrhenius concluded that halving the carbon-dioxide level would cool the planet by 5°C (9°F).

He also noted that the same relation would hold the other way round: double the carbon dioxide and you would get 5°C of warming. Industry's coal burning could thus warm the world—but only, he thought, very slowly indeed. He never imagined that the carbon-dioxide level would increase by a third in just a century.

Around the same time as Arrhenius was pondering the climate, a Norwegian scientist called Vilhelm Bjerknes was working on the physics of how heat drives fluid flow. His students applied these insights to large scale flows in the atmosphere and the oceans, laying the foundations of 20th-century weather forecasting. In 1950 one of those students' students, Ragnar Fjørtoft, was part of the team which first programmed a computer to forecast the weather by solving such equations.

The computer models central to today's climate research bring together Arrhenius's curiosity and Bjerknes's techniques. Programmes developed from weather-forecasting software calculate how the level of carbon-dioxide and other greenhouse gases is likely to affect the world's flows of heat, energy and water, and through them the future climate. To do so they use computers that can be some 25trn times faster than the one used in 1950.

These climate models do not treat the atmosphere as a whole. They divide it into millions of "cells". The conditions in each of these cells depend on the conditions in its neighbours above, below and to the sides as well as on its own history. The idea is to calculate how conditions in each cell change over time. Unlike a weather forecast, which tries to predict how a specific state of the atmosphere will evolve over a few days, these climate models simulate years, even centuries, of weather in order to discover the averages and probability distributions that define the climate—the envelope which constrains the norms and extremes of future weather. ▸▸

Dozens of teams at meteorological and research organisations around the world run such models, each using different code to capture the climate's underlying mechanisms and study everything from future peak rainfall to the tracks of storms to shifts in seasonality. Since 1995 the Coupled Model Intercomparison Project, or CMIP, has brought these teams together by providing standardised tasks for their models and then looking at the range of results. Thus, for example, the 56 different models considered in the fifth of the CMIP projects, which concluded in 2013, found that doubling the carbon-dioxide level would, in time, bring about a warming of between 1.5°C and 4.5°C. The uncertainty in what the models suggest at smaller scales is greater still. Different models can provide very different pictures of the future of regional climates.

Rows and floes of angel hair

The wide range of outcomes is, for the most part, down to the fact that no two models represent the mechanisms of the climate—and particularly its feedbacks—in precisely the same way. Some ways of doing things can be ruled out because the models they produce fail to capture the behaviour of the climate as it is, or as it was in the past (studies of the low-carbon-dioxide ice ages provide useful calibration, which would have pleased Arrhenius). But among models which reproduce past and current climates reasonably well, there is no clear way to say which one's representations are most reliable. The differences between the models represent a basic level of uncertainty, given the current state of knowledge.

This endemic uncertainty, though, does not mean the models have nothing useful to say. Given how long modelling has been going on, it is now possible to compare predictions made decades ago with the way things have turned out. A study published last year systematically assessed what models published between the 1970s and 2007 had said about the way the climate would respond to steady rises in carbon dioxide. It found that for 14 out of 17 models what had happened had been within the model's error bars; of the other three, two had overshot, one had undershot. Taking the models seriously would have been a good bet.

The most important source of uncertainty in the models lies in the clouds. As greenhouse gases warm the atmosphere its humidity changes, as does the extent to which it cools with altitude. These changes affect how clouds develop; the clouds, in turn, change surface temperature. Most clouds warm the world; some cool it.

The problem is that the processes which control a cloud's thickness, lifetime and other qualities work on pretty small scales. The models do not. Even if every layer of the atmosphere is represented by hundreds of thousands of grid cells, they still end up being hundreds of kilometres on a side—much too large to capture the processes responsible for individual clouds.

Not all the feedbacks sit squarely within the atmosphere; some extend beneath it. Various feedbacks link the atmosphere to the oceans, which store, move and release heat in ways that do a great deal to shape the climate. In the 1960s modellers began trying to capture these effects by "coupling" models of the ocean to models of the atmosphere, so that what they saw in the atmosphere reflected changes in the oceans and vice versa.

Feedbacks involving the land matter, too. Cold weather brings snow; snowy ground, especially under clear skies, reflects away more sunlight, cooling things further. Biology adds yet more complexity. A tropical forest pumps water vapour into the atmosphere with far greater efficiency than a savannah does. In warmer oceans it is harder for nutrients to rise to the surface, which reduces the ability of plankton to suck carbon dioxide from the atmosphere. Melting permafrost produces copious microbial methane—a gas which absorbs infrared much more strongly than carbon dioxide does. Over the decades modellers have attempted to build more and more of these interrelationships into their models, adding greatly to their complexity.

Unfortunately increasing complexity does not always reduce uncertainty. A model which ignores, say, the instability of ice sheets—as most did until recently—is clearly missing something important. However, because there are always different ways to incorporate something new, two models updated to capture ice-sheet dynamics may diverge more after this "improvement" than they did when, unrealistically, they simply ignored the issue. In the CMIP6 process, which is currently winding up, preliminary results show a wider range of uncertainties than was seen in CMIP5.

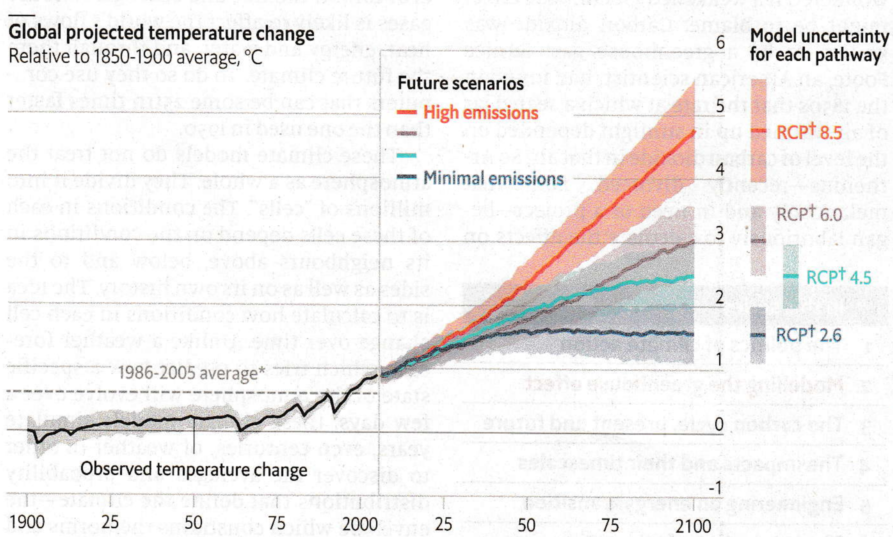
The biggest source of uncertainty, though, lies not inside the models but outside them. Climate change is a problem because human activity is adding carbon dioxide, methane and other greenhouse gases to the atmosphere at a rate that is both prodigious and impossible for the physics, chemistry and biology encoded in the models to predict.

To estimate how changes in policy might affect emissions a different family of models is used—"integrated assessment models" (IAMS) which import simplified results from climate models into models of the economy.

One of the things that CMIP5 asked climate modellers to look at is the way that the climate might evolve if emissions followed four standardised "pathways" developed from four particular IAMS in the 2000s. Three were generated from IAMS trying to simulate various types of climate policy. The fourth, RCP8.5, though often referred to as "business as usual", was generated from an IAM run featuring high population growth, low technological progress and very large scale use of coal. As a result it shows emissions increasing at a spectacular rate, which makes it scary, but not a helpful baseline.

The uncertainties in what the models predicted was as striking as ever (see chart). But they all agreed that only the pathway embodying the strongest climate action—much stronger than what is seen and promised today—might allow the world to keep the temperature rise since the 18th century well below 2°C in the 21st, the target enshrined in the Paris agreement of 2015. ■

→ **Climate models can guide policy even if they are not precise**



Source: IPCC AR5, adjusted to an 1850-1900 baseline *Uncertainties calibrated to 1986-2005, as shown †Representative Concentration Pathway