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Global warming

A changing climate of opinion?

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Some scientists think climate change needs a more radical approach. As well as trying to curb greenhouse-gas emissions, they have plans to re-engineer the Earth

THERE is a branch of science fiction that looks at the Earth's neighbours, Mars and Venus, and asks how they might be made habitable. The answer is planetary engineering. The Venusian atmosphere is too thick. It creates a large greenhouse effect and cooks a planet that is, in any case, closer to the sun than the Earth is to even higher temperatures than it would otherwise experience. Mars suffers from the opposite fault. A planet more distant from the sun than Earth is also has an atmosphere too thin to trap what little of the sun's heat is available. So, fiddle with the atmospheres of these neighbours and you open new frontiers for human settlement and far-fetched story lines.

It is an intriguing idea. It may even come to pass, though probably not in the lifetime of anyone now reading such stories. But what is more worrying—and more real—is the idea that such planetary engineering may be needed to make the Earth itself habitable by humanity, and that it may be needed in the near future. Reality has a way of trumping art, and human-induced climate change is very real indeed. So real that some people are asking whether science fiction should now be converted into science fact.

Tinkering with the atmosphere or the oceans on the scale required to do this would be highly risky and extraordinarily complex. But the alternative, getting the world's population to give up fossil fuels, is proving exceedingly hard. Geo-engineering, as it has come to be known, may be a way of buying time for the transition to a low-carbon economy to take place in an orderly manner.

In the past, geo-engineering was taboo because many felt that the very possibility of fiddling with the climate would create an excuse to avoid the hard choices a low-carbon economy would impose. However, the feeling is now growing that if politicians came to scientists for advice on the matter, it would be a good idea for them to have some to offer. To that end, the Royal Society, Britain's oldest scientific academy, has published a series of papers in its *Philosophical Transactions* outlining some of the options, and suggesting a few experiments to test whether they would work.

Transactional analysis

Broadly, these ideas fall into two categories. One is to remove excess carbon dioxide from the atmosphere. The other is to compensate for the climate-warming greenhouse effect this carbon dioxide and other gases cause, by reducing the amount of sunlight reaching the ground.

The most plausible way to remove carbon dioxide is to increase the amount of photosynthesis going on. Photosynthesis creates plant matter out of carbon dioxide and water. But rotting plant matter returns carbon dioxide to the atmosphere. So, if the gas is to be removed permanently, that rotting has to be avoided.

One widely discussed idea, which the Royal Society's correspondents re-examine, is to fertilise the oceans with iron. The growth of plankton in the sea is always limited by something. It may be light, or a familiar nutrient such as nitrate or phosphate. In some places, though, iron is the limiting nutrient. Adding iron to such places should cause a bloom of planktonic algae, thus sucking carbon dioxide out of the atmosphere.

Several preliminary experiments have shown that plankton do, indeed, bloom when iron is added. What is not clear is what happens to the carbon. For the idea to work, some of it would have to sink to the ocean floor and stay there.

One reason to think this might happen is that during recent ice ages the cold, dry conditions caused a lot of iron-rich dust to blow around. Supporters of the iron-fertilisation theory believe this dust produced blooms of oceanic algae that then sank to the seabed, taking large amounts of carbon with them, which helped to reduce temperatures still further.

Victor Smetacek, of the Alfred Wegener Institute for Polar and Marine Research in Germany, and Wajih Naqvi, of India's National Institute of Oceanography, therefore propose conducting experiments that look not only at how much carbon dioxide is sucked up, but also at what happens to it. In particular, they are interested in the fate of diatoms. These are single-celled algae which seem to absorb almost all of the extra carbon dioxide captured when the ocean is fertilised with iron. The crucial question is what happens to these diatoms when they die. If enough of them sink to the ocean floor and stay buried there, the idea should work. If they do not, it won't. By reviewing studies of the ooze at the bottom of the sea (which is often made of the shells of diatoms) Dr Smetacek and Dr Naqvi reckon the best rate of burial is to be found in the south-west Atlantic, and they propose to carry out an experiment there next year.

The advantage of fertilising the oceans is that it could be done with existing technology. The disadvantage is the unknown knock-on effects. Planktonic algae are at the bottom of the food chain. If more of them are around, the rest of that chain will be affected. This could be a good thing, of course. More algae might mean more krill, and that might mean more whales and other large sea animals. On the other hand, shallow-water blooms caused by nitrate and phosphate pollution often swamp the local environment.

A second idea for scrubbing excess carbon dioxide from the atmosphere, alluded to in the *Transactions* but not much discussed, is to plant more trees. In principle, any old trees would do—although they die and rot, more forest cover would lock up more carbon dioxide. However, genetically modified trees might grow faster. Such trees are being developed to help the lumber, pulp and biofuel industries. But fast-growing forests could also be planted in order to capture carbon dioxide quickly.

Another possibility that the Royal Society's writers consider is recycling carbon dioxide from the atmosphere into fuel, by reacting it with hydrogen. Of course, that would require a supply of hydrogen, and producing hydrogen takes energy—which would have to be generated in a way that produces no carbon dioxide.

Perhaps the most intriguing idea—which was published last year, though not discussed by the Royal Society—is to eject carbon dioxide from the atmosphere at the Earth's poles, using the planet's magnetic field. This may sound absurd, but oxygen already leaks out this way (the phenomenon is the subject of a paper just published by Hans

Nilsson of Swedish Institute of Space Physics). Alfred Wong, a researcher at the University of California, Los Angeles, proposes that a system involving powerful lasers and finely tuned radio waves could encourage carbon dioxide to take the same route. His calculations suggested that using lasers to ionise molecules of carbon dioxide, and radio waves to get them to spin at the correct rate, would cause those molecules to spiral away from Earth along the lines of magnetic force until they were lost for ever in space.

Reflecting on the future

Space is likewise the destination in the other set of approaches. Reflecting sunlight back into outer space (increasing the Earth's albedo, as it is known) would also cool the planet, and the Royal Society's authors consider two ways of doing so.

One, which has been widely touted in the past is, perversely, to increase the amount of pollution in the atmosphere. Governments have spent the past half-century trying to reduce the amount of sulphur compounds in the air. These compounds are the main cause of acid rain. They also, however, have a tendency to form tiny particles that reflect sunlight back into space. That effect is most noticeable when a volcano erupts explosively, as Mount Pinatubo did in 1991, or Tambora did in 1815. Those eruptions put sulphate particles into the stratosphere, and because that is above the part of the atmosphere where weather occurs, these particles tended to stay there rather than being washed out by rain. That cooled the whole climate. The year after Tambora's explosion was known for a long time as the "year without a summer".

The reverse is also true. When civilian flights over the United States stopped in the wake of the terrorist attacks of September 2001, the lack of sulphur-laden contrails led to a perceptible rise in temperature. Philip Rasch, of the National Centre for Atmospheric Research, in Boulder, Colorado, and his colleagues are therefore exploring the idea of deliberately polluting the stratosphere with sulphate in order to reflect solar heat back into space.

To offset the rise in temperature expected by the middle of the century if things carry on as they are, the amount of sunlight reaching the Earth's surface would have to be cut by just 1.1%. That is still a lot of energy in absolute terms, but the sums suggest it is within reach. It would require the addition of about 10m tonnes of finely divided sulphate particles to the stratosphere each year. These could be sprayed out of special aircraft-borne injectors, or produced by burning high-sulphur aviation fuel.

If aviation fuel were used in this way, and was 5% sulphur (between ten and 100 times today's levels), it would require 1m flights a year to the middle of the stratosphere (between 15km and 25km up), assuming an average flight was four hours. Those flights alone would use up half as much fuel as civil aviation now consumes. However, you could achieve part of the effect by making civil aviation use dirty, high-sulphur fuel. It would not be a perfect solution. Civilian jets cruise at an altitude of 10km, the bottom of the stratosphere, and any sulphate they released would thus fall to earth faster. But it would be a lot cheaper than flying 1m special missions.

Besides polluting the stratosphere, there is another way of changing the atmosphere to make it more reflective. This is to tinker with cloud cover. One person working on this idea is Stephen Salter, a marine engineer at the University of Edinburgh best known for seeking to replace fossil fuels with Salter's duck, a device for turning ocean waves into electricity. He has also been working on the geo-engineering end of climate change.

Dr Salter and his colleague at Edinburgh, Graham Sortino, together with John Latham, one of Dr Rasch's colleagues at the National Centre for Atmospheric Research, have been looking into how clouds might be made more reflective. Their answer is to spray them with seawater. Particles of salt formed by the evaporation of ocean spray act as nuclei around which the droplets of water that form clouds can condense. Increasing the number of particles increases the number of droplets. That does not change the total amount of cloud (which is controlled by the amount of water vapour in the atmosphere). But having more, smaller droplets does increase a cloud's reflectivity.

A drop in the ocean

Dr Latham led a team of climate modellers who wondered whether, in principle, this phenomenon might be used to increase the planet's albedo enough to compensate for projected global warming. Their answer was that it could, but it would require 1.4 billion tonnes of seawater to be converted into spray each year.

Dr Salter and Dr Sortino then joined Dr Latham in trying to work out how to manage this. Their answer is a fleet of specially designed ships. These would be wind-powered—not by sails but by Flettner rotors, which are giant, rotating cylinders that extract energy from the wind using the Magnus effect. (This is the effect that causes cricket balls to swing in the air, among other things.) The ships would drag turbines through the sea to provide electricity that would both drive the cylinders and power pumps that sprayed the atmosphere with seawater, suitably broken up into droplets.

Such ships would weigh 300 tonnes. A fully operational system would require 1,500 of them. And it would have the advantage of an almost instant off switch. Stop spraying, and things would revert to normal within a couple of days.

Cui bono?

That reversibility is important. Many scientists are understandably nervous about tinkering on a grand scale with the atmosphere and the oceans. The Intergovernmental Panel on Climate Change—a scientific body appointed by the United Nations to assess the risks of a changing climate—has described geo-engineering as "largely speculative and unproven, and with the risk of unknown side-effects".

Broadly, there are two types of fears. The first is of technological hubris. History is littered with plans that went awry because too little was known about complex natural systems. As with irrigating Soviet cotton fields from the Aral Sea in Central Asia or introducing rabbits to Australia, modifying the climate will have both physical and biological consequences. Some of these will be unpredictable and some of them may be worse than the harm they were intended to treat. Critics point out, for instance, that carbon dioxide does not just warm the atmosphere. It also makes the oceans more acidic. That is bad because many marine creatures rely on shells made of calcium carbonate to protect themselves. As every schoolboy knows, if you drop calcium carbonate (limestone, for example) into acid, it dissolves. The sea would not become so acidic that shells would actually dissolve, but the extra acidity would mean making them was harder work, which might upset the oceanic ecosystem quite badly. For this reason, approaches to geo-engineering that merely reflect heat back into space need to be viewed cautiously.

The other fear is of moral hazard—the possibility that people would see the promise of geo-engineering their way out of trouble, despite its risks and uncertainties, as an excuse to continue to pollute the atmosphere as usual.

It would be a mistake to think of geo-engineering as a substitute for curbing carbon-dioxide emissions—not merely because of the acidification of the oceans, but also because if you ever stop fertilising the oceans or spraying the atmosphere or whatever, the problem will rapidly return. Nevertheless, Brian Launder of the University of Manchester, who edited the Royal Society papers, argues that the sort of geo-engineering schemes they describe might buy the world 20 to 30 years to adjust. That breathing space would be useful if something really bad, such as the collapse into the sea of part of the Greenland ice-shelf, was in imminent danger of happening, and the realisation of the danger led to a political agreement that climate change had to be stopped rapidly.

So what now? The answer is probably to carry out preliminary trials of the sort proposed by Dr Smetacek and Dr Naqvi. Correctly done, they should help to indicate what could work, what would not, and what the financial and environmental costs might be.

Local schemes, particularly ocean fertilisation, need not be that expensive. They would be well within the budget of a small country, a large company or even a tycoon. Richard Branson, a British businessman, is already offering a prize of $25m for a workable way of removing a billion tonnes of carbon dioxide from the atmosphere every year. And at least one private firm has come in for criticism for attempting to sell carbon credits based on ocean fertilisation. And yet, the effects of geo-engineering would rarely be restricted to a single country—that is, after all, the whole point.

For this reason, if geo-engineering is to be done properly, it must be regulated properly. The world needs a way of deciding the size and scope of any project, who takes responsibility for any mistakes, and whether and how to compensate losers—of whom there will be many. Schemes designed to cool the climate could harm countries such as Canada and Russia. Global warming may make their northern wastes more habitable and allow them to exploit oil and gas located under what is now an ice-covered Arctic Ocean. Meanwhile a country such as Panama would prefer a cooler world in which ice continues to seal off the North-West Passage and to prevent competition with its canal.

Some tinkering to suit local needs may be possible. Ken Caldeira of Stanford University, another of the authors, reckons that it may be feasible to place sulphates in the stratosphere near the poles and thus cool the Earth in a place where global warming manifests itself most strongly, though that would scarcely please the Russians and the Canadians. Nor does it answer the question of how to decide whose interests such tinkering should serve.

Even its advocates think geo-engineering is not to be approached lightly. Nor, though, is it something to be ignored completely. Global warming is such a threat that all the options deserve to be explored. It would be a big experiment, but it would at least be a planned one—unlike the equally big, but unplanned experiment that is now being conducted by motor cars, power stations, cement factories and logging companies all across the planet.