ADAM FERGUSON/VII MENTOR PROGRAM

Smoke signal

Carbon dioxide is not the only climate-altering pollutant. We ignore the others at our peril, says **Anil Ananthaswamy**

The brown haze that hangs over large parts of Asia is affecting the monsoon rains

NASA IMAGE COURTESY JEFF SCHMALTZ, MODIS RAPID RESPONSE TEAM, GODDARD SPACE FLIGHT CENTER

IN JUNE 1783, lava and gases began pouring from the Laki fissure in Iceland in one of the biggest and most devastating eruptions in history. Poisonous gases and starvation killed a quarter of Iceland's population. The effects of the eight-month-long eruption were felt further afield, too. In the rest of Europe, a scorching summer of strange fogs was followed by a series of devastating winters. In North America, the winter of 1784 was so cold the Mississippi froze at New Orleans.

At the time, French naturalist Mourgue de Montredon suggested the eruption might be to blame, but two centuries passed before scientists started to work out how gas and dust from volcanoes affect climate. The main culprit is sulphur dioxide, which has a cooling effect. Laki pumped an estimated 120 million tonnes of the stuff into the atmosphere, cooling the northern hemisphere by as much as 0.3 °C over the next few years.

Nowadays, we are pumping out amounts of sulphur dioxide each year comparable to Laki's emissions. Human emissions rose rapidly over the 20th century, peaking at an estimated 70 million tonnes a year in the 1990s as developed countries cleaned up their act. Even such huge amounts, however, have not been enough to stop global warming: the cooling effect has been more than offset by the warming effect of carbon dioxide and other pollutants.

We are only now beginning to understand the effects of some of those other pollutants. One of the major players is black carbon, produced by the burning of everything from dung to diesel. Some recent studies suggest it is one of the biggest causes of warming after CO_2 in the short term, contributing to the rapid warming in the Arctic and the melting of Himalayan glaciers.

These findings mean we face both a danger and an opportunity. When China and India reduce their sulphur dioxide emissions, the rate at which the planet is warming will rise dramatically. Satellite measurements show that China is already making headway, says Frank Raes of the European Commission Joint Research Centre in Ispra, Italy. As a result, the rate of warming could increase from the current 0.2 °C per decade to 0.3 or 0.4 °C per decade. "Locally, it might go to 0.8 °C per decade," Raes says. Such rapid change would make it much harder for both people and wildlife to adapt (see "Too fast, too furious", page 40).

On the plus side, we could head off this dramatic speed-up in warming over the next few years by tackling black carbon and some of the other short-lived pollutants that are helping to heat up the planet. This would buy us more time to reduce our dependence on fossil fuels.

Global dimming

Since the industrial age got under way, we have been pumping ever more pollutants into the atmosphere; not just gases like CO_2, but also substances that form fine particles, or aerosols. The result is often visible in the form of a brown haze covering cities or even entire countries. The quantity of pollution is so vast that the amount of sunshine reaching Earth's surface has declined by as much as 10 per cent in places, a phenomenon known as global dimming.

While scientists have suspected ever since the Laki eruption that natural and man-made aerosols can have a big effect on the climate, pinning down exactly what effect they have has been very tricky (see "Every cloud had a lead lining", page 42). Fortunately, natural experiments like the eruption of El Chichon in Mexico in 1982 helped establish beyond any doubt that sulphur dioxide has a major cooling effect. We now know it forms sulphuric acid aerosols in the atmosphere that reflect sunlight back into space. It also has a cooling effect through making clouds more reflective.

From the 1940s onwards there was a slight decline in temperature in the northern hemisphere which was largely due to increasing sulphur dioxide emissions. The average temperature then began to rise fast after the late 1970s as sulphur pollution began to plateau. In the southern hemisphere, by contrast, where there was little sulphur pollution, temperatures increased gradually over the 20th century. ›

INSTITUTE OF TIBETAN PLATEAU RESEARCH, CHINESE ACADEMY OF SCIENCES

Ice cores show that black carbon is partly to blame for shrinking glaciers

If sulphur dioxide is slowing the rate of warming, why cut emissions? The answer is that it is a killer. Recent studies have shown that sulphur dioxide pollution from the Laki eruption killed tens of thousands of people in the UK alone. It has been directly linked to various lung disorders, including bronchitis and asthma. It is also bad for the environment: sulphur dioxide is one of the main causes of acid rain, which can devastate fish populations and destroy forests. No one is suggesting we keep on pumping it out.

Like sulphur dioxide, black carbon shades the Earth's surface, so you might expect it to have a cooling effect, too. In fact it absorbs the sun's energy rather than reflecting it, warming the atmosphere. Global dimming does not necessarily mean global cooling. Recent studies by Veerabhadran Ramanathan at the University of California, San Diego, and colleagues suggest carbon black contributes more to global warming than previously thought (*Nature Geoscience*, vol 1, p 221).

"If sulphur dioxide is slowing warming, why cut emissions? Because it's a killer"

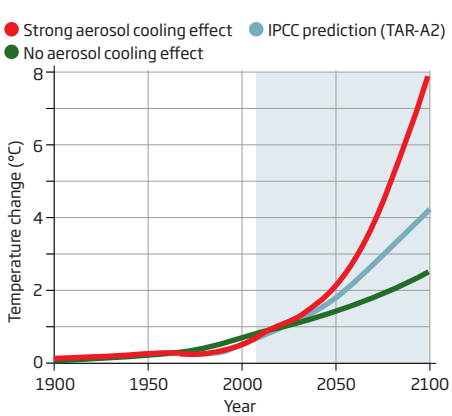
Because rapidly industrialising countries like India and China have become a major source of black carbon, its effects are particularly strong in this region. Ramanathan used unmanned aircraft to study the brown haze that hangs over much of Asia. The work revealed that the haze is mainly black carbon (*Nature*, vol 448, p 575). "My measurements show that black carbon concentrations at altitudes of 2 to 4 kilometres are as large as in downtown Los Angeles," says Ramanathan. It comes mainly from the low-temperature burning of coal, firewood and cow dung.

Black carbon can interfere with the amount of rain and snowfall. Over the oceans, it absorbs some of the sun's heat before it reaches the water surface, reducing evaporation. What's more, if black carbon settles on ice or snow, it absorbs sunlight that would normally be reflected.

All of this means that the brown haze is affecting the Asian monsoon, reducing the amount of snowfall in the Himalayas. The black carbon is also settling on snow and glaciers. The result is a double whammy. "About half of the retreat of the Hindu Kush, Himalayan and Tibetan glaciers may be coming from the black carbon solar heating, as well as the slowing down of the monsoons," Ramanathan says. It's a controversial point,

Warming unleashed

If the cooling effect of aerosol pollution is counteracting the warming effect of rising greenhouse gas levels, temperatures will rise faster than predicted as we cut aerosol pollution. The red line shows the most extreme case



SOURCE NATURE, 2005

Too fast, too furious

It's not so much global warming that threatens ecosystems as the rate at which the temperature rises.

Cleaning up the air by removing the sulphate aerosols whose cooling effect is partly counteracting global warming would uncork the temperature rise that's already in store for our planet (see graph). It could lead to a rise of as much as 0.3 °C to 0.4 °C per decade (*Atmospheric Environment*, vol 43, p 5132).

We should be seriously concerned about such rapid climate change, say Rik Leemans of Wageningen University in the Netherlands and Bas Eickhout of the Netherlands Environmental Assessment Agency. Their work suggests that nearly 70 per cent of all ecosystems and 83 per cent of all forest ecosystems would struggle to cope with temperature increases of more than 0.3 °C per decade (*Global Environmental Change*, vol 14, p 219).

Some ecologists are looking at ways to minimise the effect on ecosystems. Nancy-Anne Rose and Philip Burton at the University of Northern British Columbia in Prince George, Canada, have started identifying regions of British Columbia where the climate will remain within acceptable limits for the existing plant and animal life, despite warming elsewhere.

They argue that focusing on these "temporal corridors" will allow conservation agencies to maximise their impact. The Nature Conservancy of Canada aims to use the work to establish conservation plans for British Columbia (*Forest Ecology and Management*, vol 258, p S64).

for it puts at least some of the onus for what's happening in the Himalayas on regional pollution, and not just on the global warming induced by the industrialised west.

Further evidence comes from a study published in December by James Hansen of NASA's Goddard Institute for Space Studies (GISS) in New York and colleagues in China. The team (pictured, far left) took ice cores from five glaciers on the Tibetan plateau to find out how concentrations of black soot have changed over the decades.

They found a big peak in black carbon levels in four of the glaciers in the 1950s and 1960s. The source of this black carbon was almost certainly Europe, which has since cleaned up its act. The peak coincides with a dramatic retreat of many Tibetan glaciers during this time, most of which regained ice in the 1970s before starting to decline again more recently. The recent decline coincides with another rise in black carbon levels; this time the pollution is mostly from the Indian subcontinent.

The findings suggest that the shrinking of Himalayan glaciers could be slowed, and perhaps even reversed in some cases, if Asia were to slash its black carbon emissions. And that is vital, because the glaciers and the snowpack act as natural reservoirs, storing water in winter and releasing it in summer, when it is needed most.

The effects of black carbon are certainly not limited to Asia, however. The part of the world that is warming fastest is the Arctic, raising fears that it is nearing a tipping point. Aerosols are as much to blame as greenhouses gases, according to simulations by Drew Shindell of GISS, and colleagues. Since the 1980s, falling sulphur dioxide emissions combined with rising black carbon levels have helped drive the rapid warming, the team reported last year (*Nature Geoscience*, vol 2, p 294).

While black carbon is turning out to be a much more important contributor to global warming than previously thought, it is far from the only one (see "The climate changers", left). For instance, carbon monoxide and the nitrogen oxides are all precursors to ozone, a greenhouse gas. Methane is another one, and requires immediate attention, says Gavin Schmidt of GISS. "Methane is the second-biggest problem after CO_2," he says.

There is a growing consensus about the need to tackle these pollutants. In October, for instance, Stacy Jackson of the University of California, Berkeley, argued for separate treaties for controlling their emissions in addition to whatever follows the Kyoto protocol (*Science*, vol 326, p 526).

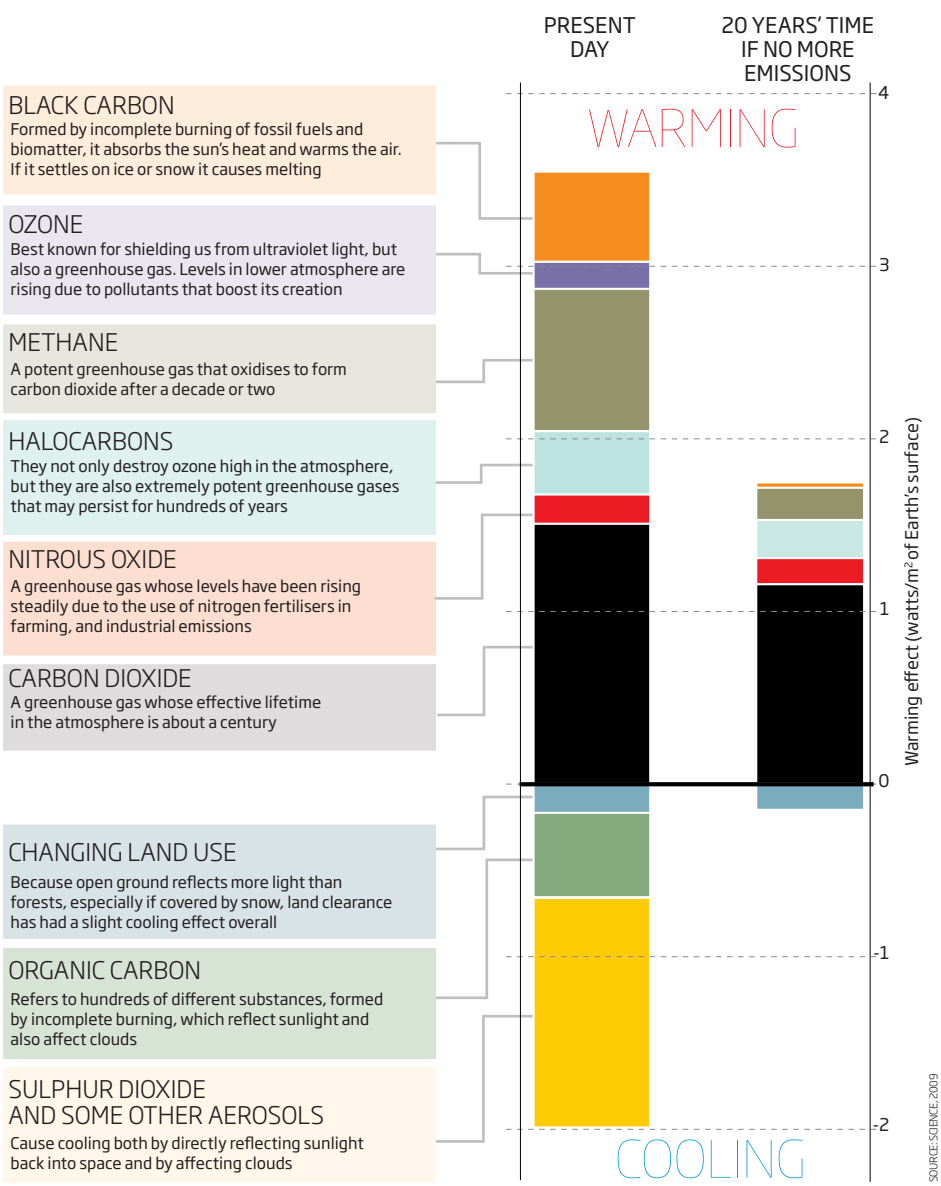
You might wonder why this issue has so far attracted little attention. It's partly because it is rather new, even to many scientists. There is also still a lot of uncertainty about how much warming or cooling various pollutants cause. The Intergovernmental Panel on Climate Change did not address the issue of regulating non-CO_2 emissions in its 2007 report. "The IPCC's fifth assessment should pay more attention to it, and it will," says Raes.

However, the difficulty of pinning down the precise effects of each pollutant and the partly regional nature of their effects could make getting international agreement even trickier than with CO_2. Some countries might argue, for instance, that their black carbon emissions matter less than other countries because the prevailing winds ensure they never land on snow or ice.

There is one low-hanging fruit, though: ›

THE CLIMATE CHANGERS

Many of the pollutants we are pumping into the atmosphere have a warming or cooling effect. This graph shows the estimated contribution of the major pollutants and also what their effect would be in 20 years if all emissions ceased tomorrow



SOURCE: SCIENCE, 2009

CYRUS READ/AVO/USGS

Every cloud had a lead lining

Pinning down the effect of small particles, or aerosols, on the climate is extremely difficult, and recent studies have thrown up a few surprises. Just last year, for instance, Daniel Cziczo of the Pacific Northwest National Laboratory in Richland, Washington, and colleagues, showed that lead particles are extremely efficient at seeding the formation of ice crystals in the atmosphere, which cool the planet by reflecting sunshine (*Nature Geoscience*, vol 2, p 333).

So while the lead added to petrol from the 1920s onwards was bad for our brains, clouds containing lead helped offset the warming effect of CO_2. When lead levels peaked in the 1970s, lead may have had an average cooling effect of up to 0.8 watts per square metre. "According to our simulations there has probably already been a warming due to the reduction in lead emissions," says Cziczo.

Another surprise finding is that global dimming boosts plant growth. Aerosol pollution has cut the amount of sunshine reaching Earth's surface by around 10 per cent in places, which you would think would limit photosynthesis. However, the pollution also scatters what light does reach the surface, meaning plants receive light from more directions. Fewer leaves are left in the shade, boosting photosynthesis, say Lina Mercado of the Centre for Ecology and Hydrology in Wallingford, UK, and colleagues (*Nature*, vol 458, p 1014). As the air gets cleaner, plant growth will fall and so will the amount of carbon those plants sequester.

the black carbon pumped out by diesel engines, mainly from vehicles in Europe and North America. All that needs to be done is to filter out the particulate emissions from the exhaust fumes of diesel vehicles. "For black carbon reduction, our first focus should be to go after diesel, because the technology is there," says Ramanathan. It would have big health benefits. too.

Other changes will be harder to achieve. The fires used by people in rural areas for cooking and heating generate a lot of soot, which contains both black carbon and cooling aerosols. The net effect remains unclear. What's more, villagers cannot afford to switch to solar cookers and clean-burning biogas even if they wanted to. There would have to be some incentive, such as payment via carbon credits, say Ramanathan. "That will overnight

Volcanoes revealed the cooling effect of sulphur dioxide

transform what's happening in villages."

To cut methane emissions, policy-makers will have to target a whole host of sources, says Schmidt, including oilfields, landfills and the sewage plants and manure pits used in industrial agriculture. It will even mean changing the way rice is grown. Flooding paddy fields generates a lot of methane. Using drip irrigation instead would both reduce emissions and save water. But persuading companies to install methane-capture technologies, and farmers to change traditional growing practices, won't be easy.

One of the reasons why the focus has always been on CO_2 is because most non-CO_2 pollutants are short-lived. Methane hangs around in the atmosphere for only a decade or two. Aerosols last only days or weeks before being washed out. CO_2, by contrast, has an effective lifetime of about a century, so it is the big problem in the long term. There is a danger, however, that any international agreement on non-CO_2 pollutants will be seen as a reason to avoid doing anything about CO_2.

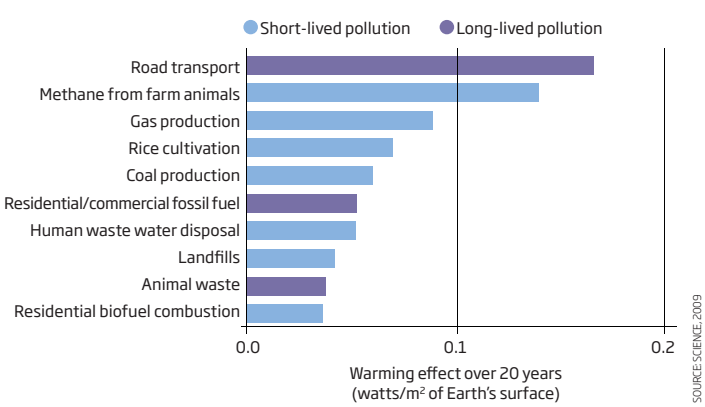
That is no idle concern, as Hansen knows. His calls for cuts in non-CO_2 pollutants back in 2000, among other measures, led to an invitation in 2001 to some meetings of the White House's climate change task force, whose members included the then vice-president Dick Cheney. Hansen says it became clear to him that Cheney saw tackling non-CO_2 pollutants as a way to sidestep CO_2 cuts.

The damaging effects of aerosols on our health could yet persuade more governments to go ahead and cut emissions regardless of any international treaties. If countries don't cut the pollutants that cause warming at the same time as the ones that cause cooling, however, we could soon see temperatures rising fast enough to convince even the most hardened climate-change sceptics. ■

Anil Ananthaswamy is a consultant for *New Scientist* based in London

The biggest causes of warming

How much warming various sources of pollution will cause over the next 20 years, assuming emission rates remain constant at 2000 levels. The purple bars indicate which sources produce long-lived pollutants, such as CO_2, which will continue to cause warming far beyond 20 years



SOURCE: SCIENCE, 2009