Earth 2020

An Insider's Guide to a Rapidly Changing Planet

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Air

Jon Abbatt

Life as we know it is possible thanks to the thin film of gases in Earth's atmosphere, which distinguishes our planet from all others in the solar system. A ride on an airplane offers the opportunity to ponder this remarkable atmospheric eggshell around us. Only a few minutes after takeoff, we reach cruising altitude around 10,000 m above sea level, with two-thirds of the atmosphere below us. This lowest portion of the atmosphere — the troposphere — contains gases that support life on our planet, as well as all the pollutants that damage our lungs. The troposphere is also home to the greenhouse gases that warm us and the clouds that cool us. If our plane were to fly another 10 or 20 km higher, it would pass through the ozone layer in the stratosphere, which filters out biologically damaging ultraviolet radiation from the Sun. As we look back to the first Earth Day in 1970, we can ask ourselves how Earth's atmosphere has changed, and what the future may yet hold.

For much of human history, our Earth-bound species has largely taken the air around us for granted, the atmosphere conceived of as an invisible and infinite conduit to the heavens above. This notion was radically challenged with the rise of industrialization, when coal-darkened skies became common in cities across North America and Europe. The 1952 acidic fog episode in London provides a famous example. At that time, England was burning poor quality bituminous coal, creating high levels of carcinogenic soot particles in the air, as well as sulfur dioxide, which is harmful to our respiratory system. In early December of 1952, low winds created a stagnant pool of air that trapped the coal fumes

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over London for four consecutive days. Conditions grew so bad that people could not see across the road, and outdoor activities were restricted. Several thousand people died as a direct effect of the air pollution (primarily those with pre-existing respiratory problems), and many thousands more suffered adverse longer-term health effects. Response to the Great Smog of London was swift. The UK passed its Clean Air Act only four years later, in 1956, which mandated the burning of cleaner fuels and led to a rapid improvement in air quality in cities across the country.

Episodes like the Great Smog of London, along with rising public awareness of environmental pollution, led to the first Earth Day in 1970. In the subsequent fifty years, environmental science and public policy have converged to address a variety of atmospheric pollution phenomena.[1] This is perhaps best illustrated by international efforts to save the ozone layer. In the early 1970s, only a handful of scientists cared about ozone. This molecule (three oxygen atoms bonded together) was known to block harmful ultraviolet light from the Sun, but there was no indication that human activity could affect its abundance. After all, ozone mostly existed in the stratosphere, 20 to 30 km above Earth's surface. At the time, it was not known that industrial chemicals, known as chlorofluorocarbons (CFCs), were percolating upwards towards the stratosphere. These compounds, invented in the 1950s, were initially viewed as a shining example of human industrial ingenuity — non-toxic, non-flammable substances with many uses in cleaning, refrigeration and aerosol sprays. Yet, in the decades that followed, the true environmental impact of these compounds would come to capture global attention.

The first measurements of global CFC abundance were reported in the 1970s by James Lovelock, who would later propose the Gaia hypothesis of Earth as a self-regulating environment sustaining life. Even though the CFC sources were largely in the northern hemisphere, where populations and industry are dominant, the abundance of these compounds was just as high south of the equator. This was one of the first indications that anthropogenic pollutants experience widespread global transport across geopolitical boundaries. Attempting to explain the behavior of CFCs in the atmosphere, researchers discovered that they decompose in the stratosphere, releasing chlorine that catalyzes ozone destruction.[2] At the time, CFCs were being used around the world in a wide range of applications, and their atmospheric concentrations were rising dramatically. Once released, there was no easy way to remove these molecules from the atmosphere.

The problem of CFC-driven ozone destruction captured public attention in the mid-1980s, with the discovery of a massive ozone hole over the Antarctic continent. This phenomenon, seen as a large and recurrent loss of ozone in the region each spring, is driven by the chlorine released from CFCs. Its location over the southern pole is attributable to unique meteorological factors that isolate cold air masses over Antarctica and make them particularly susceptible to chlorine-mediated ozone loss. Ground-based observations of the ozone layer over the Antarctic continent, which started in the late 1950s as part of the International Geophysical Year, were the first to detect the ozone hole in the mid-1980s.[3] Subsequently, satellite-derived images of the widespread Antarctic ozone hole became emblematic of human impacts on the environment — a dystopian view of human technology gone horribly wrong.

As terrifying as detection of the ozone hole was, global action was swift and extremely effective. The Montreal Protocol, first signed in 1987 and amended a number of times thereafter, led to the banning of CFC production globally.[4] Other ozone-depleting substances, such as methyl bromide, once used to fumigate strawberry fields, have also since been banned. Ozone-friendly CFC replacement compounds are now widely used, with society barely noticing the transition. Yet, the lifetime of CFCs is so long — fifty to one hundred years — that significant ozone depletion continues over the Antarctic and more slowly at mid-latitudes.[5] Once the CFCs have been naturally cleansed from the atmosphere, ozone levels will hopefully return to those present on the first Earth Day. The enactment of the Montreal Protocol and the saving of the ozone layer has undoubtedly adverted millions of cases of skin cancer. An environmental success story indeed!

Throughout the 1970s, as stratospheric ozone loss became a cause for significant concern, ozone began to accumulate in the lowest layers of the atmosphere. Increasing ground-level ozone concentrations, first identified in Los Angeles and subsequently in other large cities around the world, resulted from chemical reactions between organic molecules (including gasoline fumes) and nitrogen oxides (emitted by car engines) in sunlight. The resulting ozone caused significant damage to a variety of organic materials, from rubber tires and windshield wipers to people's breathing passages. Los Angeles, home to plenty of sunlight and automobiles, became the posterchild of photochemical air pollution, or 'smog', as it came to be known.

In response to the smog crisis of the 1970s and 1980s, California developed air pollution control strategies that are now widely adopted across the globe. Catalytic converters were added to automobile exhaust systems to remove organic and nitrogen oxide vapours, and internal combustion engines were designed to use gasoline that combusts much more efficiently, with computer-controlled tuning of air-to-fuel ratios. These measures have had a dramatic effect on air quality in Los Angeles and other major cities. Whereas the Los Angeles' automobile population has grown enormously from the 1970s, when the smog pollution was at its worst, ground-level ozone concentrations have dropped by roughly two thirds over the last forty years. In the 1970s, visitors to Los Angeles were surprised to find that the city is ringed by a range of mountains, which were infrequently invisible through the haze. Today, visibility is much improved. Additional progress will be made as gasoline-powered engines give way to electric and hydrogen-based vehicle propulsion systems. Even so, ozone production will continue from organic precursor molecules derived from a variety of consumer products, such as paints, solvents, personal care products and indoor cleaning agents.[6] These sources, long overlooked, are currently unregulated, posing an on-going challenge for long-term air quality improvement. But it seems only a matter of time before these chemicals, like automobile exhaust and CFCs, will also be subject to strict environmental regulation.

The factors that led to urban smog in cities around the world also created additional atmospheric pollution problems. In the 1970s, forests and lakes were dying in northeastern North American and northern Europe as a result of acid rain produced from sulfur and nitrogen oxides released from coal burning and vehicle exhaust. In extreme cases, the acidity of rainwater approached that of vinegar, and this low pH precipitation was deposited onto land and water surfaces with devastating effects. The strong acidity had direct biological impacts on marine and terrestrial ecosystems, and a variety of indirect effects, including the leaching of toxic metals from soils. There was also another, very visible, manifestation of acid rain in cities around the world, as low pH rain dissolved the ornate limestone structures on historical buildings and attacked the steel beams of bridges. Motivated by the mass protests on Earth Day 1970, new environmental regulations mandated the widespread use of smokestack scrubbers and cleaner coal, both of which led to a significant decrease in sulfur dioxide emissions and the associated acid rain.

Similarly effective action was taken to combat atmospheric lead pollution. The environmental toxicity of lead, from cookware to paint, has impacted human societies for millennia, and lead poisoning was famously suggested as a cause for the decline of the Roman Empire. But it was not until the twentieth century, when lead became widely used as a gasoline additive that the concentrations of this metal began to increase on a global scale through long-range atmospheric transport. As with CFCs and acid rain, the solution to atmospheric lead contamination was clear and remarkably effective. In a 1996 amendment to the US Clean Air Act, lead was banned from all gasoline products, and over the next two decades, human blood levels of lead dropped by more than 80%.

Unlike CFCs and lead, air-borne particulate matter continues to be an important component of air pollution.[7] These small solid and liquid particles, much smaller than the width of a human hair, have serious health consequences when present in high abundance. This is particularly true for the smallest size class of particles, which are readily inhaled into the lungs. The landmark ‘Harvard Six Cities’ study, initiated in the 1970s, has continually monitored the mortality of people living in six American cities.[8] After correcting for occupational hazards and smoking rates, the study has shown a strong correlation between rates of excess mortality and high amounts of air-borne particulate matter. This result has been confirmed in numerous cities, and it is now clear that atmospheric particles are one of the leading causes of shortened lifespan worldwide, leading to millions of excess deaths per year. It remains to be determined which chemical compounds of the thousands present in atmospheric particulate matter are leading to these negative health outcomes.

Particles are emitted into the atmosphere from both natural and industrial sources, both of which are likely to continue increasing for the foreseeable future. Natural sources of atmospheric particulate matter include sea spray, desert dust and wildfires. The frequency and intensity of wild-fires is predicted to increase under a warming climate, as is the expansion of some global deserts. Both of these processes should act to increase sources of atmospheric particles. Even in the absence of fires, forests can be a source of atmospheric particles by emitting gaseous organic molecules that undergo chemical transformations in sunlight. The Great Smoky Mountains in Tennessee and North Carolina get their name from this phenomenon.

Over the past five decades, human-derived sources of atmospheric particulates have increased dramatically. These anthropogenic particles are derived from both fossil fuel and vegetation burning, as well as specific industrial activities such as metal smelting. The world's population is more urbanized than it has ever been, with over half of us now living in cities. The growth of megacities with populations of more than ten million people has been remarkable, with most of these cities in industrially developing countries. These urban centers have extremely high air particle levels, resulting from the burning of dirty coal and agricultural wastes, widespread street cooking and the unregulated use of many commercial products, including small motorcycles without air pollution controls. Moreover, indoor air quality remains a serious problem in millions of homes around the world in which cooking is still performed over inefficient stoves using wood, coal or dung fuels. As reported by the recent Global Burden of Disease study, the air quality in or near these homes is one of the leading causes of pollution-related death globally, particularly for women and children.[9] The implementation of better ventilation, more efficient cook stoves, and cleaner fuels are needed to address this global health problem.

The examples of London and Los Angeles illustrate how we have dealt with air pollution crises in the past. Technological solutions exist, and with increasing wealth around the world, a growing middle-class will demand cleaner air as a fundamental human right. Indeed, recent widespread protests in China over poor urban air quality garnered significant international attention, prompting the government to pledge new environmental protection measures. When and how governments around the world deliver on this promise remains uncertain, but it would seem to be only a matter of time before air pollution levels in the world's new megacities are reduced.

While ozone depletion, acid rain and urban air pollution are being addressed, enhanced global warming associated with atmospheric release of greenhouse gases — most notably carbon dioxide, methane and nitrous oxide — remains a larger, daunting challenge. Ice core records show that the concentrations of these gases in the atmosphere are significantly higher than at any time over the last 800,000 years, with a rate of increase that may be unprecedented in Earth's history.[10] Unlike CFCs or lead, whose industrial sources could be traced to specific sources (spray cans and leaded gasoline, for example), CO_2 emissions result from the combustion of all fossil fuels, from coal and oil to wood and natural gas. For this reason, a reduction in CO_2 emission requires nothing less than a whole-scale transformation of global energy production systems.

The global warming challenge mirrors previous global air pollution threats. In the case of ozone depletion, lead, acid rain and smog, society recognized the central role played by key compounds — CFCs, sulfur dioxide, nitrogen oxides and particulate matter — and policies were put in place to successfully control these emissions. We can only hope that these previously successful approaches can provide a template for tackling global warming and transforming our energy supply network, with sound science and technological innovation tied to effective public policy. Though it has been suggested that carbon capture may be necessary to limit global warming to 1.5°C, we hopefully will not need to rely on other geoengineering schemes — such as injection of aerosol particles into the stratosphere to block incoming sunlight — to avert the most dire warming scenarios. Indeed, it is heartening to see the price for wind and solar energy rapidly dropping, to the point that these non-carbon energy sources are now economically competitive with fossil fuel energy in many places. If we apply the same focus and energy used to address air pollution issues over the past half-century, we can remain optimistic that the one-hundredth anniversary of Earth Day may see the atmosphere returning towards its pre-industrial character.

Endnotes

1. D. Davis, M. Bell and T. Fletcher, 'A look back at the London smog of 1952 and the half-century since', *Environmental Health Perspectives*, 2002, 110, A734–A735, https://doi.org/10.1289/ehp.110-a734
2. M. J. Molina and F. S. Rowland, 'Stratospheric sink for chlorofluoromethanes — chlorine atomic-catalyzed destruction of ozone', *Nature*, 1974, 249, 810–12, https://doi.org/10.1038/249810a0
3. J. C. Farman, B. G. Gardiner and J. D. Shanklin, 'Large losses of total ozone in Antarctica reveal seasonal ClOx/NOx', *Nature*, 1985, 315, 207–10, https://doi.org/10.1038/315207a0
4. Available at https://ozone.unep.org/treaties/montreal-protocol-substances-deplete-ozone-layer/text
5. World Meteorological Organization, *Scientific Assessment of Ozone Depletion: 2018*, Global Ozone Research and Monitoring Project, Report 58, Geneva: World Meteorological Organization, 2018, https://www.esrl.noaa.gov/csd/assessments/ozone/2018/downloads/2018OzoneAssessment.pdf
6. B. C. McDonald et al., 'Volatile chemical products emerging as largest petrochemical source of urban organic emissions', *Science*, 2018, 359, 760–64, https://doi.org/10.1126/science.aaq0524
7. U. Poschl, 'Atmospheric aerosols: Composition, transformation, climate and health effects', *Angewandte Chemie-International Edition*, 2005, 44, 7520–40, https://doi.org/10.1002/anie.200501122
8. D. W. Dockery, C. A. Pope, X. P. Xu, J. D. Spengler, J. H. Ware, M. E. Fay, B. G. Ferris and F. E. Speizer, 'An association between air pollution and mortality in 6 United States cities', *New England Journal of Medicine*, 1993, 329, 1753–59, https://doi.org/10.1056/NEJM199312093292401
9. S. S. Lim, T. Vos, A. D. Flaxman et al., 'A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010', *The Lancet*, 2012, 380, 2224–60, https://doi.org/10.1016/S0140-6736(12)61766-8
10. IPCC, 'Climate change 2013: The physical science basis', in *Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* ed. T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P. M. Midgley, Cambridge, UK: Cambridge University Press, 2013, 383–464, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf