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THE LAUREATE AS PUBLIC INTELLECTUAL: PAUL CRUTZEN AND THE POLITICS OF THE ENVIRONMENT

by

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This article argues that Nobel Prize-winning chemist Paul Crutzen (1933–2021) spoke in the name of science over several decades as a public intellectual who shaped research fields, environmental policy, and public understanding of the environment. It analyses the atmospheric chemist as a case study to explain the formation and influence of the scientist as a public intellectual, tracing the trajectory of his public career, focusing on his critical contributions to four significant episodes in modern environmental politics: his warnings in the 1970s of damage to the ozone layer, his catalysing impact on the nuclear winter debates of the 1980s, his turn-of-the-century conceptualization of the Anthropocene, and his late-career advocacy of solar geoengineering. It undertakes a textual analysis of four agenda-setting articles to demonstrate how Crutzen performed the public intellectual functions of testing the assumptions of scientific and policy elites, and framing new ways of understanding environmental problems. It argues that he was a technocratic public intellectual who viewed scientists as guides for society to understand and respond to human-caused environmental threats. As climate change becomes a defining issue of the twenty-second century, Crutzen's career illuminates the potential and limitations of the technocratic public intellectual to shape global environmental politics.

Keywords: Anthropocene; public intellectual; ozone layer; nuclear winter; solar geoengineering; climate change

Introduction

When he died in 2021, aged 87, the Nobel laureate Paul J. Crutzen was honoured in obituaries in scientific journals and international newspapers as a scientist who had a profound influence on modern environmental science and politics. Obituaries emphasized his foundational contributions to knowledge about the chemical processes behind the formation and destruction of ozone, which is concentrated in a thin layer in the atmosphere and protects

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the Earth from dangerous solar radiation, a historical contribution to science for which he shared the 1995 Nobel Prize in Chemistry. Writers described how he was the first to theorize in the early 1980s about a phenomenon that became known as nuclear winter, which described a world shrouded in smoke and radiation-soaked darkness after an atomic weapon exchange between Cold War superpowers. They described how he formulated and disseminated from 2000 the concept of the Anthropocene, his designation of a new geological epoch driven by human activities, one of the most far-reaching concepts in modern intellectual life. Some, but not all, obituaries noted his controversial late-career advocacy of solar engineering to address climate change. Obituaries collectively honoured a scientist who, they agreed, had an uncommon degree of influence on atmospheric chemistry, global climate policy, and public understanding of the environment.[1]

The problem this study sets out to address is how Crutzen came to occupy such a prominent cultural position and how he was able to influence various publics across a range of environment and society issues. Despite his undoubted status and influence on science and political life, Crutzen has received little scholarly attention as a public scientist, especially compared with the notable academic focus on contemporaneous public scientists who lived and worked in the Anglophone world.[2] His life and career, however, can be situated in scholarly traditions that have examined the roles and functions of scientists in society. As a Laureate who has had great sociopolitical impact, he can be positioned within the recent rise of scholarship on Nobel Prize winners who have contributed to the public image of science, a research focus that has combined approaches from the history of science, the sociology of science, and the public understanding of science and technology. As a scientist with a public profile over several decades, Crutzen's career can also be positioned within a tradition in the field of public communication of science and technology, also called science communication, that has examined how certain scientists have become culturally prominent and have exerted influence on public debates, policy dilemmas, and cultural discourses related to science and society.[3]

1 As examples of obituaries across publications, see Susan Solomon, 'Paul J. Crutzen (1933–2021)', *Science* **371**, 892 (2021); Jos Lelieveld, 'Paul J. Crutzen (1933–2021)', *Nature* **591**, 29 (2021); Pilita Clark, 'Paul Crutzen, scientist, 1933–2021', *Financial Times*, 5 February 2021, https://www.ft.com/content/ab47dbcc-d680-43e0-b0bb-db90ff7a5b85 (accessed 15 May 2023); Jan Zalasiewicz, Colin Waters and Will Steffen, 'Remembering the extraordinary scientist Paul Crutzen (1933–1921)', *Scient. Amer.*, 5 February 2021, https://www.scientificamerican.com/article/remembering-the-extraordinary-scientist-paul-crutzen-1933-2021/ (accessed 15 May 2023); John Schwartz, 'Paul Crutzen, Nobel laureate who fought climate change, dies at 87', *New York Times*, 5 February 2021, p. 11.

2 Exceptions are two volumes that contain selected writings of Crutzen, along with recollections and evaluations from scholars. The first is Paul J. Crutzen and Hans Günter Brauch (eds), *Paul J. Crutzen: a pioneer on atmospheric chemistry and climate change in the Anthropocene* (Springer, Cham, 2016). The second is Susanne Benner, Gregor Lax, Paul J. Crutzen, Ulrich Pöschl, Jos Lelieveld and Hans Günter Brauch (eds), *Paul J. Crutzen and the Anthropocene: a new epoch in Earth's history* (Springer, Cham, 2021). As examples of scholarship on contemporary public scientists, see the collective case studies by Rae Goodell, *The visible scientists* (Little, Brown, Boston, 1977) and Declan Fahy, *The new celebrity scientists: out of the lab and into the limelight* (Rowman & Littlefield, Lanham, MA, 2015). As examples of book-length scholarship on individuals, see the studies of astronomer Carl Sagan and palaeontologist Stephen Jay Gould: Keay Davidson, *Carl Sagan: a life* (John Wiley & Sons, New York, 1999); William Poundstone, *Carl Sagan: a life in the cosmos* (Owl Books, New York, 1999); David F. Pringle, *Stephen Jay Gould and the politics of evolution* (Prometheus Books, Amherst, 2009); Richard York and Brett Clark, *The science and humanism of Stephen Jay Gould* (Monthly Review Press, New York, 2011).

3 For recent scholarship on Nobels and the public image of science, see the articles in the special edition of *Public Understanding of Science* **27**(4), 2018, on the Nobel prizes and the public images of science (edited by Sven Widmalm). For the importance of visible scientists in science communication research, see: Massimiano Bucchi and Brian Trench, 'Science communication and science in society: a conceptual review in ten keywords', *Tecnoscienza* **7**, 151168 (2016).

The few critical writings that have reflected on Crutzen's public role have stressed the political dimensions to his research and communication. He was, fundamentally, an eminent scientist, one of the world's most-cited researchers, who published more than 365 refereed journal articles, another 136 scholarly publications, and 16 books. Yet writers who have looked closely at Crutzen in different contexts noted his acute political instincts. The science writer Oliver Morton observed in a popular book on geoengineering that Crutzen had 'political instincts that served him beyond academia, a feeling for the stuff that mattered and for how to get people to see that it mattered'.[4] The author of a historical account of the prestigious Max Planck Institute for Chemistry (MPIC), where Crutzen was Director of the Atmospheric Chemistry Department from 1980 to 2000, said the chemist's scientific leadership was characterized by his 'unerring sense for highly charged social and political topics'. Moreover, the author noted also that, over large parts of Crutzen's career, the scientist's 'basic research was directly carried over to specific sociopolitical or environmental issues—frequently by himself'.[5] As the observations indicate, the political dimension to Crutzen's scientific career has been central to his public reputation and social influence. An analysis of Crutzen, therefore, must be able to explain the interplay between his research, his politics, and his view of the social role of science.

Crutzen, however, is difficult to categorize within frameworks scholars have proposed to explain the role of public scientists and their cultural influence. Although he was part of expert committees that advised politicians, Crutzen's public profile has meant he cannot be categorized chiefly as a behind-the-scenes science policy advisor. Although his work advocated for policy responses, he was not an activist scientist who was aligned with overt political philosophies and programs of social change. Although he had some cultural prominence, he cannot be categorized as a 'visible scientist'—a conceptualization of scientists including astronomer Carl Sagan and anthropologist Margaret Mead, who sought to influence science policy through the mass media by cultivating a public image that attracted journalistic attention. Moreover, Crutzen does not conform to the characteristics of a 'celebrity scientist', such as Albert Einstein or Stephen Hawking, an extreme version of the visible scientist, who came to embody science through a process of intense media-driven personalization and commodification. None of these role categorizations alone can explain how Crutzen came to exert public influence.[6]

This article argues that Crutzen spoke in the name of science as a public intellectual, a role that allowed him to move between his specialist discipline and broader cultures to influence research agendas, environmental policy, and cultural understandings of the environment. It argues, moreover, that he was a particular type of public intellectual, a *technocratic public intellectual*, who attempted to persuade scientific and policy elites to respond to an escalating series of dangers, revealed by science, that have resulted from human-created

4 Oliver Morton, *The planet remade: how geoengineering could change the world* (Granta, London, 2015), p. 153.

5 Gregor Lax, *From atmospheric chemistry to Earth system science: contributions to the recent history of the Max Planck Institute for Chemistry (Otto Hahn Institute), 1959–2000* (GNT-Verlag, Diepholz, 2018), p. 131 and 111. On Crutzen's publications, see: 'Complete bibliography of Paul J. Crutzen (1965–2020)', in Benner *et al*., *op. cit.* (note 2), pp. 453–502.

6 Goodell, *op. cit.* (note 2); Fahy *op. cit.* (note 2); Hans Peter Peters, 'Scientists as public experts', in *Routledge handbook of public communication of science and technology* (ed. Massimiano Bucchi and Brian Trench), pp. 131–146 (Routledge, New York, 2014); Sheila Jasanoff, *The fifth branch: science advisors as policymakers* (Harvard University Press, Cambridge, MA, 1998); Peter J. Kuznick, *Beyond the laboratory: scientists as political activists in 1930s America* (Chicago University Press, Chicago, IL, 1987); Gary Werskey, *The visible college: a collective biography of British scientists and socialists of the 1930s* (Free Association Books, London, 1988, first published 1978).

changes in the natural world. It argues that his public intellectual writings played a crucial role in a series of environmental controversies, even as those writings were shaped by wider social, cultural, and political values and prevailing contexts. The article takes the form of a retrospective case study that examines the particular case of Crutzen to illustrate the more general processes that shape the formation and influence of scientists as public intellectuals, the processes through which scientists in their public writings can influence policy and social thought, the process through which scientific ideas can be introduced into public life *and* research fields through public communication, as well as the dynamic process through which the professional and public reputations of scientists can enhance and reinforce each other over time. The analysis of Crutzen, finally, can also illuminate the potential and limitations of the technocratic public intellectual in modern liberal democracies.[7]

Public intellectuals: role, functions, formation

Compared to the analysis of historians, literary critics, and other humanities scholars, the phenomenon of scientists as public intellectuals in modern societies has received little scholarly attention.[8] This study, in response, synthesizes the complementary ideas of several scholars into an analytic framework that is then applied to explain how Crutzen spoke in the name of science as a public intellectual. The study first draws on the ideas of social theorist Carl Boggs, who argued that scientists often occupied a position in modern societies as *technocratic* intellectuals, a class of thinkers that became prevalent in the second half of the twentieth century. These intellectuals, he argued, were based at universities and research institutions, had advanced specialist knowledge and technical skills, broadly shared a positivist epistemological position, as well as a worldview based on the Enlightenment values of rationality, technoscientific progress, and human mastery of nature, all of which were in the service of broader democratic aims. Crutzen conformed to these broad characteristics, with his positions at elite universities and research centres, his advanced knowledge in atmospheric chemistry, and his commitment, as obituarists and scholars noted, to the democratic value of science as a way to help direct social and political responses to science-intensive problems. Technocratic intellectuals, such as Crutzen, stressed that expert knowledge and technical competence should be the foundation for rational policy decisions on social and political issues. In their

7 For more on the retrospective case study, see: Gary Thomas, ‘A typology for the case study in social science following a review of definition, discourse, and structure’, *Qualitat. Inquiry* **17**, 511–521 (2011). For studies that have adopted similar case study approaches, see Goodell, *op. cit.* (note 2); Fahy, *op. cit.* (note 2). For the call for more of these types of scholarly approaches of public intellectuals around the environment, see: Matthew C. Nisbet, ‘Disruptive ideas: public intellectuals and their arguments for action on climate change’, *WIREs Clim. Change*, **5**, 809–823 (2014). Although this article is a case study rather than a formal biography, its chronological analysis of a prominent contemporary scientist has been informed by reflective accounts of the role of biography in the history of recent science. As examples, see Mary Terrall, ‘Biography as cultural history of science’, *Isis* **97**, 306–313 (2006); Mary Jo Nye, ‘Scientific biography: history of science by another means?’, *Isis* **97**, 322–329 (2006); Thomas Söderqvist, ‘What is the use of writing lives of recent scientists?’, in *The historiography of contemporary science, technology, and medicine: writing recent science* (ed. Ronald E. Doel and Thomas Söderqvist), pp. 99–127 (Routledge, London, 2006).

8 As examples of works focused on historians and literary academics as public intellectuals, see Stefan Collini, *Absent minds: intellectuals in Britain* (Oxford University Press, Oxford, 2006); Stefan Collini, *Common reading: critics, historians, publics* (Oxford University Press, Oxford, 2009); and Stefan Collini, *Common writing: essays on literary culture and public debate* (Oxford University Press, Oxford, 2016). For more general discussions of intellectuals from the humanities and their relationship to broader culture, see Richard A. Posner, *Public intellectuals: a study of decline* (Harvard University Press, Cambridge, 2003); Russell Jacoby, *The last intellectuals: American culture in the age of academe*, 2nd edn (Basic Books, New York, 2000).

communication, they largely produced 'elite-centered technocratic discourse', as elites were thought to define the parameters of debate around science and society issues—a perspective that has underpinned much of scientists' public communication historically.[9]

With Crutzen situated as a technocratic intellectual, the second element of the study's analytic framework explains Crutzen's *public* role—how he operated and wielded influence as a technocratic public intellectual. To do so, it draws on the work of social theorist Amitai Etzioni, who argued that the public intellectual, fundamentally, helped the public understand and navigate the complex terrain of modern societies, as they addressed issues of public concern, which were often inflected with political, ideological, and moral values.[10] Etzioni's ideas are especially important for understanding Crutzen because he described the process of *how* a public intellectual exerts influence through elite-focused communication. He argued that they sought to influence elites, particularly governing elites, with arguments and ideas that would then spread to the rest of society. Public intellectuals addressed what Etzioni called elites' 'communities of assumptions'. These were the

> shared worldviews, judgments about challenges faced and ways to deal with them, and much more. These assumptions typically serve as frameworks that influence the ways numerous specific public and private policies are received and evaluated.[11]

A community of assumptions is a frame of reference through which elites view the world. According to Etzioni, public intellectuals have undertaken two functions in their communications. They have first engaged in reality testing, drawing on their expertise and experience to critically review existing communities of assumptions around an issue in an attempt to, in his words, pry them open. Public intellectuals have then framed a new set of assumptions. This was essential because 'millions of people find that when communities of assumptions are not available,' wrote Etzioni, 'their world is unsettled, cluttered with details, and lacking organizing principles and an overarching, integrating picture'.[12] Public intellectuals can provide such an integrating picture, a new frame of reference that sometimes becomes the foundation for a new community of assumptions. Etzioni did not define in detail how framing operated, so this study adopts, as the third element of its conceptualization, the canonical definition from communications scholar Robert Entman, which has recurred in scholarship examining the public portrayal of scientific and environmental policy issues:

> Framing essentially involves *selection* and *salience*. To frame is to *select some aspects of a perceived reality and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation* for the item described.[13]

9 Carl Boggs, *Intellectuals and the crisis of modernity* (State University of New York Press, Albany, 1993) at p. 9. See also Carl Boggs, 'Intellectuals', in *Understanding contemporary society: theories of the present* (ed. Gary Browning, Abigail Halcli and Frank Webster), pp. 296–311 (Sage, London, 2000). On the historical trends in scientists' public communication, see Massimiano Bucchi, 'Of deficits, deviations and dialogues: theories of public communication of science', in *Routledge handbook of public communication of science and technology* (eds Massimiano Bucchi and Brian Trench), pp. 57–76 (Routledge, New York, 2014).

10 Amitai Etzioni, 'Are public intellectuals an endangered species?', in *Public intellectuals: an endangered species?* (eds Amitai Etzioni and Alyssa Bowditch), pp. 1–27 (Rowman & Littlefield, Lanham, 2006).

11 Etzioni, *op. cit.* (note 10), p. 6.

12 *Ibid.*, p. 9.

13 Robert M. Entman, 'Framing: toward clarification of a fractured paradigm', *J. Commun.* **43**, 51–58 (1993), at p. 52. For an overview of framing as applied to environmental and climate change communication, see: Mike S. Schäfer and Saffron O'Neill, 'Frame analysis in climate change communication', in *Oxford research encyclopedia of climate science* (ed. Matthew C. Nisbet) (Oxford University Press, 2017), doi:10.1093/acrefore/9780190228620.013.487.

A fourth element of this study's conceptualization explains the dynamic process through which Crutzen came to occupy the position of the public intellectual, drawing on the ideas of intellectual historians Thomas Bender and Stefan Collini. Public intellectuals first emerged because of their specialized disciplinary expertise within a professional culture of other credentialed experts. Their authority to speak to issues of public concern rested on their status within their professional culture, which for Crutzen was a professional culture of atmospheric chemistry. From that foundation, intellectuals could address a broader public culture beyond their professional culture. For Crutzen, that public culture was not the general public. It was rather an elite-centred public culture focused on the connections and interactions between the science and politics of the environment. It comprised mainly scientists from different fields of environmental science, environmental policymakers, scholars from various fields interested in policy-relevant environmental research, and scholars interested in the relationship between environment and society. In order to reach this public culture, Crutzen needed channels of communication other than the specialist journals and conference presentations through which a scholar typically reached their narrow set of disciplinary peers. For Crutzen, these channels of communication were elite-focused interdisciplinary journals that reached a broad academic readership.[14]

This study applies this analytic approach as it focuses on his critical contributions to four significant episodes in modern environmental politics: his warnings in the 1970s of damage to the ozone layer, his catalysing impact on the nuclear winter debates of the 1980s, his turn-of-the-century popularization of the Anthropocene, and his mid-2000s advocacy of solar geoengineering. To explain how Crutzen undertook the public intellectual functions of reality testing and framing, underpinned by a distinct technocratic perspective, the study will analyse one agenda-setting article by Crutzen in each of these episodes, which he published in interdisciplinary journals.

Ozone and the politics of the atmosphere

Crutzen's formation as a public intellectual can be understood against the entwined contexts of the modern history of atmospheric science and the particular features of the institution where he received his advanced intellectual training. In 1959, Crutzen, who trained as an engineer, took a job as a computer programmer at the Department of Meteorology at Stockholm University, where alongside his regular duties, he studied mathematics, meteorology, and statistics. He worked and studied at a time, from approximately 1957 to 1962, when atmospheric science emerged as a new interdisciplinary field.[15] The university housed the International Meteorological Institute in Stockholm, one of the world's most important centres for research into meteorology and an institution whose prominent members had a notable focus on public science. Established in 1955, its first director was the renowned Swedish-born meteorologist Carl-Gustaf Rossby (1898–1957), who 'made an

14 Thomas Bender, *Intellect and public life: essays on the social history of academic intellectuals in the United States* (Johns Hopkins University Press, Baltimore, 1993); Stefan Collini, *Absent minds: intellectuals in Britain* (Oxford University Press, Oxford, 2006).

15 James Rodger Fleming, *Inventing atmospheric science: Bjerknes, Rossby, Wexler, and the foundations of modern meteorology* (MIT Press, Cambridge, MA, 2016).

important turn to global environmental concerns in the later part of his career, fostering an early ethic of environmental responsibility'.[16] His graduate student who succeeded him as head of the Institute, Bert Bolin (1925–2007), was an accomplished meteorological researcher, administrator, and science diplomat, who would go on to become the first Chairman of the Intergovernmental Panel on Climate Change (IPCC).[17] Crutzen became Bolin's 'protégé'.[18]

Crutzen studied and undertook his early research during a formative time in the modern history of the environment. Between approximately 1948 and the early 1970s, argued environmental historians Warde, Robin, and Sörlin, the idea of the environment went through a phase of being conceptualized in scientific terms, especially in terms of quantitative data. Atmospheric science was influential in such a conceptualization, as it was a leader in the development and application of computer models, an approach to science that allowed researchers to test the effects of changes in large-scale systems, such as the atmosphere or the climate, that were too complex to examine experimentally. As climate science would develop, it would go on to use a variety of methods, including the analysis of historical evidence from the deep past, such as traces of past climatic changes left in ice cores or geological strata, but over time computer models became the dominant approach to analysing the changing climate. But computer models were more than a research tool. They had powerful political effects in that they could predict and test future realities, a function that allowed them to inform policy to shape the futures that the models first predicted. As experts in computer-based mathematical models, atmospheric scientists had therefore great authority to define emergent policy-related environmental problems.[19]

In these years, Crutzen in his doctoral research examined the chemistry of ozone in the stratosphere. Ozone, a gas that is concentrated in small quantities in a thin layer in the stratosphere, is fundamental to life on Earth because it can absorb most of the ultraviolet radiation from the sun. In 1970, Crutzen published a sole-authored paper that marked a major step towards understanding ozone chemistry. He built on research that postulated that nitrous oxide (N_2O), a gas produced naturally in soil, rose into the stratosphere where sunlight split it into NO and NO_2. Crutzen described a series of chemical reactions that showed how these nitrogen oxides ultimately destroyed ozone. The paper was significant because it showed how producing N_2O on the Earth's surface depleted stratospheric ozone.[20] The paper helped establish his scientific reputation within his professional culture of atmospheric chemistry. He earned his doctorate from Stockholm University in 1973, graduating at a time when it was evident that the science and politics of the environment were becoming deeply entwined.

From about 1970, the environment had moved from a phase of conceptualization into what historians characterized as a phrase of institutionalization. The phase saw the creation of

16 Fleming, *op. cit.* (note 15), p. 223.

17 Sverker Sörlin, 'Narratives and counter-narratives of climate change: North Atlantic glaciology and meteorology, c.1930–1955', *J. Hist. Geogr*. **35,** 237–255 (2009).

18 Sverker Sörlin, 'The environment as seen through the life of a journal: *Ambio* 1972–2022', *Ambio* **50**, 10–30 (2021), p. 21.

19 For the periodization of environmental intellectual history, see: Paul Warde, Libby Robin, and Sverker Sörlin, *The environment*: *a history of the idea* (Johns Hopkins University Press, Baltimore, 2018), at pp. 171–173. On the development of modern climate science and the importance of climate models, see Stephen Bocking, *Nature's experts: science, politics, and the environment* (Rutgers University Press, New Brunswick, NJ, 2004), at pp. 106–134.

20 Paul J. Crutzen, 'The influence of nitrogen oxides on the atmospheric ozone content', *Q. J. R. Meteorol. Soc*. **96**, 320–325 (1970).

institutions including ministries of the environment, Green political parties, national and international non-governmental organizations. It also witnessed an international institutional focus on the environment, which was demonstrated in the 1972 formation of the United Nations Environment Program (UNEP). A landmark event in this phase was the 1972 UN Conference on the Human Environment held in Stockholm, the first conference of its kind. It helped institutionalize the view that environmental science had a worldwide focus and so needed a global environmental politics. Therefore, the science and politics of the environment, wrote environmental studies scholar Stephen Bocking, developed in close and dynamic interaction. Moreover, the conference codified a shared technocratic framework among scientific and policy elites about how to view the environment. As the environmental historian Joshua Howe argued, the conference set out a new global view of the environment as an issue that could be understood using scientific methodologies and addressed through the ideals of cooperative international politics.[21]

Yet there were alternative views that contested this technocratic view of global environmental politics. New social movements in the 1960s and 1970s, most notably the cross-pollinating environmental, anti-war, and anti-nuclear movements, communicated about the human effects on the natural world. A theme in grassroots green activism was that environmental problems resulted from economic policies that left ecological devastation in the wake of the relentless drive for economic growth. Anti-war activists pointed to the militarization of science, especially since some of the environmental sciences had their modern roots in large-scale Cold War scientific projects. Science itself was seen as corrosive to the environment, a view that found influential public expression in *Silent spring* (1962), with its argument that the chemical industry, through its use of agricultural pesticides, was responsible for grave ecological damage. These social movements also produced their own experts who provided knowledge and facts around environmental phenomena and were active in the public communication of their concerns. Amid the contending discourses and controversies, scientists had to argue for their authority to shape environmental politics.[22]

In the 1970s, Crutzen was involved in an important controversy that allowed atmospheric scientists to become a voice in political debate. Many countries in the 1960s and 1970s planned to build a fleet of supersonic aircraft. In the USA, plans to build these supersonic stratospheric transports (SSTs) received widespread initial political and public support, but became less popular as critics questioned the planes' cost and environmental impacts, such as their fuel consumption and noise pollution from their sonic booms. These factors led the US Congress to deny funding for the aircraft in 1971. The SST debate was significant, argued Howe, because it introduced the new atmospheric science into public consciousness. In this international context, Crutzen made his first foray into writing for a public culture. His research pointed to an underexamined dimension of SSTs—their exhaust emissions contained nitrogen oxides that damaged ozone. And, crucially, he had access to a publication through which he could communicate beyond his professional culture to explain the broader implications of his research.[23]

21 Warde *et al*., *op. cit.* (note 19); Bocking, *op. cit.* (note 19); Joshua P. Howe, *Behind the curve: science and the politics of global warming* (University of Washington Press, Seattle, 2014), at pp. 68–69.

22 Jon Agar, 'What happened in the sixties?', *Br. J. Hist. Sci.* **41**, 567–600 (2008).

23 Howe, *op. cit.* (note 21).

Ambio, first published in February 1972, has been a generalist publication aimed at a broad public culture of elite readers interested in the environment. It was founded by the Royal Swedish Academy of Sciences to provide news and expert overviews of environment and society topics for a new and growing readership. Its first editor Eric Dyring wrote in his first editorial that the magazine was needed as the environment had moved beyond the narrow group of experts who first articulated concerns over humankind's damage to the environment to become an issue of global concern. Such concerns, he wrote, demonstrated 'the need for more effective communications between science and society'. *Ambio* sought to fulfil these demands by publishing articles of 'high scientific standards' directed 'not only to experts, but also to scientists in other fields and to other interested readers'. In October 1972, Crutzen was appointed to the journal's editorial board by a committee that included Bert Bolin. He would go on to have a career-long association with *Ambio*, its editor in 2021 writing that Crutzen was one of the journal's 'most notable and prominent authors through time'.[24]

In 1972, Crutzen published his first article in *Ambio*. His subject was the SST controversy. In his framing of the issue, he defined as the central problem the damage the aircrafts' emissions would cause to the ozone layer and, therefore, to life on the planet. He wrote:

> … it is now known that some of the engine exhaust gases emitted by supersonic aircraft that are to operate in the stratosphere can act in such a way as to diminish the supply of ozone in the atmosphere … the presence of ozone in the earth's atmosphere … is a necessary condition for the existence of present life on earth.[25]

In his diagnosis of the cause of the problem, Crutzen explained the chemical process through which nitrogen oxides from emissions would destroy stratospheric ozone. Based on model-derived observations, he argued that a fleet of about 500 supersonic planes, flying on regular schedules, could reduce the ozone layer by a half, or could destroy it completely. In his suggested remedy, he argued that vast numbers of SSTs should not fly until more and better research can take place to reduce the uncertainties surrounding the impacts of emissions. He wrote:

> Although it is not possible to assess at this stage the real environmental consequences of future supersonic air transport, present knowledge indicates that there exists a real possibility of serious decreases in the atmospheric ozone shield due to the catalytic action of oxides of nitrogen, emitted in the exhaust of supersonic aircraft. The minimum requirement is therefore that extensive supersonic air traffic should not take place in the stratosphere before reliable predictions can be made of the possible environmental consequences of such operations.[26]

The ultimate result of such research would be a better foundation for SST policy. He wrote:

> … it is essential that in the future, consideration be given to the environmental aspects of this area of technological development. If nitrogen oxide emissions from SST's cannot be strongly reduced, it may in the future become necessary to reach an international agreement on limitations of the world's total supersonic fleet.[27]

24 Sörlin, *op. cit.* (note 18); Eric Dyring, '*Ambio*: an introduction', *Ambio* **1**, 1 (1972), p. 1; Bo Söderström, '*Ambio*–The first 50 years', *Ambio* **50**, 1–9 (2021), p. 4.

25 Paul J. Crutzen, 'SST's—a threat to the earth's ozone shield', *Ambio* **1**, 41–51 (1972), p. 41.

26 *Ibid.*, p. 49.

27 *Ibid.*, p. 51.

This first *Ambio* article demonstrated the core features of Crutzen's public intellectual work. He wrote for an elite-centred public culture, his authority based on his newfound expertise in professional culture. He engaged in reality testing as he examined the impacts of a shared idea—the desired deployment of SSTs—using his own scientific expertise. He reframed the issue as one concerning potentially life-threatening damage to the ozone layer, a danger that the field of atmospheric chemistry was positioned to understand and address. The article helped set the agenda for *Ambio*'s scholarship on the ozone layer, as a retrospective analysis of topical themes in the journal showed that, from 1972 until the 1990s, the ozone layer was a prominent feature in research reports, reviews, and perspective articles.[28]

Crucially, the *Ambio* article demonstrated Crutzen's view of the relationship between science and politics. It is an example of what science policy scholars would come to identify as the 'linear–technocratic model of policymaking'. In this model, scientists uncovered facts about the natural world, communicated the consensus on those facts to politicians, who took the necessary policy action to address the problem scientists identified. The geographer Mike Hulme succinctly described the general model: 'The scientists would speak, danger would be revealed, policy would follow.' The technocratic model places scientists as the drivers of policy. It gives them a central role as the experts who can define the problem and who have the knowledge to offer necessary policy responses. Framing SSTs as a problem concerned primarily with the chemical composition of the atmosphere meant that atmospheric scientists were the most qualified to discuss or make decisions about the issue. As Bocking argued, such a definition had the result that the environment was understood primarily as a scientific issue, addressed using scientific ideas, based on scientific expertise as the uncontested foundation for political action.[29] Such a definition provided scientists with the authority to speak on issues of policy.

Scientific research on ozone contributed to a landmark piece of global environmental legislation. Chemists Mario Molina (1943–2020) and F. Sherwood Rowland (1927–2012) demonstrated that human-created chlorofluorocarbons (CFCs), released from industrial activities, diffused into the stratosphere where they were broken up by sunlight, a process that resulted in the production of chlorine atoms that destroyed ozone. Researchers in the Antarctic identified in the middle of the 1980s a 'hole' in the ozone layer.[30] In response, the Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in 1987. It was adapted in many subsequent amendments that strengthened the regulation of CFCs. The Protocol has continued to be held up as the historical highpoint of technocratic science policymaking, even though its success resulted from several factors including the scientific formulation of the problem, which set the frame of reference for policy debate and international agreement, and the interactions between government action worldwide, new technologies that avoided the use of CFCs, and adaptations from industries to the

28 Söderström, *op. cit.* (note 24).

29 The phrase 'linear–technocratic model' is from Reiner Grundmann, 'Ozone and climate: scientific consensus and leadership', *Sci. Technol. Hum. Values* **31**, 73–101 (2006), p. 74; Mike Hulme, *Why we disagree about climate change* (Cambridge University Press, Cambridge, 2009), p. 103. For more on the linear model of policymaking and its critiques, see: Roger A. Pielke, Jr, *The honest broker: making sense of science in policy and politics* (Cambridge University Press, Cambridge, 2007), pp. 12–14; and Bocking, *op. cit.* (note 19), at pp. 107–108.

30 Mario J. Molina and F. S. Rowland, 'Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone', *Nature* **249**, 810–812 (1974); Joe C. Farman, Brian G. Gardiner, and Jonathan D. Shanklin, 'Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction', *Nature* **315**, 207–210 (1985).

identified environmental problem. Former UN Secretary-General Kofi Annan called it perhaps 'the single most successful international environmental agreement to date'.[31]

Crutzen, Molina, and Rowland would go on to share the 1995 Nobel Prize in Chemistry for what the official citation from the Royal Swedish Academy of Sciences called 'their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone'. The media release described the specific impact of their research on politics in what can be read as a validation of the linear technocratic model of policymaking. It said: 'Thanks to our good scientific understanding of the ozone problem—and very largely to Crutzen, Molina and Rowland—it has been possible to make far-reaching decisions on prohibiting the release of gases that destroy ozone.'[32]

The nuclear winter debates

In the early 1980s, against heightened Cold War fears and cultural anxieties over atomic weapons, *Ambio* asked Crutzen to contribute to a special issue that would address the environmental consequences of nuclear war. By then, Crutzen's status in his professional culture had solidified with his position at the Max Planck Institute for Chemistry in Mainz, a world centre for atmospheric chemistry research. Among the issue's advisors (who also planned the issue, selected the authors and referees, and evaluated the articles) was Joseph Rotblat, a nuclear physicist and co-founder in 1957 of the Pugwash Conferences on Science and World Affairs, which brought together researchers and intellectuals to reduce the threat of nuclear war.[33] The introduction to the issue, published in 1982, stated its political objectives. 'This special double issue of *Ambio*', it said, 'is presented in the belief that a realistic assessment of the possible human and ecological consequences of a nuclear war may help to deter such a catastrophe'. It concluded with the technocratic hope that 'this issue, presenting a scientific appraisal of the human and ecological consequences of a nuclear war, will contribute to the growing realization that nuclear arms represent a risk that cannot be ignored'.[34]

Crutzen's article was originally intended to examine the harmful effects of nuclear war on the ozone layer. Instead, he and his co-author, atmospheric chemist John Birks, offered a new way of understanding the environmental effects of atomic explosions.[35] In their framing, the after-effects of an atomic weapons exchange would eventually result in more deaths than the immediate lives lost in missile strikes. They defined the problem as being the release of vast amounts of smoke into the air that would occur after forests and cities burned in the aftermath of the first explosions. The black smoke would absorb the sunlight with severe predicted consequences. The article was written for a public culture. It was titled 'The atmosphere after a nuclear war: twilight at noon'. The title and authors' names were imposed over a dramatic image of mushroom cloud. The article's introduction stated:

31 Edward A. Parson, *Protecting the ozone layer: science and strategy* (Oxford University Press, Oxford, 2003); Kofi A. Annan. *We the peoples: the role of the United Nations in the 21st century* (United Nations, New York, 2000), p. 56.

32 Press release. NobelPrize.org. Nobel Prize Outreach AB 2023. Monday 1 May 2023, https://www.nobelprize.org/prizes/chemistry/1995/press-release/ (accessed 1 May 2013).

33 Anon., 'About this issue …', *Ambio* **11**, 75 (1982).

34 *Ibid.*, p. 75.

35 For context to the article's history, see Howe, *op. cit.* (note 21), p. 136.

> In discussing the state of the atmosphere following a nuclear exchange, we point especially to the effects of the many fires that would be ignited by the thousands of nuclear explosions in cities, forests, agricultural fields, and oil and gas fields. As a result of these fires, the loading of the atmosphere with strongly light absorbing particles in the submicron size range … would increase so much that at noon solar radiation at the ground would be reduced by at least a factor of two and possibly a factor of greater than one hundred … Such effects have been largely overlooked or not carefully examined in previous considerations of this problem. They are, therefore, considered in some detail in this study.[36]

As with Crutzen's piece on SSTs and ozone, the article drew on model-based calculations to diagnose the cause of the problem—the release of smoke and particulate matter into the atmosphere. There was an explicit moral evaluation in the text as the authors referred to the effects of strikes as a 'nuclear holocaust'[37] and pointed to the mass deaths from starvation among the survivors of the strikes. The authors undertook reality testing as they drew on their expertise to determine novel environmental effects of an atomic weapons exchange, reframing as a result the long-term consequences of nuclear war. The authors wrote:

> It is also quite possible that severe, worldwide photochemical smog conditions would develop with high levels of tropospheric ozone that would likewise interfere severely with plant productivity. Survival becomes even more difficult if stratospheric ozone depletions also take place. It is, therefore, difficult to see how much more than a small fraction of the initial survivors of a nuclear war in the middle and high latitude regions of the Northern Hemisphere could escape famine and disease during the following year.[38]

In the last line of the article, as with the article on SSTs and ozone, the authors recommended that its novel insights be used as the basis for further research. They wrote:

> In this paper we have attempted to identify the most important changes that would occur in the atmosphere as a result of a nuclear war. The atmospheric effects that we have identified are quite complex and difficult to model. It is hoped, however, that this study will provide an introduction to a more thorough analysis of this important problem.[39]

The prosaic conclusion illustrated the underlying technocratic perspective of the article—and the *Ambio* special issue. Scientists had revealed a novel problem that warranted further research so that the effects of nuclear war would be understood in more depth in order to form a more rounded base of evidence to inform, as the special issue hoped, nuclear deterrence policies.

The article had its most consequential impact on a small scientific elite of US-based scientists who were also examining the environmental effects of nuclear war. The group was known collectively as TTAPS, an acronym that comprised the first initial of their surnames: Richard Turco, Owen Brian Toon, Thomas Ackerman, James Pollack and Carl Sagan. The *Ambio* paper was an impetus to their research. They integrated the release of smoke and soot into their models of post-strike effects. One historical account of nuclear winter called the Crutzen–Birks paper a 'first cut at the problem'. The activities of TTAPS

36 Paul J. Crutzen and John W. Birks. 'The atmosphere after a nuclear war: twilight at noon', *Ambio* **11**, 114–125 (1982), p. 115.
37 *Ibid.*, p. 121.
38 *Ibid.*, p. 124.
39 *Ibid.*

would amplify nuclear winter in popular and political cultures, especially through the activities of its most high-profile scientist, Carl Sagan. By the early 1980s, he was the most famous scientist in America. His fame granted him access to varied publications that reached different American publics. In the closing months of 1983, he wrote an article, headlined 'The Nuclear Winter', for *Parade* magazine, a syndicated mass-market publication that at the time had an estimated readership of more than forty million Americans. He wrote about the policy implications of nuclear winter for *Foreign Affairs*, which reached the heart of the US foreign policy establishment. With the support of a public relations firm, he and his TTAPS colleagues held public meetings to raise the issue's profile in public and scientific cultures. After the concept had been communicated in various public culture arenas, the group published a paper on nuclear winter's empirical foundations in *Science*.[40]

Crutzen also disseminated the concept, speaking at one of the American group's meetings and presenting at a workshop at the Pontifical Academy of Sciences in the Vatican on the atmospheric impacts of a nuclear war, the beginnings of a long association between him and the institution.[41] He also published in 1985 a co-authored trade book in German, published by the trade press S. Fischer, titled *Schwarzer Himmel*—which translated as *Black Sky*.[42] The concept influenced Cold War nuclear policy. As perhaps the highest-profile example, former leader of the Soviet Union Mikhail Gorbachev later cited the prospect of nuclear winter as one motivation behind his 1987 signing of a nuclear arms-control agreement with US president Ronald Reagan.[43] In his Nobel lecture in 1995, Crutzen devoted notable attention to nuclear winter, showing the importance he placed on the political influence of his research, and his technocratic view that polices and legislation should flow from research. He said:

> Although I do not count the 'nuclear winter' idea among my greatest scientific achievements (in fact, the hypothesis can not be tested without performing the 'experiment', which it wants to prevent), I am convinced that, from a political point of view, it is by far the most important, because it magnifies and highlights the dangers of a nuclear war and convinces me that in the long run mankind can only escape such horrific consequences if nuclear weapons are totally abolished by international agreement.[44]

The politics of the Anthropocene

Launched in 1987, the International Geosphere–Biosphere Programme (IGBP) aimed to integrate knowledge from several scientific disciplines in order to understand natural and

40 Lawrence Badash, *A nuclear winter's tale: science and politics in the 1980s* (MIT Press, Cambridge, MA, 2009), at p. 52; see also: Matthias Dörries, 'The politics of atmospheric sciences: "nuclear winter" and global climate change, *Osiris* **26**, 198–223 (2011); Carl Sagan, 'The nuclear winter: the world after nuclear war', *Parade*, 30 October, 1983; Carl Sagan, 'Nuclear war and climatic catastrophe: some policy implications', *Foreign Affairs* **62**, Winter, 257–292 (1983/84); Richard P. Turco, Owen Brian Toon, Thomas P. Ackerman, James B. Pollack and Carl Sagan, 'Nuclear winter: global consequences of multiple nuclear explosions', *Science* **222**, 1283–1292 (1983). On the readership of *Parade* in 1983, see: Philip H. Dougherty, 'Parade's $1 million campaign', *New York Times*, 28 January 1983, D8.

41 Jack Fishman, John W. Birks, Thomas E. Graedel, Will Steffen, John P. Burrows, Carleton J. Howard and Richard P. Wayne, 'A tribute to Paul Crutzen (1933–2021)', *Bull. Am. Meteorol. Soc.*, E77–E95 (2023).

42 Paul J. Crutzen and Jürgen Hahn, *Schwarzer Himmel: Auswirkungen eines Atomkrieges auf Klima und globale Umwelt* (S. Fischer Verlag, Berlin, 1985).

43 Lelieveld, *op. cit.* (note 1), and Alan Robock, 'Nuclear winter is a real and present danger', *Nature* **473**, 275–276 (2011).

44 Paul J. Crutzen, 'My life with O_3, NO_x, and other YZO_xs', Nobel Lecture, 8 December 1995, nobelprize.org/uploads/2018/06/crutzen-lecture.pdf (accessed 9 May 2023).

human-caused changes to the Earth's total environment. It was based at the Royal Swedish Academy of Sciences, in the same building as *Ambio*'s offices, and the journal was one of the main outlets for research and ideas from this new community. The IGBP, which ran until 2015, was central to the development of the holistic conceptualization of the Earth as a single system that consisted of the continuous interaction of chemical, biological, and physical processes. The idea was codified in the emergent discipline of Earth system science. Crutzen was heavily involved in the IGBP's work, which drew on ideas from the global science of atmospheric chemistry, and involved the development of conceptual frameworks that could explain the Earth as a complex, dynamic system. Over time, researchers in the programme came to view human activities as major causes of changes in the Earth system.[45]

As a Laureate, Crutzen occupied a position at the peak of the research hierarchy, as he was a member of what sociologist of science Harriet Zuckerman called 'the scientific ultra-elite', whose unrivalled status gave them authority and power within scientific communities.[46] It was at a meeting of the IGBP in 2000 that Crutzen articulated the Anthropocene idea. According to scientists present at the meeting in Cuernavaca, Mexico, he became frustrated at continued descriptions of the current geological epoch as the Holocene, which began after the last ice age about 11 700 years ago, a time of relative climate stability during which human societies developed. Crutzen said that humans had changed the Earth system so foundationally that the current epoch should be called the Anthropocene. However, he was not the first to use the term. Biologist Eugene Stoermer independently introduced the idea in the 1980s in the context of his specialist research into the ecology of bodies of fresh water. After the IGBP meeting, Crutzen contacted Stoermer and they coauthored a two-page article in *Global Change Newsletter*, the newsletter of the IGBP. One of the most significant ideas in contemporary culture was first explicated in 2000 for a small professional culture of Earth system scientists.[47]

Crutzen two years later communicated the concept in public culture. He wrote a sole-authored article for *Nature*, one of the world's most prestigious journals that publishes specialist and interdisciplinary articles for scientists across fields, as well as news and expert commentary and analysis on current issues related to science and society. It was a venue for him to introduce and frame the concept for a broad elite scientific readership. The article was a one-page essay in a section the journal published at the time—called 'Concepts'—that featured opinion-based essays explicating new ideas. In an editorial that described the motivation for creating the new section, the journal said it was a space for 'something the literature sees too little of: scientific ideas'. The essays in Concepts, the journal promised in 2001, will 'not only communicate some aspect of a concept to readers, but will also bring a touch of the author's personal perspective along with it'.[48]

45 Sybil P. Seitzinger, Owen Gaffney, Guy Brasseur, Wendy Broadgate, Phillipe Ciais, Martin Claussen, Jan Willem Erisman, Thorsten Kiefer, Christiane Lancelot, Paul S. Monks, Karen Smyth, James Syvitski, and Mitsuo Uematsu, 'International Geosphere–Biosphere Programme and Earth system science: three decades of co-evolution', *Anthropocene* **12**, 3–16 (2015). On the links between the IGBP and *Ambio*, see Sörlin, *op. cit.* (note 18).

46 Harriet Zuckerman, *Scientific elite: Nobel laureates in the United States* (Transworld, Quebec City, 1996, first published 1979), p. 11.

47 Paul J. Crutzen and Eugene F. Stoermer, 'The "Anthropocene"', *Global Change Newslett.* **41**, 17–18 (2000).

48 Nature, 'The stuff of ideas', *Nature* **409**, (2001). *Nature*'s online archive lists 125 'Concepts' articles published between 2001 and 2005.

Crutzen's paper had the evocative heading 'Geology of mankind'. It contained essentially the same argument as the co-authored Stoermer paper, as he framed the Anthropocene as a new geological epoch that demanded a fresh and drastic set of responses to manage this uncharted environmental era. In his problem definition, he wrote that the current geological categorization has failed to capture the deep and lasting impacts of human activities—and so a new designation was required. He wrote:

> For the past three centuries, the effects of humans on the global environment have escalated. Because of these anthropogenic emissions of carbon dioxide, global climate may depart significantly from natural behaviour for many millennia to come. It seems appropriate to assign the term 'Anthropocene' to the present, in many ways human-dominated, geological epoch, supplementing the Holocene—the warm period of the past 10–12 millennia.[49]

In his causal interpretation, Crutzen argued that evidence for the new categorization came in various forms, including the ten-fold increase in the human population over three centuries, the increase in the methane-producing cattle population, the exploitation by humans of between 30 and 50 percent of land surface, the rapid disappearance of rainforests, the diversion of rivers by dams, the 16-fold increase in energy use in the twentieth century, the increase in nitrogen fertilizer in agriculture, the increase in carbon emissions—all effects largely caused by one-quarter of the world's current population. He argued that this new epoch began towards the end of the eighteenth century. It was marked by the 1784 invention of the steam engine by James Watt. According to the analysis of air trapped in polar ice, it was marked also by the start of a growth in atmospheric concentrations of greenhouse gases. In his treatment recommendation, Crutzen argued that the new epoch demanded responses at all levels of society. He assigned a special role to scientists and engineers who had the required expertise to manage societies through the uncharted territory to come. And he predicted that part of that management could involve the deliberate large-scale engineering of the global climate. He concluded:

> Unless there is a global catastrophe—a meteorite impact, a world war or a pandemic—mankind will remain a major environmental force for many millennia. A daunting task lies ahead for scientists and engineers to guide society towards environmentally sustainable management during the era of the Anthropocene. This will require appropriate human behaviour at all scales, and may well involve internationally accepted, large-scale geo-engineering projects, for instance to 'optimize' climate. At this stage, however, we are still largely treading on *terra incognita*.[50]

The article had a strong technocratic perspective, envisaging an ultra-modern problem that was revealed through a new form of system-wide scientific expertise, and in his view it was up to *scientists and engineers to guide society*. In order for scientists to have such a central social function, it was essential, following a technocratic logic, for the Anthropocene to have a scientific designation. But since the concept was first introduced, it has been the subject of intense expert deliberation and struggles over disciplinary authority. Geologists have historically had the authority to officially define, and determine the demarcations between, units of geological time. The International Commission on Stratigraphy (ICS), a central

49 Paul J. Crutzen, 'Geology of mankind', *Nature* **415**, 23 (2002), p. 23.
50 Crutzen, *op. cit.* (note 49), p. 23.

scientific body concerned with such categorizations, based its classifications on the stratigraphic record, the evidence of geological change seen in rock strata and the composition of fossils within those strata. Periods of massive upheaval—such as mass extinctions, or sea level changes—leave empirical traces or signals in layers of rock, and such periods often mark the change from one geological epoch to another. A fundamental scientific criticism of the Anthropocene concept has been that its proponents inverted the traditional method of classifying geological time. They proposed a geological epoch and then set out to find evidence supporting the designation, rather than first identifying evidence in strata and then proposing a new epoch.

This unconventional conceptualization led some geologists to raise the question of whether the Anthropocene was introduced for scientific or political purposes. In 2016, the then head of the ICS wrote a co-authored article that described how, in contrast to all other geological time units, 'the concept of the Anthropocene did not derive from the stratigraphic record. It arose with Paul Crutzen (2002), a Nobel Laureate in Chemistry, who suggested that because of a greatly increased human impact on the Earth system, we had entered a new epoch, for which he proposed the term.'[51] Although diplomatically phrased, the article argued essentially that the idea's initial status relied on the authority of its promoter, who was a Laureate, but not a geologist. Moreover, the geologists asked why the Anthropocene needed to be classified as a scientific era rather than a cultural or historical epoch, such as the Renaissance. 'The only reason', they argued, 'appears to be to give it credence as a unit of the geologic time scale'.[52] The geologists wrote that proponents of the Anthropocene's scientific designation have often argued that 'the human impact on the Earth system must be officially recognized, if for no other reason than to make the public and governmental agencies aware of that impact'.[53]

In an inversion of the typical pattern of communication, after the Anthropocene had been introduced in public culture, researchers then sought to bolster its scientific status. *Ambio* was crucial in this process. In 2007, the journal published an article that set out the empirical evidence supporting the new geological designation. One of the paper's authors would later describe the article as marking 'the emergence of many key features of the Anthropocene concept in the peer-reviewed literature'.[54] In 2009, the ICS established the Anthropocene Working Group (AWG), which had Crutzen as a member, to examine whether the Anthropocene should enter the geological timescale and, if so, at what historical starting point. In 2019, the group voted to recommend the Anthropocene as a formal geological epoch, beginning in the middle of the twentieth century when evidence of human impacts of industrialization and globalization would be likely to leave geological traces. The sharpest signal for this timeframe was the presence of radioactive particles in the geological record that were spread worldwide after nuclear bomb tests from the early 1950s. In 2023, the AWG put forward Crawford Lake in Canada as the official marker for the start of the proposed epoch. The small, but deep, lake has sediments that capture the

51 Stanley C. Finney and Lucy E. Edwards, 'The "Anthropocene" epoch: scientific decision or political statement?' *GSA Today* **26** (4–10), 2016, p. 6.

52 Finney and Edwards, *op. cit.* (note 51), p. 8.

53 *Ibid.*, p. 9.

54 Will Steffen, Paul J. Crutzen and John R. McNeill, 'The Anthropocene: are humans now overwhelming the great forces of nature? *Ambio* **36**, 614–621 (2007); Will Steffen, 'Introducing the Anthropocene: the human epoch', *Ambio* **50**, 1784–1787 (2021), p. 1784.

chemical traces of nuclear fall-out. Several different geological organizations must approve the choice of the lake as the official marker of the Anthropocene's beginning.[55]

Even though its scientific status has so far remained unsettled, the Anthropocene idea has had enormous intellectual impact. A bibliometric analysis showed that, from 2000, the concept diffused outwards from early texts authored by Crutzen and close colleagues in the global change and Earth systems science communities. The concept was then taken up by geologists before it spread, from 2010 especially, through the natural sciences and then across the social sciences and humanities. By the end of 2020, the Anthropocene concept was addressed in more than 5000 peer-reviewed scientific articles in both the Web of Science and Scopus databases, in 1000 books listed on Amazon, and in almost 15 000 texts in the World Catalogue, the largest record of library collections globally. Offering explanations for the concept's influence, the author of the bibliometric analysis argued that for geologists the concept referred to 'a *turning point*' in Earth's history, while for scholars across the sciences, humanities, and social sciences the concept provided 'a new *context*' for thinking about future human societies and their relationship with the natural world. The author noted that the rapid spread of the Anthropocene idea 'has been extraordinary and is unique in scientific history for a basic concept'.[56]

The idea's impact has been connected to the prevailing context of turn-of-the-century environmental politics. It was introduced at a time when the environment had entered what historians characterized as a new phase in its intellectual history. If the Stockholm conference of 1972 marked a key moment in the institutionalization of the environment, then the 1992 Rio 'Earth' summit marked a key moment for the movement into a new phase of the environment—a phase of pluralism. The summit sought to integrate into the policy process a wider range of voices and perspectives, helping bring to the fore new ways of framing the climate, which stressed environmental justice, the need to balance economic development and ecological protection, and the way different regions and countries, based on historical contributions to greenhouse gas emissions, assigned blame and responsibility for climate change. The environment, moreover, has been increasingly integrated since then into discussions of governance and globalization, economics and political economy, justice and inequality. It has been framed by governments, politicians of different ideologies, non-governmental organizations, regional and global advocacy organizations, as well as journalists, writers, and intellectuals, all presenting different interpretations of climate change.[57]

In Etzioni's terms, this was a cultural environment that did not have clear communities of assumptions. It was unsettled, cluttered with contrasting details, filled with competing discourses and ways of viewing climate politics. In such a cultural environment, public intellectual work has an important role in the provision of an overarching picture and unifying frame of reference.[58] As scholars have observed, the Anthropocene served this function. 'Epochal and topically encompassing,' wrote one geographer, 'the concept has

55 'Working Group on the 'Anthropocene': Results of binding vote by AWG, released 21st May 2019', http://quaternary.stratigraphy.org/working-groups/anthropocene/ (accessed 31 May 2023). On Crawford Lake, see: Alexandra Witze, 'This quiet lake could mark the start of an Anthropocene epoch', *Nature* **619**, 441–442 (2023).

56 Hans Günter Brauch, 'The Anthropocene concept in the natural and social sciences, the humanities and law—a bibliometric analysis and a qualitative interpretation (2000–2020)', in Benner *et al.* (eds), *op. cit.* (note 2), pp. 289–438, at p. 379 and p. 289.

57 Warde *et al.*, *op. cit.* (note 19), p. 173; Hulme, *op. cit.* (note 29), p. 35.

58 Etzioni, *op. cit.* (note 10).

served to focus academic and political attention on the extraordinary scale, scope and magnitude of the human impact on the Earth'.[59] The term also allowed a pluralistic set of environment interests to mobilize around a common interpretation of the world's myriad environmental problems. As Warde, Robin and Sörlin wrote, the promotion and use of the Anthropocene among diverse experts focused on global change was 'a conscious effort to inject urgency into the policy process'.[60]

Yet despite the discursive success of the Anthropocene as a concept, international policy responses to climate change remained stalled—to the frustration and dismay of climate and environmental scientists.[61] Social theorists and science policy scholars, however, have examined the nature of climate change as a social problem and have contrasted it with the policies that responded rapidly to ozone depletion. As many scholars writing about environmental politics and environment and society have noted, ozone depletion is what social theorists have termed a 'tame' problem. It has a small number of identifiable causes and has been related to a relatively small number of economic activities that can be addressed through responsible regulation. These features meant the tame problem of ozone reduction could be addressed through the established mechanisms of technocratic policymaking. Furthermore, the response to ozone depletion was so successful that its policymaking framework provided the conceptual basis for international efforts to address climate change.[62]

Climate change, however, is what social theorists have called a 'wicked problem'. Bound up with the conditions of modernity, caused by almost all forms of human activity and economics, it is an intractable problem that cannot be solved in the conventional sense. It is a problem that societies will only become better or worse at managing over time. Moreover, a wicked problem cannot be defined incontrovertibly. Any proposed solution depends on how the problem is defined. Hulme argued, for example, that climate change could be defined as a scientific or engineering problem of too much carbon dioxide in the atmosphere. The solution in this case would be to scrub carbon dioxide out of the atmosphere and store it underground. But climate change, Hulme argued, could be defined in ways that are different to such science-based definitions. It could be defined, for example, as a problem that is rooted in colonialism and the unjust extraction of resources. The solution in this case would be reparations for ecological loss. It could be defined as a problem in which the cost of pollution is not reflected in market prices. The solution in this case would be to price carbon correctly.[63] A range of advocates and activists, intellectuals and writers, policymakers and politicians from around the world have defined climate change in these and other ways, with the result that scientists—who in the 1980s and 1990s were instrumental in defining it as a mechanistic geophysical problem—no longer had the privileged authority, in an age of environmental pluralism, to frame the problem for policymakers.[64]

59 Noel Castree, 'Framing, deframing and reframing the Anthropocene', *Ambio* **50**, 1788–1792 (2021), at p. 1788.

60 Warde *et al.*, *op cit.* (note 19), p. 173.

61 Isak Stoddard, Kevin Anderson, Stuart Capstick, *et al*. 'Three decades of climate mitigation: why haven't we bent the global emissions curve?' *Annu. Rev. Environ. Resources* **46**, 653–689 (2021).

62 Steve Rayner, 'Wicked problems: clumsy solutions—diagnoses and prescriptions for environmental ills', Jack Beale Memorial Lecture on Global Environment, ANSW Sydney, July 2006, https://core.ac.uk/download/pdf/288283455.pdf (accessed 15 May 2023).

63 Mike Hulme, *Climate change* (London, Routledge, 2022), at pp. xxix–xxx.

64 Howe, *op. cit.* (note 21) and Hulme, *op. cit.* (note 63).

Geoengineering and the turn to the public

In 2006, Crutzen made his last major intervention in environmental politics when he argued for intensified research into a form of solar geoengineering: technologies that would deliberately release sulfur into the stratosphere, which would lead to a cooling of the planet by reflecting the sun's rays into space. Before 2006, solar geoengineering and other forms of geoengineering had not received broad support or interest from the scientific community.[65] Opponents argued that research into geoengineering would divert resources, as well as crucial political and public support, away from the necessary greenhouse gas reductions that have been central to policies of climate change mitigation. Opponents also argued that undertaking research would legitimate technologies that have the potential for enormous unforeseen effects on the climate system. Geoengineering also raised profound issues of governance about what governments or institutions would oversee, control, and potentially regulate such efforts. These concerns revealed what one climate researcher called a strange dichotomy in atmospheric science. Researchers commonly described pessimistic or apocalyptic possible scenarios about future climate change, but they refused to condone the examination of future scenarios that could result from geoengineering.[66]

Crutzen attempted to pry open this community of assumptions. He argued that the lack of open scientific examination meant solar geoengineering had been, in his words, 'tabooed'.[67] He wrote the article for a public culture that was broader than his professional culture, publishing it in a special issue of *Climatic Change*, an interdisciplinary journal that since its foundation in the 1970s has had a focus on policy-relevant research. The journal's editor was Stephen Schneider, who ten years earlier published a special issue on geoengineering. Crutzen's 2006 article was labelled as 'An editorial essay'. It described how releasing sulfur compounds into the stratosphere would, in technical terms, increase the Earth's albedo, the amount of incoming sunlight that is reflected into space. Moreover, its title illustrated a technocratic logic, setting out a scientific idea that could set policy: 'Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?'

The policy dilemma he constructed in the article concerned the challenge of addressing climate change and air pollution. Burning fossil fuels, he wrote, released carbon dioxide (CO_2) into the atmosphere, leading to global warming. Burning fossil fuels also released sulfur dioxide (SO_2), a gas that is converted through a series of chemical processes in the atmosphere into aerosol particles, which can reflect the sun's rays back into space. SO_2 emissions and these aerosol particles, however, had serious adverse health and environmental effects. Breathing in the particles led to more than half a million premature deaths worldwide. The particles also fell back to earth as acid rain. Crutzen argued that this dilemma—which he called a Catch-22 situation, one in which the features of a particular set of circumstances prevented any attempt to escape from them—could be resolved by essentially injecting sulfur at a sufficiently high elevation in the stratosphere so

65 Ralph J. Cicerone, 'Geoengineering: encouraging research and overseeing implementation', *Clim. Change* **77**, 221–226 (2006).

66 Mark G. Lawrence, 'The geoengineering dilemma: to speak or not to speak', *Clim. Change* **77**, 245–248 (2006).

67 Paul J. Crutzen, 'Albedo enhancement by stratospheric sulfur injections: a contribution to resolve a policy dilemma?', *Clim. Change* **77**, 211–219 (2006), at p. 214.

that particles would come to reflect sunlight, but would also be at too high an elevation to breathe. He wrote:

> Therefore, although by far not the best solution, the usefulness of artificially enhancing earth's albedo and thereby cooling climate by adding sunlight reflecting aerosol in the stratosphere … might again be explored and debated as a way to defuse the Catch-22 situation just presented and additionally counteract the climate forcing of growing CO_2 emissions. This can be achieved by burning S_2 or H_2S carried into the stratosphere on balloons and by artillery guns to produce SO_2.[68]

After this initial framing of albedo enhancement as a response to air pollution deaths, Crutzen framed the technology as a response to climate change. If international climate policy continued to fail to make the necessary rapid cuts in emissions, he argued, then solar geoengineering would be needed to avoid harmful climate change impacts, as it provided, in his words, an 'escape route' from rising temperatures.[69] Therefore, he argued, accelerated research into the technology was urgently needed. He wrote:

> Given the grossly disappointing international political response to the required greenhouse gas emissions, and further considering some drastic results of recent studies … research on the feasibility and environmental consequences of climate engineering of the kind presented in this paper, which might need to be deployed in future, should not be tabooed. Actually … its research should anyhow be intensified.[70]

Compared with his earlier writings in public culture, the article marked a notable shift in Crutzen's diagnosis of the problem. As well as rising emissions, part of the problem lay with politicians for the slow implementation of climate policies. As a treatment recommendation to rising emissions and mitigation failures, a rapid shift in technological priorities was needed in order to be able to deploy solar geoengineering as the sole remaining decisive response to climate change. He wrote:

> If sizeable reductions in greenhouse gas emissions will not happen and temperatures rise rapidly, then climatic engineering, such as presented here, is the only option available to rapidly reduce temperature rises and counteract other climatic effects.[71]

His framing pointed to a loss of confidence in political leaders and the linear technocratic model of policymaking. Further evidence of this erosion of faith in policymakers came in his conclusion when he called for scientists to communicate directly with the public. Crutzen wrote:

> Building trust between scientists and the general public would be needed to make such a large-scale climate modification acceptable, even if it would be judged to be advantageous. Finally, I repeat: the very best would be if emissions of the greenhouse gases could be reduced so much that the stratospheric sulfur release experiment would not need to take place. Currently, this looks like a pious wish.[72]

68 *Ibid.*, p. 212.
69 *Ibid.*, p. 216.
70 *Ibid.*, p. 214.
71 *Ibid.*, p. 216.
72 *Ibid.*, p. 217.

This emphasis on democratic participation marked a significant shift in his writings, as he essentially sidelined politicians from discussions about social responses to climate change. Yet he nevertheless maintained a strong technocratic perspective. His appeal for public communication ostensibly brought citizens into the science policy process, an integration that researchers and some governments had advocated since at least the 1990s.[73] But from his technocratic perspective the ultimate aim of communication with an (undefined and unspecific) public was to persuade people to accept the technology. Crutzen would later reflect further on public communication around geoengineering. He argued with a co-author in an article first published in 2016 that there was a need for a 'broad, well-informed sociopolitical dialogue … to determine whether humanity as a whole is likely to actually someday provide broad support for the pursuit of full-fledged climate engineering'.[74] The view further integrated the public into discussions of technological governance, but retained the viewpoint that communication aimed at fostering public support for contentious technologies.

The 2006 article had a significant impact on scientific elites. After 2006, one study found there was a marked increase in research publications about geoengineering, although this rise was driven not only by what the authors called Crutzen's 'classic' article, but also by a rise in articles that examined the different geoengineering technology of carbon dioxide removal.[75] NASA was among the organizations to hold meetings that cautiously explored the topic. According to contemporaneous journalistic reporting, some scientists at these meetings decided to explore the field because of Crutzen's article.[76] The UK's Royal Society and the US National Academy of Sciences (NAS) published reports on solar geoengineering. Crutzen was one the dedicatees of the 2021 NAS report, which praised the way his article essentially reframed discussions of the technology. It said: 'His 2006 essay on solar geoengineering set the stage for future discussions in stark, memorable terms.'[77]

Crutzen's reputation was judged to be central to the paper's impact. In another of the essays published in the 2006 *Climatic Change* special edition, Ralph Cicerone, an atmospheric scientist who was then president of the US National Academy of Sciences, noted the fact that Crutzen's authorship of the paper caused controversy. 'I am aware', he wrote, 'that various individuals have opposed the publication of Crutzen's paper, even after peer review and revisions, for various and sincere reasons that are not wholly scientific'.[78] What Cicerone perhaps implied was made explicit by science writer Oliver Morton. 'The most important thing about the essay', he wrote, 'was that everything it said was said by Paul Crutzen, saviour of the ozone layer.'[79] Morton quoted Schneider, who had said: 'The messenger was the message.'[80] Another testament to the persuasive influence of the

73 On the history of integrating the non-specialist public into formal deliberative communications about science, see Bucchi, *op. cit.* (note 9).

74 Mark G. Lawrence and Paul J. Crutzen, 'Was breaking the taboo on research on climate engineering via albedo modification a moral hazard, or a moral imperative', in Benner *et al.* (eds), *op. cit.* (note 2), pp. 253–265, at p. 262.

75 Paul Oldham, Bronislaw Szerszynski, Jack Stilgoe, Calum Brown, Bella Eacott and Andy Yuille, 'Mapping the landscape of climate engineering', *Phil. Trans. R. Soc. A* **372**, at p. 5 (2014).

76 Eli Kintish, 'Giving climate change a kick', *Science*, 9 November 2007 (doi:10.1126/article.32752).

77 John Shepherd, *Geoengineering the climate: science, governance and uncertainty* (Royal Society, London, 2009); National Academies of Sciences, Engineering, and Medicine, *Reflecting sunlight: recommendations for solar geoengineering research and research governance* (National Academies Press, Washington, DC, 2021), p. xiii.

78 Cicerone, *op. cit.* (note 65), p. 221.

79 Morton, *op. cit.* (note 4), p. 154.

80 *Ibid.*

author's reputation was the fact that, as Crutzen himself noted, the essay had sizeable influence overall, but his framing of the issue as related to air pollution and public health was, and continues to be, ignored.[81] The article's impact, from these observations, was almost entirely based on the authority of its Nobel Prize-winning author, demonstrating the influence of Laureates to shape research and policy agendas.

Crutzen as technocratic public intellectual

Paul Crutzen spoke in the name of science as a technocratic public intellectual who viewed scientists as guides for the rest of society on how to understand and respond to a series of dangerous global environmental problems. He came to occupy this position after he first established his authority in the late 1960s and early 1970s within the emergent professional culture of atmospheric science. His professional authority became the basis for his communication to a public culture of scientific and policy elites. From the start of his career, his close relationship with *Ambio* provided him with a channel of communication to reach publics outside his discipline and frame his research as relevant to science policy. His ability to move seamlessly between his research work and his public communication was facilitated by the inextricable connection between environmental science and policy, especially from the early 1970s to the 1990s, when the prevailing view among scientific and political institutions was that global environmental problems could be best addressed through a technocratic combination of model-based scientific methods and cooperative international politics. Over his career, Crutzen's professional status and public standing reinforced each other, a dynamic evident in his Nobel award that recognized his pioneering research and its social effects, enhancing his authority in communications in public culture on the Anthropocene and in professional culture on solar geoengineering.[82]

Crutzen undertook the two communicative functions of the public intellectual. He tested the reality—often through model-based research that was a dominant approach to understanding the global environment—of established frameworks held by scientific and political elites about how to understand human-caused environmental problems. He then framed these problems in new ways for his elite publics. This model of elite persuasion reached its cultural highpoint with the Anthropocene concept, which provided a broad integrated picture of the modern ecological crisis that allowed a diversity of problems to be understood within a single idea. As a technocratic public intellectual, he aimed to persuade political elites to introduce policy and legislation to address current and future environmental threats that scientists identified.

As well as demonstrating the general processes through which a scientist becomes a public intellectual and communicates with elite publics, the specific case of Crutzen demonstrates the possibilities and limitations of the technocratic intellectual in modern liberal democracies. He demonstrated, fundamentally, how responsible scientists can undertake the democratic role of pointing to science-intensive social and political problems, a crucial social role when problems are first identified and must be framed in a way that makes them relevant to

81 Lawrence and Crutzen, *op. cit.* (note 74).

82 For a discussion of the mutually reinforcing connection between scientific status and public renown in contemporary science, see: Massimiano Bucchi, 'Norms, competition and visibility in contemporary science: the legacy of Robert K. Merton', *J. Class. Sociol.* **15**, 233–252 (2015).

policymakers. With the Anthropocene, he demonstrated also how prominent scientists can introduce scientific ideas in public culture that become incorporated into research agendas. However, he demonstrated also the limitations of elite-focused technocratic communication. When formal environmental politics became more pluralistic, and when climate change came to be viewed more broadly as a wicked problem, the technocratic perspective became one perspective among many legitimate ways of understanding complex environmental problems that have systemic historical, economic, and sociological causes. But the major limitation of such public intellectual work is the model of environmental policymaking on which it rests. The slow pace of global climate policy has demonstrated that the linear technocratic model of policymaking does not automatically lead to decisive policy and legislation. Crutzen, as a consequence, later in his career, turned to the public for the support needed to legitimate a drastic response to the risk of climate change that he and the community of atmospheric science did so much to help society understand.

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