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ARTICLE

A benchmark for the environment: big science and 'artificial' geophysics in the global 1950s†

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Abstract

Security concerns during the early Cold War prompted United States strategists to solicit worldwide assistance in studying Earth's physical environment. Comprehensive geophysical knowledge required cooperation between researchers on every part of the planet, leading practitioners to tout transnational earth science – despite direct military applications in an age of submarines and ballistic missiles – as a non-political form of peaceful universalism. This article examines the 1957–58 International Geophysical Year as a powerful fulcrum in the transfer of ideas about Earth's global environment from Western security establishments to conservationists worldwide. For eighteen months, tens of thousands of researchers across every continent pooled resources for data collection to create a scientific benchmark for future comparisons. Illuminating Earth as dynamic and interconnected, participants robustly conceptualized humanity's emergence as a geophysical force, capable of 'artificially' modifying the natural world. Studies of anthropogenic geophysics, including satellites, nuclear fallout, and climate change, conditioned the global rise of environmentalism.

Keywords: climate change; Cold War; environmental history; nuclear fallout; outer space

During the 1950s, Western security strategists promoted the comprehensive study of Earth as a complex geophysical system. Cold War competition and new war-fighting techniques drew previously remote regions such as the poles, upper atmosphere, and deep oceans into superpower struggles for global dominance. Powerful weapons, including nuclear-armed submarines and intercontinental ballistic missiles, required precise information about the planet's dynamic shape and movements, while fundamental geophysical research promised to augment the enormous economic expansion since the Second World War, known by historians as the 'Great Acceleration', a still ongoing process of social and environmental upheaval, in which human population and industry have grown with unprecedented rapidity.[1] Cold Warriors in the United States and allied countries aimed to harness the insights of earth science for their own interests, yet the physical size of the planet forced them to invite cooperation from counterparts around the world.

Downplaying the military implications of planet-wide research, Western scientists proposed an eighteen-month International Geophysical Year (IGY), running from July 1957

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[1]J. R. McNeill and Peter Engelke, *The Great Acceleration: an environmental history of the Anthropocene since 1945*, Cambridge, MA: Harvard University Press, 2016, p. 4.

to December 1958.[2] This IGY fostered ostensibly non-political collaboration between tens of thousands of researchers in more than sixty countries. It sought to record short- and long-term geophysical changes as measured by fourteen earth science disciplines, which ranged from meteorology and oceanography to solar physics, gravimetry, and glaciology. Lloyd Berkner, the US geophysicist and governmental adviser who first proposed the IGY, promoted it as providing a 'benchmark' for future earth science researchers. In Berkner's telling, the IGY constituted a peaceful affair defined by universal appeal: 'tired of war and dissention, men of all nations have turned to "Mother Earth" for a common effort on which all find it easy to agree'.[3]

The history of the IGY offers a bridge between two bodies of literature within global studies, each with bearing on recent characterizations of our current environmental crisis as an 'Anthropocene', a new geological age defined by human influence upon the natural world.[4] Literature on the rise of the United States-led post-war world order has demonstrated the centrality of US military sciences in generating notions of a worldwide 'physical environment' during the late 1940s and early 1950s. Logics of control and mastery structured the concern of military scientists and civilian consultants with the geophysical changes that produced the Anthropocene.[5] A distinct, although interrelated, line of scholarship emphasizes the emergence in the 1960s and 1970s of conservationist notions of a 'global environment', intertwined with a worldwide environmentalist movement.[6] Writers in this vein have drawn distinctions between the biologists, ecologists, and resource economists of the era and earlier geophysicists, who 'had little interest in the environment as something that was threatened by human activity'.[7] Yet the growth of earth system science in the later twentieth century, so central to notions of the Anthropocene, arose precisely from initiatives to understand the interdependencies of the biosphere – the realm of living organisms on Earth – with the other geophysical properties of our planet that make life possible. This disciplinary convergence relied on long-standing theories, methods, and technologies of data acquisition and centralization common to 'big science', a term inspired in part by the IGY, whose major outcomes included the launching of Sputnik, the regulation of Antarctica as a continent for science, the confirmation of continental drift, and the discovery of global warming.[8]

This article, by considering the planet-wide reach of the IGY, illuminates it as a fulcrum between notions of Earth's environment as, on the one hand, a set of spaces and processes for post-war militaries to exploit, and, on the other hand, an endangered treasure for subsequent environmentalists to protect. Cooperative worldwide research into naturally occurring phenomena

[2] Overviews include Roger Launius, David DeVorkin, and James Fleming, eds., *Globalizing polar science: reconsidering the International Polar and Geophysical Years*, New York: Palgrave Macmillan, 2010; Susan Barr and Cornelia Lüdecke, eds., *The history of the International Polar Years (IPYs)*, New York: Springer, 2010.

[3] L. V. Berkner, 'International scientific action: the International Geophysical Year 1957–58', *Science*, 119, 3096, 1954, pp. 570, 575.

[4] Dipesh Chakrabarty, 'The climate of history: four theses', *Critical Inquiry*, 35, 2, 2009, pp. 197–222; Libby Robin, Sverker Sorlin, and Paul Warde, 'Stratigraphy for the Renaissance: questions of expertise for "the environment" and "the Anthropocene"', *Anthropocene Review*, 4, 3, 2017, pp. 246–58.

[5] Ronald Doel, 'Quelle place pour les sciences de l'environnement physique dans l'histoire environnementale?', *Revue d'Histoire Moderne & Contemporaine*, 56, 4, 2009, pp. 137–64; Jacob Hamblin, *Arming Mother Nature: the birth of catastrophic environmentalism*, Oxford: Oxford University Press, 2013, pp. 17–128; Naomi Oreskes, 'A context of motivation: US Navy oceanographic research and the discovery of sea-floor hydrothermal vents', *Social Studies of Science*, 33, 5, 2003, pp. 697–742.

[6] Mark Lytle, *The gentle subversive: Rachel Carson*, Silent Spring, *and the rise of the environmental movement*, New York: Oxford University Press, 2007; Adam Rome, *The genius of Earth Day: how a 1970 teach-in unexpectedly made the first green generation*, New York: Hill and Wang, 2013; Perrin Selcer, *The postwar origins of the global environment: how the United Nations built Spaceship Earth*, New York: Columbia University Press, 2018.

[7] Paul Warde, Libby Robin, and Sverker Sörlin, *The environment: a history of the idea*, Baltimore, MD: Johns Hopkins University Press, 2018, p. 108.

[8] Derek de Solla Price, *Little science, big science*, New York: Columbia University Press, 1963, p. 3; Christine Borgman, *Big data, little data, no data: scholarship in the networked world*, Cambridge, MA: MIT Press, 2015, pp. 3–4.

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established a template for studies of 'artificial' forces, especially space satellites, radioactive fallout, and greenhouse gas emissions. Scientists associated with the United States security establishment circulated military and other strategic justifications for investigating anthropogenic geophysics among themselves. Yet their collaboration with fellow researchers in numerous neutral and enemy states, necessitated by the geographic extent of planet Earth, prompted Western IGY organizers to suffuse public explanations of their endeavours with depoliticized techno-optimism.[9] Emphasizing alleged advantages for economic development, they lauded the momentous 'experiments' inaugurated by the space race, nuclear testing, and climate change.

The philosopher Hannah Arendt deviated from such boosterism in her 1958 book, *The human condition*. 'For some time now', she wrote, 'a great many scientific endeavors have been directed toward making life also "artificial", toward cutting the last tie through which even man belongs among the children of nature.' Arendt lamented this tendency to seek escape from the natural constraints of Earth, which she considered 'the very quintessence of the human condition'.[10] Her critique anticipated the posture of later environmentalists. Just as the IGY provided her point of departure, the enthusiasm with which Western science administrators promoted artificial geophysics laid an intellectual and infrastructural groundwork among their collaborators around the world for more circumspect interpretations of anthropogenic influence.

Cold War science and the physical environment

The comprehensive vision of the IGY befitted an era of Cold War competition. The rise of United States hegemony after the Second World War, combined with Western efforts to contain the global spread of communism, brought history's most ambitious experiments in global governance. Internationalism and US power went hand in hand. The chartering of the United Nations (UN), the initiation of the Marshall Plan, and the Cold War's landmark military alliances, as well as the founding of the World Bank and the International Monetary Fund, reflected ambitions to draw most countries into the orbit of the 'Free World'.[11] The IGY held commonalities with these high modernist initiatives, as well as with other explicitly scientific schemes to build dams, spray pesticides, and eradicate diseases across the globe. In 1945, the Manhattan Project administrator Vannevar Bush had articulated the general value of 'basic research' in his influential pamphlet *Science: the endless frontier*, which precipitated the establishment of the National Science Foundation.[12] Less than a decade later, President Dwight Eisenhower echoed Bush when giving support for the IGY: 'The United States has become strong through its diligence in expanding the frontiers of scientific knowledge. Our technology is built upon a solid foundation of basic scientific inquiry, which must be continually enriched if we are to make further progress.'[13] Typically unstated in public pronouncements were strategic plans for asserting mastery over waterways and airways, polar landscapes, and outer space. Advances in earth science appealed at a moment when missile and submarine technologies had attuned military experts to questions of

[9]'Eisenhower's dilemma: talking peace and waging Cold War', in Kenneth Osgood and Andrew Frank, eds., *Selling war in a media age*, Gainesville, FL: University Press of Florida, 2010, pp. 140–69; Audra Wolfe, *Freedom's laboratory: the Cold War struggle for the soul of science*, Baltimore, MD: Johns Hopkins University Press, 2018, pp. 91–112.

[10]Hannah Arendt, *The human condition*, Chicago, IL: University of Chicago Press, 1998, p. 2. See Benjamin Lazier, 'Earthrise: or, the globalization of the world picture', *American Historical Review*, 116, 3, 2011, pp. 602–30.

[11]Francis Gavin, *Gold, dollars, and power: the politics of international monetary relations, 1958–1971*, Chapel Hill, NC: University of North Carolina Press, 2004, pp. 17–31; Mark Mazower, *Governing the world: the history of an idea*, New York: Penguin, 2012, pp. 191–243; Glenda Sluga, *Internationalism in the age of nationalism*, Philadelphia, PA: University of Pennsylvania Press, 2013, pp. 79–117; Stephen Wertheim, 'Instrumental internationalism: the American origins of the United Nations, 1940–3', *Journal of Contemporary History*, 55, 2, 2019, pp. 265–83.

[12]Vanavar Bush, *Science: the endless frontier*, Washington, DC: Government Printing Office, 1945.

[13]National Archives of Australia, Sydney, Australia (henceforth NAAS), C3830 C34/1 Part 1, James Hagerty, 'The White House', 25 June 1954.

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standardization and accuracy.[14] As a result, federal funding for geophysical research greatly expanded. The total National Science Foundation budget was only US$8 million in 1954. Within four years, it had received US$43 million for the IGY.[15]

Creating a benchmark for the Earth required Western scientists and administrators to draw colleagues around the globe into their project of simultaneously measuring worldwide geophysical phenomena. Practitioners and policy-makers responsible for linking the earth sciences with the US security establishment favoured international collaboration as a means of augmenting data and material resources, while also spreading US influence abroad. In 1948, the State Department solicited a report on Antarctic policy from the National Academy of Sciences. The final document, which emphasized the potential of Antarctic science to yield insights about geophysical processes across the planet, recommended a 'coordinated international program' in which US civilian and military organizations would be joined by 'an equally wide distribution of responsibility and opportunity among similar agencies in each of the participating countries'.[16] Lloyd Berkner, a co-author of this assessment, proposed the idea for what would eventually become known as the International Geophysical Year to a group of US and British earth scientists at a dinner party in April 1950. Days later, Berkner submitted another report to the State Department, this time on science and foreign relations. 'American pre-eminence thus far is in the application of scientific discovery', he argued; 'hence it is to our practical advantage to promote the fullest scientific intercourse'.[17] In a confidential appendix, he identified transnational collaboration as an intelligence asset. He recommended surveilling US scientists who collaborated with foreign colleagues to gather information about technological developments abroad, especially in the Soviet Union.[18] Subsequent approval for IGY projects echoed Berkner's twining of technological and diplomatic factors. The Central Intelligence Agency, for instance, endorsed seizing the opportunity to launch space vehicles. Orbiting satellites during the IGY 'would provide the United States with maximum favorable publicity, an international setting, worldwide scientific cooperation, a clearly established peaceful motive, and a reaffirmation of Free World scientific values and methods'.[19]

The national security motivations of Lloyd Berkner and his colleagues to study the planet as a physical environment reflected longer entanglements of state power and earth science research. Beginning during the eighteenth-century Enlightenment, the age of political revolutions spurred interest in 'catastrophic' geology, in which intellectuals imagined the Earth as a coherent geological entity with a long history of structural upheavals and transformations. Fascination among scientific and political revolutionaries from France to Venezuela for volcanoes, earthquakes, and palaeontology helped generate the epochal classification system for which the Anthropocene would become the most recent stage.[20] Contemporaneous developments in

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[14]Donald MacKenzie, *Inventing accuracy: a historical sociology of nuclear missile guidance*, Cambridge, MA: MIT Press, 1990, pp. 95–164; Deborah Jean Warner, 'Political geodesy: the Army, the Air Force, and the World Geodetic System of 1960', *Annals of Science*, 59, 2002, pp. 363–89; Ronald Doel, 'Constituting the postwar earth sciences: the military's influence on the environmental sciences in the USA after 1945', *Social Studies of Science*, 33, 5, 2003, pp. 635–66.

[15]Merton England, *A patron for pure science: the National Science Foundation's formative years, 1945–57*, Washington, DC: National Science Foundation, 1982, p. 211.

[16]*Antarctic research: elements of a coordinated program*, Washington, DC: National Academy of Sciences, 1949, p. iii.

[17]Lloyd Berkner, *Science and foreign relations: international flow of scientific and technological information*, Washington, DC: Department of State, 1950, p. 3.

[18]Allan Needell, *Science, Cold War, and the American state: Lloyd V. Berkner and the balance of professional ideals*, Amsterdam: Harwood Academic Publishers, 2000, pp. 141–9.

[19]Central Intelligence Agency Historical Collections, CIA General Records, CIA-RDP80B01676R002500100006-0, 'Earth satellite vehicle (ESV)', 4 October 1954, https://www.cia.gov/library/readingroom/docs/CIA-RDP80B01676R002500100006-0.pdf (consulted 3 September 2019).

[20]Martin Rudwick, *Earth's deep history: how it was discovered and why it matters*, Chicago, IL: University of Chicago Press, 2014, pp. 31–180; Robert Davis, 'Inventing the present: historical roots of the Anthropocene', *Earth Sciences History*, 30, 1, 2011, pp. 63–84.

early modern agriculture and forestry helped associate state power with policies to judiciously manage natural resources.[21] The expansion of European empires, meanwhile, exported cultures of improvement, which in turn became technologies of foreign rule. Deforestation and drought in overseas territories prompted colonial administrators to develop early forms of scientific climate control.[22]

The most sophisticated theories, however, emerged in the primarily continental Habsburg empire, where efforts to maintain peace within a context of rising nationalist sentiment produced incentives to tack between large and small scales of imperial scientific analysis.[23] It was an Austro-Hungarian naval officer, Karl Weyprecht, who in 1875 proposed that multiple countries participate in an International Polar Year to study Earth's ice-clad extremities. The first Polar Year occurred in the early 1880s, with a second following in the 1930s.[24] During both events, a modest number of scientists, mostly Europeans, travelled to the Arctic and Antarctic, where they examined aspects of solar–terrestrial relations that were difficult to study at lower latitudes. Their journeys resulted in discoveries valuable to state and business interests, including improvements in magnetic navigation and long-distance radio communication.

Proponents of the 1957–58 IGY modelled their project on these earlier Polar Years, and they advocated for their new, more ambitious, undertaking through the well-worn machinery of transnational science. Since the beginning of the twentieth century, an umbrella body that eventually became known as the International Council of Scientific Unions (ICSU) had coordinated a host of constituent 'unions', each responsible for managing the worldwide study of topics from geography and chemistry to biology, mathematics, and history of science.[25] In September 1950, Lloyd Berkner and his British colleague Sydney Chapman pitched a 'Third International Polar Year' to a commission of ICSU.[26] They noted that advances in radar, rocketry, and other technologies seemed to have put complete geophysical knowledge within human reach. They stressed the global nature of the undertaking, noting that it was 'polar' only in genealogy and partly in method. The principle objectives of a new Polar Year would be to improve understanding of magnetic and ionospheric storms, auroral physics, and the structures of the atmosphere. Each goal shared an intimate link with solar physics: radiation from the Sun provides heat that drives the water cycle, while Earth's magnetosphere and ionosphere expand and contract with changing solar activity; this can produce geomagnetic storms visible to humans as auroral displays. They hoped that coordinated study would yield 'as complete a picture as possible of world-wide geophysical phenomena'.[27]

By 1951, this proposal had made its way through the ICSU bureaucracy. The organization's executive board convened a special committee, whose members represented the unions for astronomy, radio science, geodesy and geophysics, geography, and pure and applied physics, as well as the World Meteorological Organization. The main period of operation was set to run from mid 1957 to the end of 1958, so that it would correspond with the next peak in the Sun's approximately eleven-year solar cycle. Finally, the name 'Polar Year' was replaced with the more expansive

[21]Fredrik Jonsson, *Enlightenment's frontier: the Scottish Highlands and the origins of environmentalism*, New Haven, CT: Yale University Press, 2013; Paul Warde, *The invention of sustainability: nature, human action, and destiny, 1500–1870*, Cambridge: Cambridge University Press, 2018.

[22]Richard H. Grove, *Ecology, climate, and empire: colonialism and global environmental history 1400–1940*, Cambridge: White Horse Press, 1997.

[23]Deborah Coen, *Climate in motion: science, empire, and the problem of scale*, Chicago, IL: University of Chicago Press, 2018, pp. 205–38.

[24]Stephen Anthony Walsh, 'Between the Arctic and the Adriatic: polar exploration, science and empire in the Habsburg monarchy', PhD thesis, Harvard University, 2014, pp. 208–70.

[25]Frank Greenaway, *Science international: a history of the International Council of Scientific Unions*, Cambridge: Cambridge University Press, 1996, pp. 33–148.

[26]*Commission mixte de l'ionosphère: compte-rendu de la deuxième réunion tenue à Bruxelles du 4 au 6 Septembre 1950*, Brussels: URSI, 1951, pp. 63–6.

[27]'Proposal made in 1951 by the Mixed Commission on the Ionosphere for an International Polar Year in 1957–1958', in *Annals of the International Geophysical Year*, vol. 2A, London: Pergamon Press, 1958, p. 70.

'International Geophysical Year', a switch acknowledging that research was not limited to the poles but required simultaneous observations in high and low latitudes.[28]

IGY boosters initially struggled to convince scientists and governments outside North America and western Europe that substantive international collaboration would be in their interests. The United States stood to gain from comprehensive geophysical knowledge more than smaller countries, which preferred to avoid large expenditures on programmes that might benefit rivals abroad. The amorphous term 'geophysics' may also have contributed to the general hesitancy, since at the time it usually referred to a restricted set of scientific practices, such as gravimetry and seismology, used for surveying and mineral scouting. In 1946, for instance, India dispatched a scientific delegation to Britain, the United States, and Canada. After touring Western facilities, this team recommended state investment in geophysics, noting: 'The Governments of all advanced countries have taken keen interest in the development and utilization of this useful science.'[29] Yet the examples given in such reports highlighted resource exploitation and other initiatives to be pursued on a strictly national basis. In November 1952, when the special committee for the IGY invited the formation of national committees, only a minority of the world's countries at first responded affirmatively. India's most influential scientist, Homi Bhabha, extricated himself from the fledgling Indian committee.[30] Argentina, which had the most extensive geophysical establishment in South America, preferred to avoid international intrusions into its affairs.[31] Australia's leading radio physicist confessed, 'I am afraid I can't raise much enthusiasm for the International Geophysical Year.'[32] Cooperation across the Iron Curtain was especially fraught. War in Korea overshadowed early negotiations, while McCarthyism in the US targeted several renowned geophysicists. State Department officials kept watch over Sydney Chapman, president of the special committee, as he courted the Soviet Union and the People's Republic of China.[33] Non-participation by the world's first and fourth largest countries by landmass would have severely limited the IGY's value, not least for Cold Warriors eager for military-grade data on the Communist Bloc.

The Soviet Union's eventual decision to participate in the IGY signalled a turning point in global research on Earth's environment. Military developments in the USSR after the Second World War roughly paralleled those of the United States, including emphasis on Arctic combat and ballistic missile production.[34] The conditions that fostered such developments, however, had also largely precluded Soviet participation in international science. Under Joseph Stalin, the USSR held membership in only two transnational science associations, the International Astronomical Union and the World Meteorological Organization. Stalin had initiated a purge of earth scientists during the 1940s to eliminate 'cosmopolitan' influences, such as leaks regarding uranium deposits. And communist ideology privileged 'applied' science over basic research, considered a bourgeois

[28]F. J. M. Stratton, ed., *The sixth general assembly of the International Council of Scientific Unions held at Amsterdam October 1st to 3rd 1952*, Cambridge: ICSU, 1953, p. 10.

[29]National Archives of India, New Delhi, India (henceforth NAI), S. S. Bhatnagar Papers, file 8, Meghnad Saha et al., 'The report of the Indian scientific mission of their visit to the United Kingdom, the United States of America and Canada during 1944–45', February 1946. On geophysics, see Matthew Shindell, 'Geophysics', in Georgina Montgomery and Mark Largent, eds., *A companion to the history of American science*, Malden, MA: John Wiley & Sons, 2016, pp. 120–33.

[30]NAI, Ministry of Education, SR-2_1953_NA_F-22(1)_53, Deputy Director of Tata Institute to T. W. Gonsalves, 12 June 1953.

[31]Adrian Howkins, 'Reluctant collaborators: Argentina and Chile in Antarctica during the International Geophysical Year, 1957–58', *Journal of Historical Geography*, 34, 2008, pp. 596–617.

[32]NAAS, C3830 C34/1 Part 1, E. G. Bowen to F. W. G. White, 27 October 1952.

[33]See correspondence in National Archives and Records Administration, College Park, MD, USA (henceforth NARA), 1955–59 Central Decimal File, box 1651, folder 3.

[34]William Leary and Leonard LeSchack, *Project COLDFEET: secret mission to a Soviet ice station*, Annapolis, MD: Naval Institute Press, 1996, pp. 7–28; Asif Siddiqi, *The rockets' red glare: spaceflight and the Soviet imagination, 1857–1957*, Cambridge: Cambridge University Press, 2010, pp. 196–289.

luxury.[35] Stalinist intransigence rendered unlikely the IGY participation of other communist countries. In China, state ministries and a newly founded Academy of Sciences concluded that the People's Republic would join if the USSR did so first.[36] Only with Stalin's death in 1953 and the rise of Nikita Khrushchev did a path open for the socialist world's integration into global geophysical cooperation. By March 1954, the president of the Soviet Academy had begun corresponding with Sydney Chapman. The USSR joined a spate of previously shunned scientific bodies, and Soviet leaders encouraged their communist allies to act likewise.[37] Although China ultimately decided not to participate in the IGY, protesting Taiwan's last-minute inclusion, other socialist countries harnessed geophysical internationalism to improve their bargaining power with the West. East Germany, especially, sought to bolster sovereignty via science diplomacy. In 1961, as the Berlin Wall went up, officials were still touting their commitment to global geophysics in the face of exclusion from bodies like the UN.[38]

Cooperation between the United States and the Soviet Union cemented the reputation of the IGY as transcending geopolitical differences. Most countries came to see involvement as advantageous. Official membership rosters grew across the mid 1950s to include sixty-six of the world's ninety-seven states. Scientists treated the IGY as a gold mine for funding and equipment. They highlighted the benefits of international cooperation, while stoking fears of falling behind in prestige and technical competency. Uruguay's national committee, pointing to the large outlays of neighbouring Brazil and Argentina, promised 'great value to the development of science and technology'.[39] This logic persuaded government backers. The Swiss president and chancellor told the Federal Assembly in 1956 that 'It is self-evident that Switzerland cannot act indifferently toward an international effort of this scope.'[40] Multinational organizations with long histories of transnational cooperation, such as the Pan American Institute of Geography and History, based in Mexico City, recalibrated old patterns of coordination under the IGY regime.[41]

Colonial powers operated most research stations in Africa and the Pacific, as well as in parts of Asia and Latin America. The London-based Scientific Council for Africa South of the Sahara, in existence since 1949, and its advisory body headquartered in Congo, the Commission for Technical Co-operation, coordinated research in African territories held by Belgium, Britain, France, Portugal, and Spain, as well as in apartheid South Africa and the Federation of Rhodesia and Nyasaland.[42] South Africa's foreign minister, Eric Louw, demonstrated the racism of this arrangement at one 1954 assembly: 'while the interests of all the inhabitants must be protected and furthered, the interest of the white inhabitants – the descendants of those who brought civilization to Africa, and who opened up and developed

[35]Loren Graham, *Science in Russia and the Soviet Union: a short history*, Cambridge: Cambridge University Press, 1993, pp. 137–206; Konstantin Ivanov, 'Science after Stalin: forging a new image of Soviet science', *Science in Context*, 15, 2, 2002, pp. 317–38.

[36]Zuoyue Wang and Jiuchen Zhang, 'China and the International Geophysical Year', in Launius, DeVorkin, and Fleming, *Globalizing polar science*, pp. 144–9.

[37]Rip Bulkeley, 'Aspects of the Soviet IGY', *Russian Journal of Earth Sciences*, 10, ES 1003, 2008, pp. 1–17.

[38]For example, Archiv der Berlin-Brandenburgischen Akademie der Wissenschaften, Berlin, Germany, Akademieleitung, 1945–1968, file 500, Günther Rienäcker, 'Mitteilung eines Beschlusses des Praesidiums', 5 December 1961.

[39]Archivo General de la Nación, Montevideo, Uruguay, Ministerio de Instrucción Pública, file 634, Germán Barbato and Hugo Frigerio Herrán to Clemente Ruggia, 12 September 1956.

[40]Schweizerisches Bundesarchiv, Bern, Switzerland, E6100B#1970/298#106*, Markus Feldmann and Charles Oser, 'Botschaft des Bundesrates an die Bundesversammlung über die Bewilligung eines Beitrages für die Beteiligung der Schweiz am "Internationalen Geophysikalischen Jahr 1957–1958"', 11 June 1956.

[41]The National Archives, Kew, London, UK, AIR 2/14174, Manuel Maldonado-Kordell, 'El Año Geofisico Internacional y la VIII reunión de consulta sobre cartografia del Instituto Panamericano de Geografia e Historia, La Habana, Cuba, Febrero 12–21, 1958'.

[42]Edgar Barton Worthington, *Science in the development of Africa: a review of the contribution of physical and biological knowledge south of the Sahara*, London: Commission for Technical Co-operation in Africa South of the Sahara, 1958, pp. 49–58.

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its different countries and territories – should be a paramount consideration'.[43] Yet for recently decolonized countries, too, the IGY offered a means of asserting legitimacy, as well as comparative advantage over rivals. Morocco and Tunisia joined in 1956, upon securing independence from France. When the Gold Coast was decolonized a year later, a new Ghana committee took over extant British plans.[44]

That a majority of the world's states co-sponsored the IGY clarifies how cooperative inquiry into Earth's physical environment, born out of US security concerns, became widely touted as an instrument of global peace. As in the United States, a preponderance of IGY funding worldwide came from militaries and national governments. Yet, despite the clear security implications of geophysical data, both at the broadest scales and in regional contexts, supporters portrayed IGY research as a powerful antidote to the political divisions of the day. Public justifications discussed security applications only vaguely and in passing. They more often emphasized prospects such as enhanced meteorological knowledge for shipping, aviation, and agriculture. UNESCO's director general, Luther Evans, dubbed the IGY 'an inspiring example of international understanding and co-operation', while *Life* magazine called it 'the single most significant peacetime activity of mankind since the Renaissance'.[45] K. R. Ramanathan, president of the International Union of Geodesy and Geophysics, contrasted the programme with nuclear weapons, declaring that 'The greatest single achievement of organized science in history was perhaps the building of the first atom bomb. The IGY is in my view an undertaking of greater magnitude and difficulty, because it has involved the bringing together of workers of many nations with differing ideologies' and that 'potentialities for the unification of mankind are infinitely greater'.[46] By skating over the original drivers of IGY organizing, proponents like Evans and Ramanathan exposed the necessity of downplaying geopolitical ambitions in service of scientific internationalism. But they also revealed an enthusiasm for managing the physical environment to improve human beings' relations with both nature and themselves. The IGY's global appeal transcended the militarist impulses that first gave it form.

The rise of artificial geophysics

Coordinated global plans to comprehensively study Earth's physical environment from mid 1957 through 1958 stimulated inquiries into humanity's influence on geophysical processes. While the IGY aimed to furnish an epochal benchmark for studies of naturally occurring phenomena, whose origins long predated humanity's existence, assessing their character and import required knowing whether human beings might be affecting their course. Moreover, new scientific techniques were increasingly believed to double as geophysical processes. 'Artificial satellites' could approximate the orbit of Earth's natural satellite, the Moon, while also providing scientists with upper atmospheric data and precise geodetic coordinates. Nuclear weapons tests produced 'artificial radiation', which researchers could track through the atmosphere and oceans, gleaning insights about the movements of air and water currents. And carbon dioxide released by 'artificial burning' of fossil fuels since the Industrial Revolution offered windows into Earth's ancient history, as well as the planet's fluctuating heat balance.

[43]Archive for Contemporary Affairs, Bloemfontein, Republic of South Africa, E. H. Louw Papers, file 44, Eric Louw, 'Address by the Minister of Economic Affairs (the Honourable Eric H. Louw) on the occasion of the opening of the meeting of the Scientific Council for Africa, South of the Sahara', 20 September 1954.

[44]National Archives and Records Service of South Africa, Pretoria, Republic of South Africa (henceforth NARSSA), BLO 611 PS31/13, 'Report on first 12 months of International Geophysical Year in Ghana', July 1958.

[45]Luther Evans, 'Preface', in Werner Buedeler, *The International Geophysical Year*, Paris: UNESCO, 1957, p. 4; 'The new portrait of our planet', *Life*, 7 November 1960, p. 75.

[46]University of Toronto Archives, Toronto, Canada, B1993-0050, box 22, folder: 'IUGG delegates & papers', K. R. Ramanathan, 'Presidential address', 3 September 1957.

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Like the natural phenomena studied during the IGY, artificial geophysics held strategic implications. Satellite data could aid spy craft and fine-tune ballistic missiles; nuclear fallout could be directed across enemy territory; and global warming might flood coastal cities or melt valuable Arctic waterways. The military applications of these possibilities, as well as the capacity of some powerful countries to produce them on command, complicated desires among Western scientists to study them on a worldwide basis. Yet the cooperative framework of the IGY, well underway by the mid 1950s, supplied an avenue for the normalization of research into artificial geophysics within the global scientific community. That the IGY had become portrayed as a peaceful endeavour advantageous to all humanity helped prompt scientists across the globe to robustly conceptualize anthropogenic efficacy within Earth's environment.

Philosophers, scientists, industrialists, and others had long employed the language of artificiality to distinguish human creations from objects and processes in the natural world that they aimed to approximate or supplant. Thomas Hobbes wrote in *Leviathan* in 1651, 'NATURE (the Art whereby God hath made and governs the world) is by the *Art* of man, as in many other things, so in this also imitated, that it can make an Artificial Animal', referring to humans' ability to construct a 'COMMON-WEALTH, or STATE'.[47] This usage cast human state-building as an extrapolation of natural forms. Causality could also flow in the other direction, as when state-sponsored violence in mid-nineteenth-century wars helped popularize the notion of 'artificial limbs'.[48] Industrialization and its discontents generated anxieties about new modes of production and labour. By the early twentieth century, global trade networks, wartime commodity shortages, and health concerns fostered debates about the virtues of 'artificial sweeteners'.[49]

Marxist critiques of mechanical reproduction, as well as Heideggerian preoccupations with ontological authenticity and the uncanniness of life in a technological age, influenced political theorists and phenomenologists like Hannah Arendt.[50] In her 1951 book *The origins of totalitarianism*, Arendt described how Nazi Germany and Stalin's USSR deployed state propaganda to create an 'artificially fabricated insanity'. Totalitarian regimes maintained control by 'using, and at the same time transcending, the elements of reality'.[51] The rise of science as a new god of the Cold War era refocused Arendt's attentions. Seven years later, she opened *The human condition* with a critique of Sputnik, the best-known IGY project. A pale imitation of Earth's natural Moon, the first human-made object launched into orbit represented for Arendt a troubling desire among modern humans to transcend the natural world. She went on to speak of techniques then gaining prominence as 'artificial insemination' and 'artificial intelligence'.[52]

Geophysicists imported ideas of artificiality to articulate humans' capacity to alter the physical environment on a planetary scale. Already, earth scientists were accustomed to devising procedures that approximated natural processes, and they routinely controlled for anthropogenic factors within their measurements. Astronomers, for example, devised 'artificial meteor trails' to study the composition of Earth's atmosphere, while geomagneticians situated their observatories outside urban areas to reduce 'artificial magnetic disturbances' from power lines or trolley cars.[53]

[47]Thomas Hobbes, *Leviathan*, ed. Richard Tuck, Cambridge: Cambridge University Press, 1996, p. 9.

[48]Jennifer Davis McDaid, '"How a one-legged rebel lives": confederate veterans and artificial limbs in Virginia', in Katherine Ott, David Serlin, and Stephen Mihm, eds., *Artificial parts, practical lives: modern histories of prosthetics*, New York: New York University Press, 2002, pp. 119–43.

[49]Bridget María Chesterton and Timothy Yang, 'The global origins of a "Paraguayan" sweetener: ka'a he'e and stevia in the twentieth century', *Journal of World History* 27, 2, 2016, pp. 256–8.

[50]Walter Benjamin, 'The work of art in the age of mechanical reproduction', in *Illuminations*, New York: Mariner Books, 2019, pp. 166–95; Martin Heidegger, *The question concerning technology and other essays*, New York: Garland Publishing, 1977.

[51]Hannah Arendt, *Totalitarianism: part three of the origins of totalitarianism*, New York: Harcourt, 1976, pp. 51, 60.

[52]Arendt, *Human condition*, pp. 1–6.

[53]James Bartlett, 'Projection of artificial meteor trails on the Moon', *Science*, 107, 2771, 1948, pp. 141–2; *Report of the Superintendent of the Coast and Geodetic Survey*, Washington, DC: Government Printing Office, 1902, p. 85.

As alignments between geophysical science and state power tightened, attempts to influence environmental phenomena expanded in scope. Weather modification is illustrative. By the late 1940s, multiple countries had begun researching rain-making.[54] In addition to cloud-seeding experiments using crushed dry ice dropped from aeroplanes, military researchers sought to determine whether atomic explosions could produce 'artificial rainfall'.[55]

The relative novelty of such inquiries is underscored by the belated entry of artificial phenomena into the IGY programme. Satellites, radiation, and anthropogenic warming joined its research agenda only during the mid 1950s, when administrative organizing was already well underway. Handwritten notes by the IGY architect Sydney Chapman from a 1952 meeting in Canberra identified relevant disciplines as meteorology, geomagnetism, auroral science, ionospheric physics, oceanography, cosmic rays, solar activity, geography, geology, and geodesy.[56] The first worldwide IGY planning conference, held in Brussels in 1953, substantially followed this list, although glaciology was added, and both geology and geography were removed, as they were considered overburdened with political controversy.[57] By contrast, satellite launchings entered the IGY framework in 1954, discussions of radiation monitoring began in 1955, and CO_2 measurements received approval the following year within existing oceanographic and meteorological programmes.

Earth satellites comprised the first and most prominent addition to the IGY programme under the rubric of artificiality. United States military officials and civilian scientists coordinated to inaugurate the Space Age through the medium of IGY orbital vehicles. While Eisenhower's Department of Defense supported this programme primarily to establish a precedent for subsequent military spacecraft, geophysicists worldwide celebrated the prospect of studying objects in orbit through both visual and radio methods. Space enthusiasts such as the science writers Willy Ley and Arthur C. Clarke, the astronomical illustrator Chesley Bonestell, and the rocketeer Wernher von Braun generated anticipation in the United States and abroad for the 'artificial moons'.[58] The IGY became so closely identified with satellites that some called it the 'Year of the New Moons'.[59]

In 1956, Soviet spokespersons announced their own IGY space programme, yet the launch of Sputnik still came as a monumental surprise to non-scientists around the globe, and it marked a critical moment in Cold War power relations. The USSR's achievement signalled its acquisition of missile technology powerful enough to strike targets anywhere on Earth. Sputnik became a byword within the Communist Bloc for socialist achievement. Khrushchev claimed that the USSR had now surpassed all capitalist states, including the US, in science and technology.[60] Mao Zedong adopted a similar line during his November 1957 visit to the Soviet Union. He marvelled at how communism had transformed the 'relatively backward' USSR into a country capable of launching a 'little moon'.[61] Four days later, he announced his Great Leap Forward, through which China sought to model Soviet economic breakthroughs, including in space. Mao had already begun acquiring ballistic missile technology, and he soon approved a satellite project.[62]

[54]Kristine Harper, *Make it rain: state control of the atmosphere in twentieth-century America*, Chicago, IL: University of Chicago Press, 2017, pp. 87–164.

[55]NARA, RG 330, Entry UD UP 23, box 1, folder: 'G & G numbered papers', 'Report of the Ad Hoc Committee for Review of R&D Proposal for Operation Greenhouse', *c.* December 1949.

[56]Fenner Archives of the Australian Academy of Science, Canberra, Australia (henceforth FAAAS), MS053, box 1, folder 1/1, Sydney Chapman, 'The International Geophysical Year, 1957/8', September 1952.

[57]'Reports on CSAGI disciplines', in *Annals of the International Geophysical Year*, pp. 4–15.

[58]Michael Neufeld, *Spaceflight: a concise history*, Cambridge, MA: MIT Press, 2018, pp. 142–6.

[59]J. Tuzo Wilson, *IGY: the year of the new moons*, New York: Alfred A. Knopf, 1961.

[60]Archives diplomatiques, La Courneuve, France, 372QO/640, 'Discours de N. Khrouchtchev', 22 January 1958; Roger Launius, John Logsdon, and Robert Smith, eds., *Reconsidering Sputnik: forty years since the Soviet satellite*, Amsterdam: Harwood Academic Publishers, 2000, pp. 43–116.

[61]Jeremi Suri, *Power and protest: global revolution and the rise of détente*, Cambridge, MA: Harvard University Press, 2005, p. 67.

[62]Brian Harvey, *The Chinese space programme: from conception to future capabilities*, New York: John Wiley & Sons, 1998, p. 6.

In January 1959, Soviet rocketeers scored another victory against their US competitors, when a USSR space probe escaped Earth's gravity to fall into continuous orbit around the Sun. *Pravda* dubbed it the solar system's first 'artificial planet'.[63]

After spacecraft, nuclear fallout became the next artificial phenomenon to receive general consideration from IGY planners. In March 1955, scientists from the Netherlands proposed an IGY study of the world's naturally occurring atomic radiation background, potentially under auspices of its meteorological programme: 'As the pollution of the air by radioactive matter may in the long run become a serious menace to health and even might influence meteorological phenomena, it seems highly desirable to know the basic value of the radioactivity.'[64] Atomic fears, and even doomsday scenarios, long preceded this period, dating to the discovery of radioisotopes and the invention of x-ray technology in the late nineteenth century.[65] Thus, while ideas of artificial radioactivity were not new, they became associated with geophysics only after the Second World War.

The word 'fall-out' (later 'fallout') began appearing in the *Bulletin of the Atomic Scientists* by 1948.[66] Government handbooks and Civil Defense propaganda nonetheless downplayed the threat for communities located far from peacetime test ranges.[67] In 1954, the dangers of fallout elicited global outcry, however, when a US test in the Pacific Ocean exposed a Japanese fishing boat to life-threatening radiation. Japan, already the only country to experience atomic warfare, developed an enormous anti-nuclear movement.[68] The UN soon established a Scientific Committee to examine health risks.[69] While this group focused on medical implications, IGY scientists took up the other side of fallout research, studying the naturally occurring levels of Earth's background radiation and tracking artificial radioisotope 'tracers' (analogous to those used in medical science) through ocean and air currents. A new working group designed ways to measure naturally occurring and anthropogenic radionuclides 'for the benefit of the scientific disciplines sponsored by [the IGY], especially meteorology, oceanography, and the rapidly developing interest in the biosphere'.[70]

Third and finally, IGY scientists resolved to study the impact of anthropogenic carbon dioxide on the global climate. This complemented broader IGY efforts to understand Earth's 'heat budget', which held implications for agriculture, weather control, and navigation by sea and air. US administrators planned worldwide measurements of ocean salinity, surface temperature, and glacial movements, as well as comparisons of solar radiation within and above Earth's atmosphere using satellite measurements.[71] Counterparts in the USSR similarly hoped to analyse 'the total balance of heat and moisture on the earth'. They placed emphasis on the polar regions, since large-scale

[63]FAAAS, box 951, folder: 'Soviet Information Bureau', 'For the good of mankind', 21 January 1959.

[64]National Physical Laboratory, New Delhi, India, K. S. Krishnan Papers, 'The use of harmless radioactive tracer materials for the study of circulation and mixing in the atmosphere and ocean' *c.* October 1955.

[65]Spencer Weart, *Nuclear fear: a history*, Cambridge, MA: Harvard University Press, 1988, pp. 17–76.

[66]R. E. Lapp, 'Atomic bomb explosions: effects on an American city', *Bulletin of the Atomic Scientists*, 4, 2, 1948, pp. 49–54. See also Joseph Masco, 'The age of fallout', *History of the Present*, 5, 2, 2015, pp. 137–68.

[67]Samuel Glasstone, ed., *The effects of atomic weapons*, Washington, DC: Government Printing Office, 1950, pp. 33–7; Richard Gerstell, *How to survive an atomic bomb*, Washington, DC: Combat Forces Press, 1950, pp. 14–26.

[68]Toshihiro Higuchi, 'An environmental origin of antinuclear activism in Japan, 1954–1963: the politics of risk, the government, and the grassroots movement', *Peace & Change*, 33, 3, 2008, pp. 333–66; Jacob Hamblin and Linda Richards, 'Beyond the *Lucky Dragon*: Japanese scientists and fallout discourse in the 1950s', *Historia Scientiarum*, 25, 1, 2015, pp. 36–56.

[69]Soraya Boudia, 'Global regulation: controlling and accepting radioactivity risks', *History and Technology*, 23, 2007, pp. 389–406.

[70]National Academy of Sciences, Washington, DC, USA (henceforth NAS), International Geophysical Year 10.6, folder: 'Nuclear radiation: Utrecht agenda & background material 1956–1957', 'Nuclear radiation programme', September 1956. See Jacob Hamblin, *Poison in the well: radioactive waste in the oceans at the dawn of the nuclear age*, New Brunswick, NJ: Rutgers University Press, 2008, pp. 99–142.

[71]James Rodger Fleming, *Inventing atmospheric science: Bjerknes, Rossby, Wexler, and the foundations of modern meteorology*, Cambridge, MA: MIT Press, 2016, pp. 172–9.

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melting or freezing 'may change the level of the oceans and the position of the axis of the earth's rotation'.[72]

Already in the nineteenth century, European scientists, who knew that atmospheric gases trap heat at different rates, had begun suggesting that fossil fuel combustion could change worldwide climatic conditions. A British researcher, Guy Stewart Callendar, gave this theory a modest boost in the 1930s. Callendar argued in a paper entitled 'The artificial production of carbon dioxide and its influence on temperature' that fossil fuel combustion correlated with a global warming trend.[73] Although he could not directly measure the percentage of atmospheric carbon dioxide released from anthropogenic versus other sources, the development of radiocarbon dating – an offshoot of nuclear science – in the late 1940s offered a means of checking his theory. Because the radioisotope carbon-14 decays over time, natural carbon dioxide in the atmosphere could be distinguished from that produced by much older fossil fuel sources excavated from underground. In 1952, meteorologists in Scandinavia began studying the balance of artificial carbon dioxide in the atmosphere above Denmark, Finland, Norway, and Sweden.[74] These Scandinavian scientists, through contacts with the US Weather Bureau and the Scripps Institution of Oceanography in California, helped introduce carbon dioxide measurements into the global IGY programme by 1956.[75]

Associations of anthropogenic geophysical phenomena with artificiality tended to cast them as positive. Sputnik and other Soviet spacecraft generated enormous fear in the West, but anxieties fixated on the USSR's military capabilities, not space flight as such. A well-advertised US satellite programme preceded Sputnik's launch, and Eisenhower intensified post-Sputnik space initiatives by establishing NASA in 1958. Nuclear testing, too, inspired criticism. Japanese fallout studies prompted demands for the 'immediate discontinuation of experiment, production and use of mass-massacring weapons including the atomic'.[76] In India, which likewise lay in multiple fallout paths, Prime Minister Jawaharlal Nehru convened a committee to study the health effects of bomb testing, and Indian scientists instituted a countrywide monitoring net.[77] Yet leading geophysical researchers celebrated the capacity of radioactive tracers to augment meteorological or oceanographic knowledge. Roger Revelle, director of the Scripps Institution, encouraged fellow IGY participants to eschew the pejorative phrase 'nuclear "fall out"' in favour of 'artificial radiation'.[78]

Brazen techno-optimism similarly coloured Revelle's treatment of anthropogenic global warming. Speaking to one congressional subcommittee, he described large-scale fossil fuel combustion

[72]A. Khrgian, 'Some problems in processing IGY materials', *Soviet-Bloc IGY Translations*, 6 January 1959, pp. 22–3. For context, see Jonathan Oldfield, 'Imagining climates past, present, and future: Soviet contributions to the science of anthropogenic climate change, 1953–1991', *Journal of Historical Geography*, 60, 2018, pp. 41–51.

[73]Guy Callendar, 'The artificial production of carbon dioxide and its influence on temperature', *Quarterly Journal of the Royal Meteorological Society*, 64, 275, 1938, pp. 223–37. See also Spencer Weart, *The discovery of global warming*, Cambridge, MA: Harvard University Press, 2008, pp. 1–18; James Fleming, *The Callendar effect: the life and work of Guy Stewart Callendar (1898–1964)*, Boston, MA: American Meteorological Society, 2007, pp. 65–87.

[74]Maria Bohn, 'Concentrating on CO_2: the Scandinavian Arctic measurements', *Osiris*, 26, 1, 2011, pp. 165–79; Ronald Doel et al., 'Strategic Arctic science: national interests in building natural knowledge: interwar era through the Cold War', *Journal of Historical Geography*, 44, 2014, pp. 60–80.

[75]'The fourth meeting of the CSAGI (Barcelona, 10–15 September 1956)', in *Annals of the International Geophysical Year*, pp. 328, 350.

[76]Dwight D. Eisenhower Presidential Library, Abilene, Kansas, USA (henceforth DDEPL), Dwight D. Eisenhower, White House Office, National Security Council Staff: Papers, 1948–61, OCB Central File Series, box 11, folder: OCB 000.91 (1), 'Statement of the Meteorological Society of Japan concerning hydrogen bomb', 20 May 1954.

[77]Nehru Memorial Museum and Library, New Delhi, India, 190 (LLXX) D. S. Kothari, folder 9, Jawaharlal Nehru, 'Prime Minister's secretariat', 21 March 1955; K. G. Vohra, V. V. Shirvaikar, and C. Rangarajan, 'Radioactive fallout measurements made in India during 1956–57', *Indian Journal of Meteorology and Geophysics*, 9, 1958, pp. 332–40.

[78]Scripps Institution of Oceanography Archives, La Jolla, California, USA (henceforth SIO), SIO Subject Files 1890–1982, box 75, folder 19, Georges Laclavère to Participants of the Göteborg meeting of the Working Group on Oceanography 15–17 January 1957.

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as 'perhaps the greatest geophysical experiment in history'.[79] The *Washington Post* extrapolated from Revell's remarks, hypothesizing that, by 2010, Arctic melting might render the Soviet Union a 'great maritime nation', while *Time* wondered if 'salt water [would] flow in the streets of New York and London'.[80] Yet IGY administrators allayed such concerns. George Dufek, a rear admiral who oversaw logistics for US Antarctic research, predicted that satellites would soon facilitate instantaneous global communication; nuclear power would provide limitless energy, pacifying international tensions; and weather modification would enable humans to thrive in polar, desert, and other extreme environments.[81]

Artificial geophysics, despite such visions of peace and prosperity, never strayed far from Cold War military applications. Eisenhower, in perhaps the most telling example, approved a top-secret project in March 1958 to explode atomic weapons in space. Known as Operation Argus, this test series sought to create shells of electrons around Earth. Scientists theorized that, if a warhead detonated in near space, the planet's geomagnetic field would, in a matter of hours, diffuse fissile material around the globe in an encircling radioactive layer. Extremely powerful bursts would produce a shell hot enough to incinerate any ballistic missile flying through it; lower yields could disable satellites or ground-level communication infrastructure.[82] In August and September 1958, the US Navy launched three low-yield missiles from a ship in the south Atlantic Ocean. Monitoring equipment circled overhead in an IGY satellite. Data collected by this spacecraft, as well as by special military observers and normal IGY stations, confirmed the 'Argus effect'. Analysts assessed that warheads and anti-missile defences would have to be redesigned.[83]

United States IGY administrators collaborated with Argus, but they also feared backlash from the Soviet Union for withholding data.[84] At scientists' urging, military authorities declassified Argus in 1959. This was the only clandestine United States nuclear test since the Second World War, holding major implications for military policy. Yet officials portrayed it as a triumph of peaceful civilian science.[85] The US National Academy of Sciences held a symposium at its Washington, DC, headquarters on the 'scientific effects of artificially introduced radiations at high altitudes' and released results through a standard IGY report series.[86] If Operation Argus epitomized the war-fighting potential of artificial geophysics, its reinvention as a symbol of human cooperation highlighted the IGY's capacity to internationalize environmental science.

Global cooperation and the IGY benchmark

The creation of worldwide monitoring networks for the IGY globalized discussions of anthropogenic influence on Earth's physical environment well beyond the 1950s. To generate comprehensive data for the fourteen IGY disciplines, planners linked thousands of extant research stations, while identifying gaps to be filled through the construction of new posts. Projects in every field involved multiple processes for transnational collaboration, including conferences for standardizing recording and reporting methods, technology transfers across state borders, and personnel

[79]Roger Revelle, 'Testimony before the House Committee on Appropriations, February 8, 1956', in Joshua Howe, ed., *Making climate change history: documents from global warming's past*, Seattle, WA: University of Washington Press, 2017, pp. 62–3.

[80]Lloyd Norman, 'Flumes seen warming Arctic seas', *Washington Post*, 19 March 1956; 'One big greenhouse', *Time*, 28 May 1956.

[81]George Dufek, *Through the frozen frontier: the exploration of Antarctica*, Leicester: Brockhampton Press, 1960, pp. 171–86.

[82]Nuclear Testing Archive, Las Vegas, Nevada, USA (henceforth NTA), 0059492, 'The Argus experiment', 29 July 1958.

[83]NTA, 0304398, James Killian Jr, 'Memorandum for the President', 3 November 1958.

[84]DDEPL, Dwight D. Eisenhower, Records as President (White House Central Files), Confidential File, box 44, folder: 'National Aeronautics and Space Administration (4)', Robert Piland to James Killian Jr, 12 November 1958.

[85]Lisa Mundey, 'The civilianization of a nuclear weapon effects test: the ARGUS operation', *Historical Studies in the Natural Sciences*, 42, 4, 2012, pp. 283–321.

[86]*IGY satellite report series*, no. 9, Washington, DC: National Academy of Sciences, 1959.

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exchanges designed to ensure the smooth functioning of new techniques and machines. Observatories, expedition teams, and ship crews sometimes featured multinational staff. Others functioned entirely through local volunteer labour. Research into artificial geophysics, like more long-standing studies of naturally occurring processes, required participation by individuals across multiple continents and oceans. Studies of space satellites, nuclear fallout, and anthropogenic carbon dioxide unfolded along the evolving contours of Cold War scientific internationalism. Despite the recent addition of these topics to the IGY agenda, research communities around the world quickly integrated them into local infrastructures and epistemologies.[87] Administrators planned to warehouse data about natural and artificial phenomena alike for future use, reflecting their coequal status as constituent elements of the environmental benchmark to be furnished by the IGY for 1957 and 1958. World data centres in Australia, Japan, the Soviet Union, the United States, and various countries in western Europe collected records.[88] These repositories ensured the longevity and accessibility of IGY data, which numerous scientists eventually put toward conservationist ends.

As the IGY's first, highly conspicuous foray into artificial geophysics, the United States' satellite initiative elicited the most elaborate new global observation network. Gleaning scientific results about near space and the upper atmosphere necessitated erecting a worldwide system of ground-based tracking stations. Since US spacecraft were projected to orbit over a latitudinal band stretching from 33 degrees north of the equator to 33 degrees south, administrators invited the construction of tracking facilities among countries within this range. The Naval Research Laboratory headed a radio tracking programme, while the Smithsonian Astrophysical Observatory led efforts to view IGY satellites optically. Military officials established a line of ten radio posts from the US to Chile, plus outlying sites in Australia and South Africa. The visual programme totalled twelve high-precision stations on five continents. A network of radio amateurs was called 'Operation Moonbeam', while amateur astronomers were 'Moonwatch'.[89]

Foreign partners mobilized through a combination of idealism and material incentives. The Navy and the Smithsonian each offered equipment, financial aid, and technical staff. Argentina's Córdoba Observatory, for instance, accepted a telescopic camera useful for a myriad of astronomical tasks.[90] South Africa approved one radio station in the hopes of setting a precedent for future missile cooperation.[91] Britain and Australia, more than other countries, envisioned short-term defence gains. These Commonwealth partners jointly ran a Long Range Weapons Project in South Australia. Authorities planned to install tracking equipment and then, outside IGY parameters, use this technology to improve missile accuracy.[92] Meanwhile, dozens of volunteer teams formed across the globe. One Japanese scientist reported: 'there are so many amateurs proposing to participate [in] the work, that it is felt rather difficult to us to quantify them'.[93]

The founding of a space programme in the Soviet Union further expanded satellite tracking. Sputnik was expected to range 65 degrees north and south of the equator, given the high latitude of its launch site in Kazakhstan. Observation posts for USSR spacecraft would therefore need to

[87]Paul Edwards, *A vast machine: computer models, climate data, and the politics of global warming*, Cambridge, MA: MIT Press, 2010, pp. 8–12.

[88]Elena Aronova, 'Geophysical datascapes of the Cold War: politics and practices of the World Data Centers in the 1950s and 1960s', *Osiris*, 32, 2017, pp. 307–27.

[89]Patrick McCray, *Keep watching the skies! The story of Operation Moonwatch and the dawn of the Space Age*, Princeton, NJ: Princeton University Press, 2008, pp. 58–164.

[90]Archivo del Ministerio de Relaciones Exteriores y Culto, Buenos Aires, Argentina, fond 79, box 11, folder: 1956 27, Enrique Gaviola to Francisco Bello, 5 September 1956.

[91]NARSSA, SAB HEN_3315_505/3/2_2 vol. 1, Minister van Finansies, 'Radiowaarnemings van die Aard-Satelliete (Radio observations of the Earth satellites)', *c.* October 1957.

[92]National Archives of Australia, Canberra, Australia (henceforth NAAC), A2031 264/1956, Defence Committee, 'International Geophysical Year', December 1956.

[93]Smithsonian Institution Archives, Washington, DC, USA, SAO Satellite Tracking, box 23, folder: 'Japan – administration', Masasi Miyadi to Fred Whipple, 7 February 1957.

cover a larger geographical swath than for US satellites. Soviet administrators kept many details secret, yet remarkable coordination occurred across the Iron Curtain. In June 1957, the director of the Soviet Academy's programme for visual observations of space vehicles, Alla Masevich, exchanged 'Moonwatch' telescopes with her US counterpart, Fred Whipple.[94] Three months later, experts from twelve countries gathered in Washington, DC, for a conference to discuss spacecraft instrumentation and tracking methods. This body was still meeting on 4 October, when Sputnik's appearance initiated a scramble to track the first artificial moon.

Observations from stations outside the Communist Bloc confirmed orbital predictions released by Masevich and her colleagues in Moscow. Their data came primarily from the Soviet Union's more than one hundred radio and visual tracking teams, as well as from independent amateurs. Academy officials also requested that submissions from foreign stations be sent directly to their computer centre. US administrators encouraged their international partners to cooperate.[95] The Moscow facility was soon processing forty or more satellite observations per day, one-third of which came from abroad.[96] Simultaneously, numerous additional tracking teams formed in regions that the US had no immediate capabilities to overfly, but which Sputnik regularly traversed, including Canada, Czechoslovakia, East Germany, Italy, Poland, Spain, Turkey, and West Germany. By the end of 1958, more than 400 tracking stations across the world had produced observations of the total of nine spacecraft launched for the IGY by the Soviet Union and the United States.

Paralleling the globalization of satellite science, IGY efforts to study artificial radiation helped civilianize fallout monitoring on a worldwide scale. Already in the late 1940s, the United States and Britain had built a sprawling station network across Europe, the Pacific, and North America. While Western scientists successfully registered fallout from the first Soviet atomic bomb test in 1949, their counterparts in the USSR maintained their own posts. Analysis of debris from US thermonuclear tests aided the rapid development of Soviet hydrogen bombs.[97] IGY administrators faced the challenge of integrating fallout measurement stations from countries with opposed military interests. Australia, for example, required prodding to declassify radiation data due to ongoing British nuclear tests in the Outback. Authorities agreed in principle, but nonetheless withheld measurements for dates corresponding to tests conducted in September and October 1957.[98] The Soviet Union eagerly accepted fallout data from abroad, but chose not to release its own measurements through IGY channels.[99]

The participation of countries like Japan and India, leaders of a global anti-nuclear protest movement, raised inverse issues. US scientists aimed to dispel accusations from such states that they had misrepresented the health hazards of radiation. These researchers considered the IGY 'an excellent lever to use to get an international radioactivity measuring system established – a chance we may not get again'.[100] In addition to studying the atmosphere and oceans by tracking the circulation of radioisotopes produced by bomb tests, they hoped to maintain control of global measurement standards by providing assistance toward the erection of foreign stations and offering to

[94]Alla Masevich, *Zvezdy i sputniki v moyey zhizni (Stars and satellites in my life)*, Moscow: Institute of Astronomy, 2007, pp. 48–9.

[95]NAS, International Geophysical Year Records Group, series 10.1, folder: 'CSAGI participating countries India 1956–1959', Hugh Odishaw to A. P. Mitra, 26 March 1958.

[96]A. G. Masevich and A. M Lozinskii, 'Optical tracking methods for the first artificial satellites', *Publications of the Astronomical Society of the Pacific*, 70, 412, 1958, pp. 81–2.

[97]Néstor Herran, '"Unscare" and conceal: the United Nations Scientific Committee on the Effects of Atomic Radiation and the origin of international radiation monitoring', in Simone Turchetti and Peder Roberts, eds., *The surveillance imperative: geosciences during the Cold War and beyond*, New York: Palgrave, 2014, pp. 71–2.

[98]FAAAS, box 1, folder 2/2, J. P. Baxter to Hugh Webster, 3 May 1957; 'Global fallout in Australia during the period 26 November 1956 to 31 December 1957', *Australian Journal of Science*, 21, 1, 1958, pp. 8–9.

[99]Aronova, 'Geophysical datascapes', p. 315.

[100]NAS, International Geophysical Year 10.6, folder: 'Nuclear radiation: Utrecht agenda & background material 1956–1957', 'Ad hoc meeting Radioactivity Panel', 14 December 1956.

process other countries' samples at US laboratories.[101] Plans to utilize fallout for geophysical science benefited from the ongoing work of the UN's Scientific Committee on atomic radiation, which furnished IGY organizers with its list of experts, then operating in twenty-one countries.[102] World data centres for artificial radiation ultimately received submissions from more than 400 monitoring stations in forty-three countries.[103]

Fallout research, like spacecraft technology, yielded insights about Earth's geophysical properties, while also entwining notions of a global environment with Cold War anxieties. Years afterward, the US fallout expert Lester Machta remarked that the IGY had transformed radiation science into a '*bona fide* geophysical discipline'. He acknowledged that 'the monitoring needs for atomic tests stimulated much of the IGY nuclear radiation program', reflecting his professed commitment to non-political transnational science, while also underscoring the reality that virtually all research in this field depended on the schedule and content of weapons tests.[104] Prior to the onset of a brief testing moratorium in November 1958, a profusion of British, Soviet, and US bomb detonations largely muddled geophysicists' attempts to track radioactive debris from specific blasts. Only one unique tracer, tungsten-185, was known to have been produced. This radioisotope rendered the United States' 1958 Pacific tests particularly valuable to Machta and his co-workers.[105]

Yet this series further enmeshed IGY research in anti-nuclear politics. A test on 12 July exposed two Japanese oceanographic vessels to fallout. These ships requested emergency permission to dock in Papua New Guinea, where the crews received treatment from Australian medical authorities. Although US and Australian officials downplayed the incident, the All-Japan Seamen's Union sent a protest letter to Eisenhower, and the hydrographic chief of Japan's Maritime Safety Agency vowed that his country would not conduct further Pacific surveys until the United States suspended nuclear testing. He considered the recent expedition 'completely spoilt', declaring a 'great loss to the scientific world'.[106] As much as US researchers wished to certify anthropogenic modifications to Earth's environment as unproblematic, the global character of geophysical cooperation raised persistent accusations of contamination.

Inquiry into anthropogenic greenhouse gases during the IGY, in contrast to satellite tracking and fallout monitoring, occurred almost entirely outside the Soviet Bloc. The only communist contribution involved a USSR oceanographic cruise, during which an accompanying Swede took carbon dioxide samples.[107] Nevertheless, Cold War tensions helped propel global warming research, especially in the Arctic, and IGY results were soon discussed in Moscow.[108] Findings reflected a programme reaching most oceans and every continent but Africa. The Scandinavian meteorologists responsible for the first CO_2 measurement network, eager for comparative data from the southern hemisphere, helped to establish a station in Australia.[109] Simultaneously, scientists in the United States began measuring CO_2 released by 'artificial fuel

101 United Nations Archives, New York, S-0262-0017-10, 'Letter received from the representative of the United States to the United Nations offering technical assistance in the measurement of radioactive fallout', 13 June 1956.

102 NAS, International Geophysical Year 10.6, folder: 'Nuclear radiation: Utrecht agenda & background material 1956–1957', Eizo Tajima to Lester Machta, 18 December 1956.

103 *Summary of the observation results for airborne radioactivity in the world during IGY-IGC*, Tokyo: Science Council of Japan, 1962, p. 5.

104 Lester Machta, 'The nuclear radiation program of the International Geophysical Year', in *Annals of the International Geophysical Year*, vol. 32, Oxford: Pergamon Press, 1964, p. 130.

105 Herbert Feely and Jerome Spar, 'Tungsten-185 from nuclear bomb tests as a tracer for stratospheric meteorology', *Nature*, 188, 4756, 1960, pp. 1062–4.

106 NAAC, A452 1958/1685, H. D. Anderson, 'Japanese I.G.Y. survey vessels', 7 August 1958.

107 Georg Neumann, 'The Fourth Annual Conference in Atmospheric Chemistry, May 20–22, 1957', *Tellus*, 10, 1, 1958, p. 166.

108 SIO, Norris Watson Rakestraw Papers, box 1, folder 18, Charles Keeling, 'Preliminary results of the atmospheric carbon dioxide abundances program prepared for presentation at the IGY meetings in Moscow USSR', 3 July 1958.

109 NAAS, C3830 C34/1 Part 3, Carl Rossby to E. G. Bowen, 3 October 1956.

combustion' in seawater and at various altitudes within the atmosphere.[110] The Scripps Institution of Oceanography and the US Weather Bureau coordinated dozens of land-based stations across the continental US, as well as in Antarctica, the Arctic, Bermuda, Bolivia, Chile, Colombia, the Dutch and French West Indies, Guam, and Mexico. Technicians bottled local air in glass flasks, and shipped them to Scripps for analysis. Weather Bureau employees often performed this labour onsite, taking advantage of the United States' semi-imperial meteorological infrastructure.[111]

Foreign IGY committees sometimes oversaw the work themselves, as in the case of Mexico.[112] Japan ran the largest programme outside Europe and the Americas.[113] The atmospheric chemist Charles Keeling also developed expensive but highly accurate machines capable of continuous CO_2 analysis, deployed in Antarctica, California, Hawaii, and on oceanographic expeditions. For accessing high-altitude samples, the US Air Force bottled flasks during routine meteorological flights.[114] Finally, oceanographic institutions including the University of Washington, Woods Hole in Massachusetts, Texas A&M, and the Lamont Geological Observatory of Columbia University studied CO_2 concentrations in air and seawater throughout the Atlantic and Pacific.

Global IGY carbon dioxide research laid a basis for correlating artificial emissions of greenhouse gases with anthropogenic climate change. Comparisons between oceanographic and meteorological data suggested that human-produced CO_2 remained in the atmosphere for a significant length of time, rather than quickly being absorbed by seawater. The broad geographic distribution of ground stations demonstrated that atmospheric carbon dioxide was diffused relatively evenly across the planet, indicating that precise analysis of CO_2 concentrations at a single well-chosen location could yield insights about global trends. While CO_2 monitoring was greatly reduced after the IGY, Charles Keeling and his colleagues at Scripps maintained a continuous carbon dioxide analyser at the Mauna Loa Observatory in Hawaii. Data from this site, produced from 1958 to today, shows a steady upward progression of the concentration of atmospheric CO_2. The graph of this 'Keeling curve' has become one of the most iconic images connecting human activity to rising global temperatures.[115]

Meanwhile, glaciologists helped correlate past climatic changes, such as the Ice Ages, with changing global CO_2 levels. In the summer of 1954, researchers from Woods Hole and Dartmouth College had examined 'fossil air' trapped in icebergs off the Labrador coast.[116] Subsequent work on the Norwegian island of Spitzbergen – conducted in cooperation with the University of Oslo – yielded ice dated at 15 to 600 years of age.[117] An expanded 1958 team included participants from Britain, Denmark, and the Netherlands. This group spent three months in Greenland mining air from ice walls and bergs.[118] Tens of thousands of dollars for their Greenland expedition came from the United States military, concurrently attempting to

[110]Roger Revelle and Hans Suess, 'Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO2 during the past decades', *Tellus*, 9, 1, 1957, p. 18.

[111]Clark Miller, 'Scientific internationalism in American foreign policy: the case of meteorology, 1947–1958', in Clark Miller and Paul Edwards, eds., *Changing the atmosphere: expert knowledge and environmental governance*, Cambridge, MA: MIT Press, 2001, pp. 167–218.

[112]SIO, Charles David Keeling Papers (2003–18), box 8, folder 8, Charles Keeling to Paul Humphrey, 5 July 1957.

[113]SIO, Norris Watson Rakestraw Papers, box 1, folder 15, 'Atmospheric carbon dioxide content at various localities including Antarctic Ocean', 1959.

[114]SIO, James Arnold Papers, box 37, folder 7, 'Carbon dioxide abundances and radio-chemistry analysis program, January–March 1957'.

[115]Joshua Howe, *Behind the curve: science and the politics of global warming*, Seattle, WA: University of Washington Press, 2014, pp. 16–43.

[116]P. F. Scholander, John Kanwisher, and D. C. Nutt, 'Gases in icebergs', *Science*, 123, 3186, 1956, pp. 104–5.

[117]L. K. Coachman, E. Hemmingsen, and P. F. Scholander, 'Gas enclosures in a temperate glacier', *Tellus*, 8, 4, 1956, pp. 415–23.

[118]SIO, Per Fredrik Scholander Papers, box 6, David Nutt, Per Scholander, Lawrence Coachman, and Willi Dansgaard, 'Arctic Institute Greenland expedition 1958 field report', 1 September 1958.

build secret installations under the ice cap.[119] By using fossil air, scientists accessed new environmental benchmarks from the deep past.[120]

Conservationists worldwide began touting IGY insights about the efficacy of humanity on a planetary scale during the 1960s, even as the term 'artificial' faded from earth science discourse as a synonym for 'anthropogenic'. With the deepening of the space race, satellites became sufficiently commonplace that scientists ceased to distinguish human-made objects from the naturally occurring Moon. But if spacecraft less frequently held connotations as geophysical phenomena in their own right, they became essential tools for global environmental monitoring.[121] Artificial radiation, meanwhile, lost much political salience with the 1963 Partial Nuclear Test Ban Treaty, in which Britain, the Soviet Union, and the United States agreed not to detonate atomic weapons aboveground. As most testing became subterranean, the atmosphere no longer distributed regular anthropogenic additions to Earth's natural radiation background, nor could geophysicists consistently track atomic tracers from bomb tests through air and water.[122] Yet the scientific and popular legacies of fallout persisted in anxieties about nuclear war, civilian reactor failures, and waste dumping, and as a metaphor among budding environmentalists. In her 1962 book *Silent spring*, the biologist Rachel Carson notably invoked atomic radiation to explain the dangers of chemical pollutants.[123]

Finally, anthropogenic climate change grew fitfully as a perceived danger to global environmental equilibrium. Conservationists, in turn, narrated fossil fuel combustion in the pejorative language of 'pollution', rather than as a positively connoted form of artificiality. The economist Barbara Ward and the microbiologist René Dubos, in their popular 1972 book *Only one Earth*, written to accompany a UN conference on the human environment, described global warming as a threat to human survival 'serious enough to arouse real concern'.[124] Artificiality's decline as a term of art among geophysicists occurred just as IGY studies of anthropogenic influence found new approbation among environmentalists worldwide.

Conclusion

The IGY, by creating an environmental benchmark for earth scientists, simultaneously helped initiate a transformation in human attitudes toward the planet. Globalizing scientific inquiry into anthropogenic geophysical phenomena, the IGY represented a pivot point between Western security interests in the natural world after the Second World War and later conservationist notions about an interconnected yet fragile Earth. Historians of environmentalism have acknowledged the influence of the IGY for subsequent global conservationist agreements and ecological initiatives,

[119]SIO, Per Fredrik Scholander Papers, box 6, D. C. Nutt to IGY DC Program Officer, 22 April 1958; Janet Martin-Nielsen, 'Security and the nation: glaciology in early Cold War Greenland', in Ronald Doel, Kristine Harper, and Matthias Heymann, eds., *Exploring Greenland: Cold War science and technology on ice*, New York: Palgrave Macmillan, 2016, pp. 99–118.

[120]Alessandro Antonello and Mark Carey, 'Ice cores and the temporalities of the global environment', *Environmental Humanities*, 9, 2, 2017, pp. 181–203.

[121]Erik Conway, *Atmospheric science at NASA: a history*, Baltimore, MD: Johns Hopkins University Press, 2008, pp. 39–93; Angelina Callahan, 'Satellite meteorology in the Cold War era: scientific coalitions and international leadership 1946–1964', PhD thesis, Georgia Institute of Technology, 2013, pp. 187–252.

[122]Vojtech Mastny, 'The 1963 Nuclear Test Ban Treaty: a missed opportunity for détente?' *Journal of Cold War Studies*, 10, 1, 2008, pp. 3–25; Kai-Henrik Barth, 'The politics of seismology: nuclear testing, arms control, and the transformation of a discipline', *Social Studies of Science*, 33, 5, 2003, pp. 743–81.

[123]Ralph Lutts, 'Chemical fallout: Rachel Carson's Silent Spring, radioactive fallout, and the environmental movement', *Environmental Review*, 9, 3, 1985, pp. 210–25; Hamblin, *Poison in the well*, pp. 219–51; Joseph Masco, 'Bad weather: on planetary crisis', *Social Studies of Science*, 40, 1, 2010, pp. 7–40; Weart, *Nuclear fear*, pp. 273–390.

[124]Barbara Ward and René Dubos, *Only one Earth: the care and maintenance of a small planet*, New York: Penguin, 1972, p. 267. See Stephen Macekura, *Of limits and growth: the rise of global sustainable development in the twentieth century*, Cambridge: Cambridge University Press, 2015, pp. 91–136.

such as the legal regulation of outer space and a decade-long International Biological Program that began in 1964.

Yet the IGY's impact on environmental thinking extended beyond its capacity to provide 'a template for organizing large-scale international collaborative research'.[125] Logics, data, and infrastructures developed by geophysicists directly shaped other disciplinary contexts. The global networks of research stations, scholarly connections, methods of standardization, and data repositories generated by the IGY constituted resources for scientists for decades afterwards to compare environmental developments to the benchmark established for 1957 and 1958 by Lloyd Berkner and his colleagues around the world. The emergence of earth system science, in particular, facilitated the integration of ideas of a living biosphere with mainstays of geophysical research, including the planet's lithosphere, hydrosphere, cryosphere, atmosphere, ionosphere, and magnetosphere. Methods of studying these regions as pioneered during the IGY, notably including satellite reconnaissance, have remained central to environmental science.[126] Since 2000, when the atmospheric chemist Paul Crutzen popularized the term 'Anthropocene', IGY-era notions of greenhouse gases and nuclear fallout as artificial phenomena have re-emerged in debates about the onset of this new epoch.[127]

Alignment between state interests and big science during the early Cold War enabled the IGY's contributions to the development of environmental thought. The dynamics of worldwide cooperation, initiated by scientists linked with Western security establishments to elicit data from colleagues across the planet, helped to transition connotations of geophysical research from military might and economic hegemony to associations with peaceful universalism. If the security implications of earth science largely remained hidden from public view, however, they wielded significant influence behind closed doors. Joseph Kaplan, chairman of the United States IGY committee, lifted the veil of depoliticized geophysics when he remarked to one military development board that modern weapon systems required 'comprehensive knowledge of the physical environment in which they have to operate'.[128] Armed forces on each side of the Iron Curtain harnessed IGY data to improve missile targeting, submarine navigation, and other technologies. Operation Argus, in which 'the environment of the earth was briefly modified on a global scale by artificial means', inspired larger space weapons tests by the United States and the Soviet Union, and both superpowers integrated high-altitude explosions into their Cold War arsenals.[129] Conservationists could certainly invoke geophysical research to challenge military ambitions, as during the 1980s, when climate science and fallout studies re-converged during discussions about the possibility of a devastating worldwide 'nuclear winter', in which debris triggered by thermonuclear war would

[125]Warde et al., *The environment*, p. 135.

[126]Elena Aronova, Karen Baker, and Naomi Oreskes, 'Big science and big data in biology: from the International Geophysical Year through the International Biological Program to the Long-Term Ecological Research Program, 1957–present', *Historical Studies in the Natural Sciences*, 40, 2, 2010, pp. 183–224; Tiffany Vance and Ronald Doel, 'Graphical methods and Cold War scientific practice: the Stommel diagram's intriguing journey from the physical to the biological environmental sciences', *Historical Studies in the Natural Sciences*, 40, 1, 2010, pp. 1–47; Naomi Oreskes, 'Changing the mission: from the Cold War to climate change', in Naomi Oreskes and John Krige, eds., *Science and technology in the global Cold War*, Cambridge, MA: MIT Press, 2014, pp. 141–87; Roger Launius, '"We will learn more about the Earth by leaving it than by remaining on it": NASA and the forming of an earth science discipline in the 1960s', in Thomas Heinze and Richard Münch, eds., *Innovation in Science and organizational renewal: historical and sociological perspectives*, New York: Palgrave, 2016, pp. 211–42.

[127]Simon Lewis and Mark Maslin, 'Defining the Anthropocene', *Nature*, 519, 7542, 2015, pp. 171–80; Jan Zalasiewicz et al., 'Colonization of the Americas, "Little Ice Age" climate, and bomb-produced carbon: their role in defining the Anthropocene', *Anthropocene Review*, 2, 2, 2015, pp. 117–27.

[128]NAS, International Geophysical Year Records Group, series 16.1, folder: 'US Air Force Scientific Advisory Board Geophysics Research Panel 1955–1959', Joseph Kaplan to James Doolittle, 16 July 1956.

[129]NTA, 0311447, 'Argus', *c.* early 1959.

obscure sunlight and lower global temperatures, potentially extinguishing life.[130] Catastrophic scenarios raised opposition to Cold War posturing, but they also revealed the political baselines of the era as defined by geostrategic competition, not a shared ethos of ecological stewardship.

The global environment as an idea might usefully be contextualized alongside historical structures that explain how its connotations developed. Recovering the constitutive power of Cold War security measures in stimulating global research on Earth processes can illuminate why conservationist movements that reformulated insights and data generated in this period have been so unsuccessful at slowing the Great Acceleration. Environmentalists have gained only modest traction outside state power, and, when operating within it, their efforts to resist humanity's reordering of the natural world have frequently been subordinated to interventionist goals.[131]

In *The human condition*, Hannah Arendt predicted a confluence between scientific artificiality and a global politics driven more by machines than by mind. Fearing that 'knowledge (in the modern sense of know-how) and thought have parted company for good', Arendt warned against a world in which the inertia of industrial and military progress would propel humanity's march into the future. Fully embracing the promises of technological life, she believed, entailed a surrender of political decision-making to the mechanization of scientific achievement. For her, modernity's greatest danger was not humanity's capacity to utterly transform or destroy the planet, but its practical inability to choose a different path. Abandoning the earthly conditions that lent them agency, humans would become 'thoughtless creatures at the mercy of every gadget which is technically possible, no matter how murderous it is'.[132] Arendt's analysis suggests a reality in which environmentalist thought could arise from, yet pose little challenge to, regimes of expansion and control. In this sense, assertions of discontinuity between military-inflected earth science and ideas of a depoliticized planetary environment appear themselves, at their core, artificial.

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[130]Matthias Dörries, 'The politics of atmospheric sciences: "nuclear winter" and global climate change', *Osiris*, 26, 1, 2011, pp. 198–223; Lawrence Badash, *A nuclear winter's tale: science and politics in the 1980s*, Cambridge, MA: MIT Press, 2009, pp. 49–62.

[131]Naomi Oreskes, *Merchants of doubt: how a handful of scientists obscured the truth on issues from tobacco smoke to global warming*, New York: Bloomsbury Publishing, 2010, pp. 169–215; Hamblin, *Arming Mother Nature*, pp. 217–51.

[132]Arendt, *Human condition*, p. 3.

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