# Chapter 10

# What Was Whole about the Whole Earth? Cold War and Scientific Revolution

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In 1948 the astronomer Fred Hoyle speculated what the Earth would look like from space, and predicted: "once a photograph of the Earth, taken from outside, is available, we shall, in an emotional sense, acquire an additional dimension . . . once let the sheer isolation of the Earth become plain to every man whatever his nationality or creed, and a new idea as powerful as any in history will be let loose."[1] In 1970 he found himself in a position to reflect upon his prophecy.

> Well, now we have such a photograph, and I've been wondering how this old prediction stands up. Has any new idea in fact been let loose? It certainly has. You will have noticed how quite suddenly everybody has become seriously concerned to protect the natural environment. Where has this idea come from? You could say from biologists, conservationists and ecologists. But they have been saying the same things now as they have been saying for many years. Previously they never got on base. Something new has happened to create a world-wide awareness of our planet as a unique and precious place. It seems to me more than a coincidence that this awareness should have happened at exactly the moment man took his first step into space.[2]

Hoyle placed first the whole Earth photographs firmly in a technological rather than an environmental context. The space program, despite its orientation defined by the surveillance imperative, allowed ordinary citizens to share an objective view of the Earth as an object in the solar system previously attained only by scientific thinkers: the revolution was technological, not ecological. The *Apollo* Earth photographs have often been seen as a technological windfall for an environmental movement that was unprepared for it but rapidly recognized its significance.[3] In Thomas Kuhn's model, a scientific revolution is a "change of world view," which follows a period of intellectual struggle within an existing model that no longer fits the observations. Here, it seems, the new world view arrived first and the rethink followed.[4]

[figure 10.1 approx here]

Hoyle's judgment that the whole Earth pictures had a powerful impact has been widely shared. The *Apollo* "Blue Marble" Earth has been called both "the most influential scientific photograph ever taken" and "the most influential environmental photograph ever taken" (see Figure 10.1).[5] Donald Worster writes that the image of Earth from space came as "a stunning revelation" that nourished the young discipline of ecology.[6] Betty Jean Craige, biographer of the ecologist Eugene Odum, finds that the surge of interest in ecology at the end of the 1960s was stimulated by the first distant views of the Earth from space: "From the perspective of the Moon, human beings were indistinguishable components of the indivisible biosphere. The sight of the blue planet spinning in space alerted its inhabitants to its vulnerability and reminded us of our dependence on its stability . . . Americans turned to ecology." J. R. McNeill and Corinna Unger have argued that satellite photography of the Earth "fostered a rediscovery of organic thinking and the emergence of deep ecology,"[7] and Erik Conway states that the *Apollo* Earth photos "became the root of a global environmental consciousness."[8] Several articles and even whole books have been written attempting to analyze and explain this phenomenon.[9] The *Apollo* years of 1968–72 coincided with rise of the modern environmental movement and also with the run-up to the UN Conference on the Human Environment in Stockholm, the first “Earth Summit,” providing a context in which the two were likely to be linked.

At the same time it has to be recognized that the first whole Earth photographs did not, as it were, drop out of a clear blue sky. There had been a period when number of thinkers had been dissatisfied with the divided understanding of the Earth’s dynamic processes produced by the separate scientific disciplines. As Worster writes:

> The view of the Earth as organism was an old one, going back into prehistoric cultures, but it was reborn in the modern age, and ironically the image of an ailing but ancient organic planet came from the highly polished lens of a mechanical camera carried aloft in a mechanical spaceship.[10]

In the nineteenth and twentieth centuries, individual investigators with unusual powers of vision had conceptualized the Earth as an integrated whole. “The field of the Geologist’s inquiry is the Globe itself,” declared the British geologist William Buckland (1784–1856).[11] Reading Alexander von Humboldt’s encyclopedic work of natural history *Cosmos* (1845–58), Laura Dassow Wild comments: “In mind’s eye, Humboldt saw Earth as Sagan’s generation learned to see it: a blue globe above, alone, an astonishment in the black abyss of space.” Humboldt’s original title had been Gaia.[12] In the late nineteenth century the Swiss biologist Eduard Suess, in coining the term “biosphere,” imagined gazing from space at “the face of the Earth.” Alexander Vernadsky, popularizing the term in the 1920s, also imagined studying the Earth from space as “a harmonious integration of parts that must be studied as an indivisible mechanism.”[13] The work of Suess and Vernadsky helped bring into being a compound field of science known for a time as “biogeochemistry,” which resurfaced in the work of James Lovelock in the 1960s and 1970s. Lovelock formulated the Gaia hypothesis, that the Earth as a whole behaved as a self-regulating entity, after conceptualizing the Earth from the outside, and felt that the *Apollo* pictures when they arrived confirmed and deepened his view.[14] While they might rhetorically have resembled long-standing organic philosophies, all of these interpretations of the dynamic workings of the planet were based on interdisciplinary investigations that challenged the distinction between the life and the non–life sciences.

In the postwar decades, there appeared for the first time planetary-scale research to match these planetary-scale hypotheses, thanks to the military research programs of the Cold War. The Pentagon had declared in 1961: “[the] environment in which the Army, Navy, Air Force, and Marine Corps will operate covers the entire globe and extends from the depths of the ocean to the far reaches of interplanetary space.”[15] These programs supported not only surveillance-driven space exploration programs but also a huge growth in what have since become known as the Earth sciences. The environmental sciences and even environmentalism were the beneficiaries of these programs long before the apparent windfall of the whole Earth photographs, which were the product of the Cold War space race. As Michael Aaron Dennis puts it: “going about the task of understanding how to destroy the enemy, the Earth sciences produced a new picture of the Earth and its complexities.”[16] Joseph Masco, enlarging on the work of Paul Edwards, writes that: “the Cold War nuclear project enabled a new vision of the planet as an integrated biosphere [. . .] a new vision of the globe as an integrated political, technological and environmental space.”[17] This begins to sound like a change of world view, which anticipated the images of the Earth from space. So, were the first whole Earth images just incidental pictures, afterward conscripted into the service of various versions of globalism and environmentalism? Or were they themselves products of scientific globalism, historically connected with the themes and discoveries that they were held to represent? Was there anything in the Cold War Earth sciences that corresponded to the holistic claims made about the Earth in the aftermath of those first photographs from space? In short, we have to ask: What was whole about the whole Earth?

This chapter attempts a kind of high-altitude survey of planetary concepts and models in the Cold War Earth sciences, broadly defined, in four sections. Any account of the global Earth sciences has to begin with the International Geophysical Year (IGY) of 1957–8. This is followed by an overview of what seems (at least to this nonspecialist) to amount to an Earth sciences revolution, singling out geodesy, plate tectonics, and atmospheric science. Thirdly, attention shifts to the related fields of cybernetics, systems theory, and ecology. Here, it is argued, there occurred the key development in scientific whole Earth thinking: the convergence of biological and nonbiological models. This leads into a fourth section on James Lovelock's Gaia hypothesis, which related to and anticipated both orthodox planetary science and the first pictures of the Earth from space. Like a space-age version of Newton's windfall apple, the image of the whole Earth fell ripe from orbit in full view of a scientific public ready to receive it.

## The International Geophysical Year

Geophysics has been described as "the area of science in which the whole Earth is the laboratory and nature conducts the experiments," and the IGY was presented as "the world studying itself."[18] Experiments were conducted on a global scale to explore the electromagnetic radiation in the atmosphere, the solar storms through which the planet occasionally passed, the cosmic rays reaching the surface, the temperature, pressure, and chemical composition of the atmosphere, the global circulation of both atmospheric and ocean currents, the dynamics of the "energy balance" as the Earth simultaneously absorbed and radiated solar heat, the topography and seismology of the sea bed, and the extent and nature of the polar ice caps. The now-global phenomenon of nuclear fallout was studied from a planet-wide network of monitoring stations. Through its sheer scale, the IGY fostered an understanding of the Earth as a set of integrated systems.[19] As yet there was no camera stationed beyond the atmosphere but several "world days" of simultaneous observation offered what amounted to "a snapshot of the Earth."[20]

It would be a mistake to project back onto the IGY a whole Earth concept which was developed later. It took place at a period when understanding of the Earth was most commonly associated with surveillance, exploitation, and control, and when the despoliation of the global environment was decisively accelerating, a phenomenon that has been diagnosed as "1950s syndrome." There were proposals to use atomic explosions to dig a new Panama Canal, melt the arctic icecap, and destroy the newly discovered van Allen belts.[21] When a stratospheric nuclear test did seriously disrupt the Earth's electromagnetic field, the *New York Times* science correspondent welcomed it as "an intellectual triumph . . . an experiment that enveloped almost the entire planet."[22] The IGY project had a contentious Cold War history, which belied its idealistic aspirations. Even its global icon, which incorporated zones of both day and night, seemed to mirror the divided world in which it took place.[23]

Yet, as so often during the Cold War, divisive forces generated unifying visions which acquired a life of their own. President Eisenhower's promotion of the IGY as "a striking example of the opportunities which exist for cooperative action among the peoples of the world" may have been a maneuver in the Cold War but it drew upon a widespread ideal that science could provide "the common language of mankind." One of the IGY's most important consequences was the 1961 Antarctic Treaty, which (albeit for geopolitical reasons) suspended national claims to sovereignty and declared the continent an international reservation for science.[24] The Antarctic

Treaty in its turn became a model for the 1963 nuclear test ban treaty, which has been described as "the first global environmental treaty," and for the 1967 Outer Space Treaty, which declared outer space to be "the province of all mankind."[25] Although clandestine Cold War ambitions often lay behind such treaties, their adoption of legislation extending to the whole Earth entailed an enhanced understanding of human stewardship of the natural world. The systems for global scientific monitoring which were established were of great long-term significance. The $CO_2$ measuring station in Hawaii and the polar research bases set up during the IGY were eventually to provide conclusive evidence for climate change on a planetary scale. The IGY gave a decisive push to the convergence of the Earth sciences, which yielded important insights into the interdependence of the Earth's natural systems.

One thing that the IGY lacked was an actual image of the Earth. The US National Academy of Sciences issued a lavishly produced booklet entitled *Planet Earth: the Mystery with 10,000 Questions* complete with six specially commissioned color posters representing the different scientific fields, each incorporating an image of the Earth. Before the space age, however, all of these images were necessarily schematic.[26] The most naturalistic of the posters incorporated a painting of what appeared to be the whole Earth commissioned by the chief US meteorologist Harry Wexler. On closer inspection, it showed weather systems over North America converted into a globe through a fish eye lens effect, but its depiction of land, water, and clouds, without any of the traditional geographical grids and boundaries, was innovative. Wexler had been inspired by the earlier V-2 pictures of the curving planet, and perhaps too by the experimental color photographs of North America taken in 1954 by the *Aerobee* sounding rocket. His own concern was with the details rather than the whole: "by a bird's-eye view of a good portion of the Earth's surface and the cloud structure," he wrote, "it should be possible by inference to identify, locate, and track storm areas and other meteorological features."[27] When *Life* magazine published an issue titled "A New Portrait of our Planet," on the IGY's findings, its cover featured an image of a cloudless geographic globe.[28] It is an interesting counterfactual exercise to consider what the impact of the IGY's survey of the Earth would have been had the *Apollo* whole Earth pictures been available a decade earlier.

The coming of the space age provided the technology to continue the IGY's program Earth sciences at a new level, but at the same time it shifted attention from the exploration of the Earth to the exploration of space. The launch of *Sputnik* in October 1957, although presented as part of the Soviet IGY effort, created an association between space and national security that dominated the 15 years of the first space age (1957–72) and hampered the kind of cooperation upon which the IGY had been built. Cold War priorities affected not only space technology but less obviously contentious areas such as oceanography, where genuinely international activity was replaced by (at best) intergovernmental cooperation with a secondary brief of "easing tensions."[29] NASA itself had been founded during the IGY as a civilian agency (albeit one sustained by extensive "black" programs funded by the Department of Defense), with a brief that included study of the Earth, but the order in 1961 to race the Soviet Union to the Moon ensured that the US space program faced away from the Earth for most of the 1960s and 1970s.

The IGY model of a synoptic project to study the Earth was taken up by biologists and ecologists in the International Biological Program (1964–74). The diversity of the biological sciences however made a single focus impossible to achieve, and when a theme was settled upon – 'the biological basis of human productivity and welfare' – it provided a focus only for disagreement. Oceanography and the emerging field of ecosystems ecology had unifying ambitions but these foundered on resistance from more traditional biologists who regarded big science as a ‘contagion’ and a ‘disease.’ Half-way through the program, however, a group of ecologists set up a Global Network of Environmental Monitoring, which was adopted by the International Council of Scientific Unions SCOPE Commission, and thence by the 1972 UN Conference on the Human Environment—the first Earth summit.[30] Notwithstanding the reservations of many biologists, it was to be the coming together of the physical and natural sciences that would generate a new understanding of the Earth as whole as the climactic years of the space age coincided with the environmental renaissance of the late 1960s and early 1970s.

Thus it was that during a formative period for the Earth sciences NASA suffered from institutional Earth blindness, only occasionally disturbed by second thoughts. This helps to account for the space agency’s notable lack of preparation for the first views of Earth from space, and the sense of incongruity and surprise that accompanied their arrival. But while NASA turned its corporate back on the Earth, advances in the Earth sciences in several fields were constructing models of the planet which meant that, ironically, other parts of the scientific community were better prepared than the space agency for the sight of the whole Earth.

## The Earth Sciences Revolution

During the 1950s and 1960s the physical Earth sciences were expanding their observations and models to a global scale, putting together large-scale observations and measurements to develop an understanding of the Earth’s systems on a planetary level on the back of military programs. This section will survey three such fields: geodesy, plate tectonics, and meteorology and climate.

In the 1960s one lesser-known discipline provided an unseen image of the Earth: geodesy, the exact measurement of the shape of the planet, or geoid. This was, according to its historian John Cloud, a planetary enterprise that provided “one of the most important intellectual achievements of the Cold War.”[31]

Geodesy had become a pressing practical problem with the advent of long-range ballistic missile. The hoard of maps seized from Germany at then end of the war had revealed discrepancies of hundreds of meters between national maps prepared from different reference points—enough to make a decisive difference in the targeting of long-range missiles, as the V-2 program had discovered to its cost. The problem was that the Earth's shape was neither a globe nor even regular, as assumed by cartographers, owing to the combination of the flattened shape caused by the planet's rotation and the irregular distribution of land masses. The exact shape was difficult to measure since conventional methods relied upon gravity, whose force varied with the radius of the Earth. The relationship between gravity and radius, however, was not constant, varying in its turn according to the mass and density of the Earth at the point of measurement. Ingenious attempts to measure the shape of the Earth independently of gravity by taking highly accurate photographs of the stars in relation to the Moon and the Earth had not quite come off.[32] The coming of the satellite made it possible to measure the geoid independently of gravity.

The image of the geoid remained invisible partly because it was constructed from a variety of nonvisual data and partly because it was obtained through the US Department of Defense's satellite surveillance programs, which remained a military secret until after the end of the Cold War. Between 1960 and 1972 the CORONA satellite network took high-altitude photographs of the Earth, parachuting the cameras back to Earth in reentry capsules which were caught in mid-air by cargo planes equipped with nets. The pictures were reconciled with German and Soviet geodetic charts and correlated against other satellite observations from the Department of Defense's World Geodetic System. One Department of Defense satellite, named DODGE, produced the first color picture of the whole Earth as early as August 1967, a low-resolution television image taken through colored glass filters. Although it prompted one of the first ever color printings of a major newspaper and made its way into *National Geographic,* the DODGE Earth photo made little impact compared with the more naturalistic Earth images that were soon to follow.[33] The accurate reconstruction of the geoid was significant for the whole Earth in another way for, writes Cloud, it involved "a great re-convergence of the now disparate disciplines of astronomy, geodesy, geography, geology, cartography, photogrammetry, and geophysics." The processes behind this clandestine development of an invisible image of the Earth thus paralleled the convergence of the Earth sciences happening elsewhere.[34] Geodetic measurements were also important for the manned space program. As Cloud puts it, nicely reversing the more familiar Earthrise story, "reaching the Moon required first discerning the Earth."[35]

For geologists the Earth came to life in the 1960s as a synthesis of work in geology, seismology, oceanography, vulcanology, and studies of the Earth's magnetic field came together in the discipline of plate tectonics. Ever since Lyell, the orthodoxy had been that geological processes were extremely gradual. The continents were essentially static, modified incrementally over eons by slow processes such as upheaval, sedimentation, and erosion, with limited local assistance from earthquakes and volcanoes. Lyell's views in turn conditioned Darwin's model of evolution as a steady accumulation of small variations, although it is worth noting that Darwin, having experienced earthquakes, found himself "impressed with the never-ceasing mutability of the crust of this our world."[36] In the late nineteenth century the Swiss geologist Eduard Suess, impressed by the evidence for rapid geological upheavals, had challenged but not dented the static Earth orthodoxy. The early twentieth-century German meteorologist Alfred Wegener had put forward a theory of continental drift, but in the absence of a plausible mechanism or even a coherent set of measurements his ideas were widely rejected.[37]

After World War II the US Navy became the major patron of oceanography, transporting scientists around the world's oceans to develop new technologies of measurement. Deep-sea topography mapped the boundaries of the continental shelves, which revealed a much better fit between continents than the visible coastlines. Investigations of the ocean floor revealed a "world-girdling" system of ocean ridges and rifts ripe for further exploration during the IGY.[38] Surveys of thermoclines, prompted by the need to understand how they altered sonar signals, yielded evidence of high heat flow in geologically significant patterns: at the mid-ocean ridges new rock was emerging as magma.[39] Meanwhile the World-Wide Seismography project, designed to detect underground nuclear tests and to distinguish them from earthquakes, provided a kind of x-ray of the Earth. It revealed that earthquakes were clustered along the boundaries where continental plates slowly moved under or past each other.[40] The final piece in the jigsaw was provided by studies of the magnetism of the ocean floor, arising from the military need for accurate magnetic navigation. This revealed barcode-style patterns of magnetic stripes imprinted on the emerging magma as it solidified, evidence of successive reversals of the Earth's magnetic poles. This calibrated the spreading sea floor over time and enabled mobile plate boundaries to be matched and mapped. Through a series of international conferences and high-profile discoveries in the years 1962–66 there emerged a unified account of plate tectonics, amounting, in the words of one participant, to a "revolution in Earth science."[41] In a related development, the US Navy's investigations into deep-sea listening posts led to the discovery of deep ocean vents and of new forms of life based on chemosynthesis rather than photosynthesis; undersea geology was connecting with the life sciences.[42]

The dynamic view of the Earth's geology was associated with visual thinking. Eduard Suess in his 1885 book *The Face of the Earth* had imagined the Earth as it appeared to a visitor from space, "pushing aside the belts of red-brown clouds which obscure our atmosphere, to gaze for a whole day on the surface of the Earth as it rotates beneath him".[43] Richard Fortey comments that with seismic mapping of the ocean floor "it was possible to look at the whole Earth for the first time". In October 1967, just as the first color satellite photographs of the whole Earth were appearing, *National Geographic* began publishing a series of color maps of the ocean floors, crafted to show rifts and mountain ranges, continental shelves, and mid-ocean ridges. Widely used in schools and colleges, such maps conveyed a sense of the planet as a single geological entity.[44] When in the early 1970s the cell biologist Lewis Thomas put into words his response to the first whole Earth photos, he had plate tectonics very much in mind: "If you had been looking for a very long, geologic time, you could have seen the continents themselves in motion, drifting apart on their crustal plates, held aloft by the fire beneath. It has the organized, self-contained look of a live creature, full of information, marvelously skilled in handling the sun".[45]

Even more than studies of continental plates and oceans, study of the atmosphere involved global model-building. In the late 1940s the head of the US Weather Bureau Harry Wexler had given a contract to the Lowell Observatory to try and understand the general circulation of the atmospheres of Mars and Venus, but astronomers were not able to see well enough.[46] The IGY of 1957-8, wrote Walter Sullivan, had brought an awareness that the planet was surrounded by a single "ocean of air . . . one great, mobile reservoir covering two-thirds of the globe and carrying, within its deep, slow currents, the seeds of latent climate change that might destroy existing civilizations and make possible new ones." The comment now appears prophetic, but at the time studies of the atmosphere were driven primarily by meteorology and the desire for better weather forecasting. As Sebastian Grevsmühl shows in this volume (chapter 8), it took some time for meteorologists—even the globally minded Harry Wexler—to see satellites as more than just a better method of observing existing weather systems, although the satellite perspective of the Earth's atmosphere from the outside did lead to new classifications and insights. Big-picture thinking about the dynamics of the planetary climate as a whole, over time scales much longer than those of ordinary weather forecasting, emerged more gradually.

From the beginning, the World Meteorological Organization, conceived by the UN in 1947 and founded in 1951, aimed to study the Earth as a single physical system.[47] Advances in computing led to the first general circulation models of the atmosphere in the mid-1950s, supplemented by visual monitoring from the TIROS satellite series from 1960 onward and the first satellite TV weather pictures from NIMBUS in 1964. At first it was hoped that the sight of weather systems from orbit would lead to much longer-range forecasts, but the see-and-predict model produced disappointing results. Television pictures proved intractable and were soon abandoned, and even when a global network of seven satellites was set up in the 1970s they could not improve upon the existing five-day forecast horizon. This in turn prompted the development of the mathematics of complex systems, which gave rise to chaos theory. The key insight here was that while small changes in one part of the atmosphere could give rise to large changes in another part, this did not happen in any consistent way: what could be modeled in principle could not be predicted in practice. As Edwards explains: "conceiving weather and climate as global phenomena helped promote an understanding of the world as a single physical system." This, however, was a complex process mediated by layer upon layer of data processing and modeling procedures; there was no sudden rise in awareness.[48] While the work of meteorologists involved some of the first truly global datasets, they were using global tools for local purposes; even when instrumental in securing photographs of the whole Earth from space they were unable to see the Earth for the clouds.[49]

For all the impulse that meteorology gave to global atmospheric modeling, fully integrated study of the global atmosphere was stimulated by environmental concerns. An early instance of this was provided by the international network of monitoring stations to measure the levels of radioactive carbon in the atmosphere from nuclear bomb tests. This made possible the 1963 Partial Test Ban Treaty, which Edwards describes as "not only [. . .] the first global environmental treaty, but also [. . .] the first to recognize atmosphere as a circulating global commons that could be directly affected on the planetary scale by human activities."[50] The next major push came with the four-year program of preparations for the 1972 United Nations Conference on the Human Environment in Stockholm: the first Earth summit. While the *Apollo* photographs of 1968–72 are the most famous, distant images of the whole Earth began to appear in the late summer of 1966 while stunning orbital photographs taken from outside the capsule by spacewalking Gemini astronauts had begun to appear in mid-1965. These helped build public support for the creation in 1966 of the Earth Resources Observation Satellite program (EROS), which eventually developed into the Landsat program.[51]

Concerns raised in both the UN and the WMO about the effect of $CO_2$ and chlorofluourocarbon (CFC) emissions on the climate created a need for global data sets in order to filter out long-term "signals" of climate change from short-term "noise" of natural variation. In 1970, at the instigation of the UN, Massachusetts Institute of Technology (MIT) produced its *Study of Critical Environmental Problems,* with follow-up reports in 1971 and 1972. The long-delayed Global Atmospheric Research Program was developed during the 1970s, with NASA at last adopting the program; the last Nimbus weather satellite (1978–84) was modified to detect atmospheric pollution, yielding data for the first maps of the global biosphere. In 1980 NASA put together 20 months of data on the distribution of marine phytoplankton in the oceans collected by the Nimbus-7 satellite's Coastal Zone Color Scanner with three years of observations of land surface vegetation from the National Oceanographic and Atmospheric Agency (NOAA-7) satellite to produce what it called "the first composite image of the global biosphere."

These programs culminated in 1979 with a massive global atmospheric observation project reminiscent of the IGY. The WMO held its first global climate conference in the same year, launching the World Climate Program of the 1980s, which in turn led to the establishment in 1988 of the Intergovernmental Panel on Climate Change and the vast programs of scientific and political activity which followed.[52] In the end, as Edwards puts it: "meteorology was only one part of a larger project in constructing a global panopticon."[53] Thus, idealized models of the Earth first developed for meteorology soon became bound up with the emergence of concerns about the planetary environment as a whole. These concerns were inspired in part by the first views of the Earth from space, and they fostered an interdisciplinary understanding of the planetary climate.

## Ecology and Ecosystems

An image of Earthrise from the Moon formed the frontispiece the 1971 edition of Eugene P. Odum's foundational textbook *Fundamentals of Ecology*. It was described in the caption as a photograph of Earth at "the biosphere level." Odum, described by Joel Hagen as "the philosophical leader of modern ecosystem ecology," liked to compare the Earth to a space capsule, in that the inhabitants of both were part of a closed ecosystem, mutually dependent upon each other and upon their environment in order to survive. The parallel had occurred to him when the *Apollo 13* accident, which left three astronauts struggling for survival as they gazed down upon their own receding planet, occurred around the time of the first Earth Day in 1970.

As the astronauts urgently tried to understand what had gone wrong with the space capsule in order to save it, Odum mused that the situation was not so different on Spaceship Earth: "Our global life-support system that provides air, water, food and power is being stressed by pollution, poor management, and population pressure." He kept a poster of the *Apollo 8* Earthrise on his study wall.[54] For Odum in 1971 ecology entailed both the study of the interacting forces at work within and between species in nature and a philosophical commitment to the principles of group selection and "coevolution" (or "reciprocal selection"). As Odum emphasized in his preface, "the holistic approach and ecosystems theory [. . .] are now matters of world-wide concern," applicable to human survival and environmental stability as well as to understanding of the natural world.[55]

There are so many overlapping ideas here, jostling for position around the still-fresh image of the whole Earth, that it is difficult to know where to begin unraveling them. They are perhaps most familiar from ecological and countercultural activism but for that reason the links with science are perhaps less clearly appreciated, at least outside the specialist literature. This section will look at two areas where interaction between living and nonliving systems formed part of orthodox science from the 1940s: systems theory and ecology. When pictures of the Earth from space arrived in the late 1960s much of the talk was about the Earth as a set of systems, of which humankind was (visibly) a part. The picture was novel but the mode of thinking was well-established in two related fields that had both been established in the mid-1940s: cybernetics (or systems theory) and ecosystems ecology. Both, in different ways, arose out of military problems in the war and early Cold War.

The founding text of systems theory was Norbert Wiener's *Cybernetics, or Control and Communication in the Animal and the Machine* (1948). As its title suggests, Wiener ranged across the disciplines, developing his principles through work on problems as apparently diverse as antiaircraft fire, the physiology of the heart, and computing, to arrive at a general science of control. Wiener's key concept was "feedback," the means by which a movement in one variable triggers compensating movements in other variables and even in other linked systems. Applicable to systems of any kind, mechanical, biological, or social, Wiener's work generated insights in just about every area of scientific and intellectual endeavor. The dust jacket advertised the book as "a study of vital importance to psychologists, physiologists, electrical engineers, radio engineers, sociologists, philosophers, mathematicians, anthropologists, psychiatrists and physicists," and so it proved to be.[56] *Cybernetics* was the most prominent product of a series of 10 conferences on the subject held in New York between 1946 and 1951, which attracted many leading thinkers in the natural and social sciences eager to be involved with what was proclaimed as "one of the major transitions or upheavals in the history of ideas." They ranged from associates of the RAND Corporation seeking in systems theory a "complete science of warfare," such as John von Neumann, who was in the process of developing game theory into the mathematics of Armageddon, to the anthropologist Gregory Bateson, who was seeking to put together a social science equivalent of the Manhattan project in order to discern the deeper causes of conflict and so avert atomic warfare.[57] The processing and transmission of signals, which was the concern of cybernetics, was also fundamental in the development of Cold War surveillance networks.

The science of systems was first scaled up to global level through the development of world modeling (or world dynamics) in the late 1960s and early 1970s. Buckminster Fuller's "World Game," originally proposed as an exhibit for Expo '67, was played across university campuses in the United States, Canada, and Britain in the summer of 1969 and was the subject of a supplement to the *Whole Earth Catalog* in 1970. Fuller, originator of the term "spaceship Earth" and author of *Operating Manual for Spaceship Earth*, envisaged that "The young may take over and operate 'Spaceship Earth.'"[58] The 1972 Club of Rome report *Limits to Growth*—conceived and researched during the Apollo years of 1968–72—brought world modeling to a mass audience, its central argument being that economic growth was already coming up against environmental limits. Jay Forrester of MIT, the founder of system dynamics, later recalled a conversation on a plane returning from an international economic conference in Switzerland conference. "We haven't tackled the rally hard problem," he said to a colleague. "What's that?" "The world." Forrester sketched a flow diagram of the forces operating in the planet with feedback loops, which gave the same results every time: excessive population growth, collapse of population and living standards, and slow recovery.[59] By later standards the techniques now appear crude and simplistic, modeling human activity with the environment appearing simply as a resource constraint. The significance of these exercises in world modeling was that they sought to demonstrate the interaction of science and technology with politics, society, economy, and the environment, and that they popularized an integrated mode of thinking about global developments. They were developed and publicized in parallel with the development of similar modes of thinking in the Earth sciences, and with the appearance of images of the Earth from space which showed, as no model could, that the Earth was indeed both whole and limited.

Systems theory was also a resource for ecologists, whose discipline had run into trouble. Ecology had grown up in the 1920s, 1930s, and 1940s, led by the Chicago school of animal ecology, which argued for the role of coexistence and cooperation in evolution. For ecologists, the natural world was only fully intelligible at the level of the group or (to use a term coined in 1935) the ecosystem. This vision of harmony in nature had a powerful appeal and an affinity with organic models of human society. Such "organicist" thinking, however, had become tainted by its ideological associations with Nazism and by its scientific associations with vitalism, the idea that natural processes were driven by intangible inner forces. Systems theory promised a new integral approach to understanding the world, based not on intangible forces but on the measurable interactions of a myriad individuals. It indicated a way forward for ecology that was compatible with the evolutionary "modern synthesis" established in the 1940s.[60]

Among the early enthusiasts for cybernetics was the ecologist G. Evelyn Hutchinson, whose 1946 paper "Circular Causal Systems in Ecology" argued that groups of organisms used feedback loops to maintain their state (for example in the way that populations tend over time to maintain a viable balance within their environments) and could be considered as self-regulating systems. He was an early practitioner of the integrated discipline of biogeochemistry and the champion in the west of the work of the Russian Vladimir Vernadsky and his 1926 book *The Biosphere*. Hutchinson was one of the first to suggest that the carbon balance in the atmosphere might be regulated biologically—a suggestion that would later find full expression in James Lovelock's Gaia hypothesis.[61] Among Hutchinson's pupils was Howard T. Odum, younger brother of Eugene, who made early use of cybernetics in a 1950 PhD which argued that 'energy flows' had kept the chemical balance of the oceans constant over millions of years.[62] Howard Odum developed a distinctively technocratic approach to ecology—he would later write of "ecological engineering"—which appealed beyond environmentalists to policy analysts and, in time, even economists.[63]

In the 1950s Eugene and Howard Odum established systems ecology as a distinct subdiscipline. Like its cousins in the postwar Earth sciences, systems ecology (initially known as "radiation ecology") piggybacked on military and atomic programs to generate insights at a global level. Eugene Odum gained grants from the Atomic Energy Commission to do ecological research at nuclear sites, first at the Savannah River atomic plant in Georgia and subsequently at the hydrogen bomb test site of Eniwetok atoll in the Pacific Ocean and at nuclear test sites in Nevada. With Howard Odum he traced concentrations of radiation through the food chain and the environment, founding an Institute of Radiation Ecology. At Eniwetok they were able to show that the coral reefs were stable because of the mutual relationship of coral and algae. At the 1955 Atoms for Peace conference Odum urged that atomic programs of all kinds should proceed cautiously until the total effects of radiation on ecosystems were known. The Odums also pioneered the study of energy flow in ecosystems, demonstrating that the ecosystem of the coral at Eniwetok was not only self-sustaining but actually generated energy.[64]

When the "year of ecology" was proclaimed by *Time* on August 15, 1969, and the "age of ecology" by *Newsweek* on January 26, 1970, Eugene Odum was featured on the covers of both along with his dictum that 'all nature is interconnected'. His 1953 textbook *Fundamentals of Ecology,* with its second edition in 1959 and its third on the way in 1971 (complete with Earthrise frontispiece), had taught generations of ecologists and environmentalists to see the natural world as an interconnected web of systems and prepared them to interpret the visual revelation of the whole Earth in similar terms.[65] The fundamental compatibility of cybernetics and systems on the one hand and ecology and ecosystems on the other lay in the way that they treated living and nonliving phenomena in similar terms, fostering study of the links between them. Cybernetic concepts scaled up easily to planetary level, ready to inform scientific as well as public responses to the *Apollo* pictures. In the 1960s some philosophers of biology, inspired by Gregory Bateson, proposed that living organisms could be understood not as physical entities but as systems, whose enduring core feature was self-organization and which in turn acted as elements of higher order ecosystems.[66] Thus for the biologist and philosopher Rene Dubos, who in 1969 was among the first publicly to compare the Earth as seen from space to a living organism, "Earth and man are thus two complementary components of a system, which might be called cybernetic, since each shapes the other in a continuous act of creation."[67] Successive editions of the *Whole Earth Catalog*, published from 1968 to 1972, printed the *Apollo 8* Earthrise picture, the last of them with a quotation which reflected its editor, Stuart Brand's, interest in cybernetics: "The flow of energy through a system acts to organize that system."[68] When Lewis Thomas reflected upon the image of the Earth from space, he too used the language of systems:

> The most beautiful object I have ever seen in a photograph, in all my life, is the planet Earth seen from the distance of the moon, hanging there in space, obviously alive. Although it seems at first glance to be made up of innumerable separate species of living things, on closer examination every one of its working parts, including us, is interdependently connected to all the other working parts. It is, to put it one way, the only truly closed ecosystem any of us know about. To put it another way, it is an organism.[69]

All these observations came from biologists. The suggestion that the Earth's complex systems were analogous to a living thing was, however, most fully set out by James Lovelock, an engineer and physical scientist, and it is to this larger vision that we now turn.

## The Gaia Hypothesis

"Can there have been any more inspiring vision this century than that of the Earth from space?" exclaimed James Lovelock in his autobiography *Homage to Gaia*. Yet while the Apollo Earth images seemed to embody Lovelock's understanding of the Earth, he made clear that his own revelation of Earth as a living planet had already been formed through orthodox scientific endeavor. "Moments of intuition do not come from an empty mind; they require the gathering together of many apparently unconnected facts. The intuition that the Earth controls its surface and atmosphere to keep the environment always benign for life came to me one afternoon in September 1965 at the Jet Propulsion Laboratory (JPL) in California and it was here that most of the facts were gathered."[70] Lovelock's Gaia hypothesis, of an Earth where living and nonliving systems interact to regulate the global environment, offers an apt case study for Kuhn's model of scientific revolution as a change of world view.

Before Lovelock was given the term "Gaia" in 1970 by his friend and neighbor the novelist William Golding his working description of the Earth was "a cybernetic system with homeostatic tendencies." The whole Earth rhetoric in which the Gaia hypothesis was packaged for a wider public came later.[71] In late 1964 or early 1965, while working for NASA, Lovelock was asked to advise a team at JPL working on life detection experiments intended for a Mars lander.[72] After listening for hours to a gathering of biologists discussing ways to directly detect Earth-like life-forms in the Martian soil, Lovelock turned the problem round. Instead of looking for specific types of life, NASA should look for the generic signature effects of life in the Martian atmosphere through "a general experiment . . . that looked for entropy reduction." His remarks "seemed to annoy many of those present," who complained to management. Challenged to come up with an experiment in a matter of days to test his ideas he turned to Erwin Schroedinger's 1944 book *What is Life?* which discussed the subject from the point of view of a physical scientist, making use of the concept of entropy reduction. Lovelock reasoned that the atmosphere of a planet that harbored life would exhibit "effects which cannot be accounted for by abiological processes," such as a strong presence of oxygen or other combustible gases, a complex structure in a state of disequilibrium, or other anomalously orderly features – perhaps even regular sounds. In short, "knowledge of the composition of the Martian atmosphere may . . .

reveal the presence of life."[73] NASA was impressed enough to make him acting chief scientist for the life detection program in March 1965, but within six months, thanks in part to lobbying from indignant biologists, the Voyager Mars lander program was cancelled.

Lovelock developed his ideas further in another visit to JPL in September 1965. In the meantime, images from the *Mariner* spacecraft had shown that Mars was "all rock or desert." This time he was present when results of an infrared spectrographic analyses of the Martian and Venusian atmospheres from ground-based radio telescope came through, showing that both were overwhelmingly dominated by carbon dioxide (see Figure 10.2).

[figure 10.2 approximately here]

"I knew instantly that Mars was lifeless," recalled Lovelock. "It was an equilibrium atmosphere." He immediately switched viewpoints to ask himself how Earth's complex atmosphere could also remain stable.

> It came to me suddenly, just like a flash of enlightenment, that to persist and keep stable, something must be regulating the atmosphere and so keeping it at its constant composition. Moreover, if most of the gases came from living organisms, then life at the surface must be doing the regulation.

Afterwards Carl Sagan told him that the Sun was thought to have been some 30 percent less luminous early in the life of the Earth than it was now, yet Lovelock also knew that there had been no corresponding long-term rise in the temperature of the Earth.

> Suddenly the image of the Earth as a living organism able to regulate its temperature and chemistry at a comfortable steady state emerged in my mind.[74]

Around the same time, Sagan was working on an American edition of a 1962 book called *Universe, Life, Mind* by the Soviet astrophysicist Iosif S. Shklovskii. It came out in 1966 as *Intelligent Life in the Universe* by Sagan and Shklovskii and sold very well. Shklovskii, doubtless aware of Vernadsky's earlier work on the biosphere, had written: "Such a vast amount of oxygen as is present in the Earth's atmosphere can be explained only in terms of extensive biological activity." Sagan was doubtful, but his contribution on this point seems to bear the influence of his conversations with Lovelock: "I wonder whether an intelligent anaerobic organism, who finds oxygen a poison gas, would conclude very readily that an extensive oxygen atmosphere can only be the product of biological activity."[75]

Lovelock went on to attend the second "Origins of Life" conference at Princeton in May 1968, where the reception he received showed how far from the mainstream his ideas were at that stage. His attempts to suggest that the Earth's atmosphere had a partly biological origin met with blank incomprehension; natural scientists rejected him as a physicist, while physical scientists marked him down as a biologist.[76] Lyn Margulis, editor of the conference proceedings and his future coauthor, was also present and later wondered aloud to Lovelock why they had not met. "He said, because the first time I opened my mouth, Preston Cloud yelled at me and was so intimidating and rude that I didn't speak for the rest of the conference." Margulis's innovative work on cell biology provided Lovelock with the missing link, a biological mecahnism to account for the presence of methane in the Earth's atmosphere. Another space scientist interested in extraterrestrial life proved receptive: this time it was Alistair Cameron, editor of an early volume of essays on the subject and now chairman of the National Academy of Sciences Space Science Board. "He saw a couple of paragraphs that Lovelock and I had written about the effect of life as a planetary phenomenon," recalled Margulis. "He totally and immediately understood.

He told me he never understood anything biologists talked about at all. It doesn't make any sense to me at all; this is the first time I've seen sense."[77]

By 1972 US and Soviet probes had established that both Mars and Venus had simply structured atmospheres hostile to life, Mars at extremely low temperatures and pressures and Venus at extremely high ones. This highlighted the question of how Earth alone had remained hospitable to life over billions of years.[78] In a series of articles in 1972–4 Lovelock and Margulis discussed the explanation for the "anomalous nature" of the Earth's atmosphere and presented the Gaia hypothesis, "the concept that the Earth's atmosphere is actively maintained and regulated by life on the surface, that is by the biosphere." They explained: "We have written the paper to be comprehensible to a wide scientific audience, recognizing that an understanding of the Earth's atmosphere will come only from the cooperation of many scientists: planetary astronomers, geologists, meteorologists, chemists, physicists, and biologists."[79] The wider philosophical claims of the Gaia hypothesis proved controversial but, as Conway points out, it provided "a view of Earth that could be grasped by systems engineers."[80] Indeed, Margulis and Lovelock presented a speculative graph of oscillations of planetary temperature over the past 100,000 years and suggested that a "hypothetical planetary engineer would probably recognize this as a chart of the behavior of an unstable control system in which instability had developed leading to oscillation yet control had not failed altogether."[81]

The Gaia hypothesis broke scientific ground in several ways. First, it fostered a convergence of the physical and biological sciences. Second, the Gaia hypothesis represented the ultimate application of system theory and cybernetics. Gaia was not at first the living planet but the homeostatic planet. At the formative period Lovelock was not aware of Vladimir Vernadsky's 1926 organicist work *The Biosphere,* with its claim that "life is a geological force."

The Russian practice of integrating the study of geology, chemistry and biology – 'biogeochemistry' – was rooted in the study of particular environments and lacked the capacity to travel which the language of systems would have allowed it. When Lovelock was eventually introduced to this work he commented that Vernadsky "did not seem to have a feeling for system science."[82] Gaia was particularly strongly attacked by evolutionists, led by Richard Dawkins, for the concept of a single collective organism managing its own evolution appeared to violate the basic principles of natural selection.[83] Among life scientists, felt Lovelock, only Eugene Odum "understood that an ecosystem is a deterministic feedback system," reflecting Lovelock's understanding that "Gaia is the ecosystem of the Earth." Thirdly, Lovelock's work married the perspectives of ecology with those of planetary science, allied to a shift of time scale from the historical to the astronomical. Gaia, in the words of Donald Worster, was "how things look to the cosmic eyeball"—that is, in time as well as space.[84] The serendipitous appearance of the first photographs of the Earth from space helped to propagate this mode of whole Earth thinking to a global public just as the environmentalist renaissance took off. But Lovelock (a visual thinker affected by dyslexia) had already achieved his insights imaginatively, without the aid of pictures from space.

By the 1980s, notwithstanding considerable scientific hostility to the full-blown Gaia hypothesis, the view that life played a role in forming the physical Earth had become orthodox.[85] As Erik Conway has shown, the scientists who worked with the planetary probes of the 1960s and 1970s—Mariner, Viking, Pioneer, and Voyager—which searched for evidence of dynamic change and life elsewhere in the solar system, became used to combining physical, chemical, geological, atmospheric, and biological investigations in pursuit of planetary questions, much as the freelance Lovelock had sought to do for the Earth. The budgetary crisis that afflicted planetary science in the late 1970s and early 1980s brought many of these NASA planetary scientists to the study of the Earth, at a time when the Earth sciences were acquiring global data sets as a consequence of their Cold War expansion. This in turn generated a wave of research and observation of the planetary dynamics of the Earth, and a swell of concern over environmental issues such as ozone depletion and climate change. Acceptance of a world view that integrated life and non–life sciences was fostered by the name chosen for the new field in 1986: distancing itself from organicist views (such as Vernadsky's "biogeochemistry") NASA opted for "Earth systems science."[86]

## Conclusion

In September 1970 *Scientific American* produced a special issue on "The Biosphere," later published as a book (see Figure 10.3). It opened with the observation that "photographs of the Earth show it has a blue-green color" and continued with an introductory essay by G. Evelyn Hutchinson, invoking Vernadsky as the father of the concept of the biosphere and rewriting the entire history of life on Earth in its light. Successive essays explained the various cycles operating at global level: the energy cycles of both planet and biosphere; the water, carbon, oxygen, nitrogen, and mineral cycles; and the human cycles of food, energy,

[figure 10.3 approx here]

<text run on…>and metal production, each identified as "a cycle in the biosphere." Similar flow diagrams in each chapter signified that all these cycles could be understood in systems terms. Hutchinson's essay featured the master diagram of the biosphere, showing physical, biological, and human cycles interacting. It demonstrated how far holistic thinking about the Earth had come in the year of the first Earth Day, even before the *Apollo 17* Blue Marble appeared.[87]

Ideas of the whole Earth preceded the pictures, but the pictures had a powerful impact because there already existed ideas and models of planetary processes which had been developed in several different fields, conceptualized through dynamic models of the Earth as seen from the outside. The early images of the home planet in turn accelerated and propagated a whole Earth style of thinking whose defining mark was the understanding of biological and physical mechanisms as interdependent. The Cold War expansion of the Earth sciences in association with the space program generated both the research data and the Earth images upon which the new understanding was founded. The combined insights of a dozen separate disciplines had shown that the Earth was whole after all. Both literally and metaphorically, it was a change of world view. Arguably, it was a scientific revolution.

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[2] From Hoyle's after-dinner speech at the *Apollo 11* lunar science conference, 6 January 1970, quoted in Donald D. Clayton, *The Dark Night Sky* (New York: Quadrangle, 1975).

[3] For discussions of this line of argument, see: Frank White, *The Overview Effect* (Reston, VA: 1998 [1987]); De Witt Douglas Kilgore, *Astrofuturism* (Philadelphia: University of Pennsylvania Press, 2003); Charles S. Cockell, *Space on Earth: Saving Our World by Seeking Others* (London: Macmillan, 2007); Fred W. Spier, *Big History and the Future of Humanity* (London: Wiley-Blackwell, 2010).

[4] Thomas S. Kuhn, *The Structure of Scientific Revolutions* (Chicago: Chicago University Press, 1996 [1962]), chap. 10.

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[11] Charles C. Gillespie and Nicolaas Rupke, *Genesis and Geology* (Cambridge, MA: Harvard University Press, 1951), 104.

[12] Laura Dassow Wild, *The Passage to Cosmos: Alexander von Humboldt and the Shaping of America* (Chicago: Chicago University Press, 2009), 217, 241.

[13] Vladimir I. Vernadsky, *The Biosphere* (New York: Copernicus, 1998 [1926]), 41, 43–5, and Lyn Margulis et. al., "Foreword," 14–19.

[14] Poole, *Earthrise,* Chapter 8.

[15] Ronald E. 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): 635–666, on 656–7.

[16] Michael Aaron Dennis, "Earthly Matters: on the Cold War and the Earth Sciences," *Social Studies of Science* 33:5 (Oct. 2003): 809–819, on 817.

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