Distinguishing Gaia from the Earth system(s)

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If we are going to try to land on Earth, it is useful to know what we are landing on – or in. This question may seem trivial, as the planet has been a recognizable entity since long before some of our species had the chance to photograph it from space. But it is really the Critical Zone at the surface that we are trying to land within – what is the nature of that? It seems distinct from the planet as a whole. In the last half-century, different scientists have introduced the concepts of "Gaia" and the "Earth system," which might describe it. Some have treated these concepts as synonymous. However, the Earth system has at least two distinct definitions, and Gaia is something entirely different.

Blurred boundaries

In systems thinking, it is usual to start by identifying your system of interest and defining its boundaries – what is within the system and what is outside it. The great bulk of the inner Earth functions independently of Life[1] in the Critical Zone at the surface, with causality flowing in only one direction – suggesting it is a separate entity. However, the boundary between the inner Earth and the Critical Zone is actually a blurred one that depends on the timescale of interest.

The inner Earth is a partly molten ball of rock still carrying some of the residual heat of the immense collisions that formed it over 4.5 billion years ago, together with the heat released by decaying radioactive elements. That inner heat source seems as alien to the Critical Zone as the Sun – because processes at the Earth's surface do not influence it. It offers some protection to the Critical Zone in that the circulation of the liquid iron outer core provides the magnetic field that shields the Earth's surface from the solar wind. Above the core, the slow convection of the mantle couples with the movement of the crust's tectonic plates – although geophysicists are still arguing about how. The resulting recycling of the crust and its sediments return biologically useful elements to the Critical Zone. Mantle plumes also provide some material to the surface and occasionally punch a large enough hole through the Earth's crust to wreak the havoc of mass extinction in the Critical Zone. However, the vast majority of material used by Life at the surface is recycled within the Critical Zone. It would thus appear sensible to distinguish the surface Earth system from the inner Earth.

NASA's Earth System

That said, the first scientific use of the term "Earth system" – derived from cogitations convened by the US National Aeronautics and Space Administration in the 1980s[2] – includes the inner planet (see fig. 1). At the time, NASA needed a bold and ambitious research program to prevent the massive cuts in funding promised by the Reagan administration, which argued that the US had already visited the solar system. Hence the space agency turned toward the Earth by developing an expensive program of new satellites. At the same time, global changes (climate change and the ozone hole) together with the relatively new theory of plate tectonics gave scientists a new vision of the Earth as more dynamic and interconnected than recognized beforehand. This led to the realization that the Earth system is a *real* object comprising "physical, chemical, biological and human components" and seen as "a related set of interacting processes operating on a wide range of spatial and temporal scales, rather than as a collection of individual components."[3] NASA's Earth system science program needed the support of both the community studying the surface Earth and that studying solid Earth geophysics: thus, it included all the timescales of Earth's history.

To delineate the boundaries of NASA's Earth system requires identifying all processes occurring on Earth and the way they interact. NASA proposed to structure its interdisciplinary research program according to the timescales of the processes studied rather than according to their material nature – biological, physical, or chemical – as traditionally done by disciplines. As a consequence, the inner boundary of NASA's Earth system extends downward into the inner Earth as the timescale of consideration increases. On the longest timescales, the whole inner Earth becomes part of NASA's Earth system, but on shorter timescales much of it can be excluded.

This may seem alarming for those of us seeking to land in the Critical Zone: are we landing on movable foundations? Well, yes – but the extent of our rocky foundations should not be our primary concern. Instead, we should be alarmed that, whether or not it includes the inner Earth, NASA's Earth system is an abiotic one. For NASA, there can be a Mars system just as there can be an Earth system (and a study of Mars' climatology, past tectonics, etc.), even if there is no life on Mars. NASA's Earth system offers only an abiotic notion of habitability – the presence of liquid water. This misses the most crucial thing about the Critical Zone – the extraordinary flourishing of Life, which depends on far more than just liquid water. If we try to land in NASA's Earth system, we will soon be dead.

IGBP's Earth System

A very different approach to defining the Earth system, which emerged in the 1990s, went to another extreme. The International Geosphere Biosphere Programme (IGBP) took as its imperative to study the global changes affecting human existence. The IGBP thus defined its Earth system and its boundaries by (I) identifying human conditions of existence, and (II) connecting these conditions of existence to all known materials and processes affecting it. This approach necessarily focused on short timescales compared to NASA's Earth system. For example, guided by the imperative to understand how global changes will affect human conditions of existence in the future, IGBP's study of the past is restricted to recent Earth history, because it can give us quantitative data useful for informing future projections. As a result, it tends to take for granted several human conditions of existence, such as an oxygen-rich atmosphere, which are actually the product of a long history of other life forms. It also means IGBP's Earth system is spatially restricted, spanning the atmosphere, ocean, cryosphere, and biosphere, but only scratching the surface of the lithosphere – by including the rocks at the very top of the crust that get weathered, and the sediments being deposited at the bottom of the ocean.

This very human-centric IGBP Earth system has been an influential concept and idea generator. IGBP championed the idea of "global change" and expanded it beyond a pure physics of climate to include biogeochemical cycles as well as human aspects.[4] The concepts of "the Anthropocene," "tipping elements" and "planetary boundaries"[5] (see fig. 2) all emerged from the IGBP stable. Nevertheless, if we try to land in IGBP's Earth system, we will soon be in trouble, because by focusing just on what is required for human life, we will be missing the central role of Life in shaping habitable conditions at Earth's surface.

Gaia

To appreciate that statement, we must look before both NASA's and IGBP's definitions of the Earth system to James Lovelock's concept of Gaia, developed with Lynn Margulis. Gaia named a newly discovered entity:[6] "the biosphere and all of those parts of the Earth with which it actively interacts" – where the "biosphere" meant "the total ensemble of living organisms."[7] Gaia was also the name given to a hypothesis: that living beings could collectively regulate the global environment, including the chemical composition of the atmosphere and oceans, and potentially also the climate. The idea of "regulation" (see fig. 3) often led Lovelock to compare Gaia with an organism, and sometimes with a thermostat, since both are regulators. However, Gaia is a distinct phenomenon, which cannot be equated with the Earth system, either.

The recognition of Gaia stemmed from two sources. Thinking about the detection of life on other planets, Lovelock came to recognize,[9] and then strongly emphasize,[10] that Life's imprint on the Earth is visible in the constitution of the atmosphere, maintained in extraordinary chemical disequilibrium by organisms' metabolisms producing oxygen and methane (and other reduced gases). At the same time, Lovelock's observational science, armed with his Electron Capture Detector, led him to cross the oceans and atmosphere where he found that chemicals produced by living beings, e.g. dimethyl sulfide (DMS),[11] and by human activities, e.g. chlorofluorocarbons (CFCs)[12] were ubiquitous. Both scientific journeys led to the realization that if living beings *produce* their environment, then their material boundaries no longer stop at their membranes and epidermis; rather, they expand as far as their influence on the "geological" environment can reach. Thus, what was beforehand thought of as "abiotic," such as the atmosphere, can now be seen as an extension of Life "like the fur of a mink or the shell of a snail."[13] This insight redefined our conceptions of Life and the environment.

To trace Gaia's boundaries requires (I) identifying all living beings (bacteria, horses, etc.) on Earth; (II) tracing carefully the chemical and material interactions and connections between those living beings and what is outside their membranes; (III) establishing which of those connections are relevant to habitability (or to Life's persistence); and (IV) recognizing Gaia as the entity isolated by the resulting network of connections.

The Distinction

Gaia is distinct from NASA's or IGBP's Earth systems because it places Life at its center. For NASA, there was an Earth system before there was Life on Earth, and there will be an Earth system after Life ceases (but before the Sun expands to a red giant and consumes the planet). The Earth system therefore represents a frame of reference for Gaia – albeit one with a somewhat movable inner boundary. Gaia is a phenomenon that has extended itself in space and time within that frame of reference: the Earth system. NASA deemed the frame habitable if it can maintain liquid water at the surface, and IGBP used the guideline of whether it can maintain human life. Gaia recognizes that Life affects its own diverse conditions of habitability – profoundly influencing some aspects of the Earth system that are crucial for Life's survival and flourishing – such as nutrient cycling – but having much less influence on other properties that Life does not need or that are already at habitable levels.

If we try to land in Gaia, we will find that we have everything we need and are “part of, or partner in, a very democratic entity,”[14] surrounded by all the other living beings actively creating their own conditions for survival and flourishing.[15]

References

[1] We use “Life” with a capital L not as a term of class, but as a *proper name* designating a singular entity; see Dutreuil, “Gaia Is Alive,” this volume, xxx–xxx.
[2] See NASA Advisory Council and Earth System Sciences Committee, *Earth System Science: Overview; A Report on Global Change* (Washington, DC: National Aeronautics and Space Administration, 1986).
[3] Ibid., 15.
[4] See Chunglin Kwa, “Interdisciplinarity and Postmodernity in the Environmental Sciences,” *History and Technology* 21, no. 4 (2005): 331–44; Chunglin Kwa, “Local Ecologies and Global Science Discourses and Strategies of the International Geosphere-Biosphere Programme,” *Social Studies of Science* 35, no. 6 (2005): 923–50; Ola Uhrqvist, “Seeing and Knowing the Earth as a System: An Effective History of Global Environmental Change Research as Scientific and Political Practice” (PhD thesis, Linköping University, 2014); Sébastien Dutreuil, “Gaïa: hypothèse, programme de recherche pour le système Terre, ou philosophie de la nature?” (PhD thesis, Université Paris 1 Panthéon-Sorbonne, 2016).
[5] The terms come, respectively, from Paul J. Crutzen and Eugene F. Stoermer, “The ‘Anthropocene,’” *IGBP Newsletter*, no. 41 (May 2000): 17f; Timothy M. Lenton et al., “Tipping Elements in the Earth’s Climate System,” *Proceedings of the National Academy of Sciences* 105, no. 6 (February 2008): 1786–93, doi: 10.1073/pnas.0705414105; and Johan Rockström et al., “A safe operating space for humanity,” *Nature* 461 (September 2009): 472–75.
[6] See James Lovelock, “Gaia as seen through the atmosphere,” *Atmospheric Environment* 6, no. 8 (August 1972): 579f.
[7] James Lovelock and Lynn Margulis, “Atmospheric homeostasis by and for the biosphere: The Gaia hypothesis,” *Tellus* 26, no. 1–2 (1974): 2–10, here: 3.
[8] See Lovelock and Margulis, “Atmospheric homeostasis by and for the biosphere”; James Lovelock and Lynn Margulis, “Homeostatic tendencies of the Earth’s atmosphere,” *Origins of Life* 5, no. 1–2 (January 1974): 93–103; Lynn Margulis and James Lovelock, “Biological Modulation of the Earth’s Atmosphere,” *Icarus* 21, no. 4 (April 1974): 471–89.

[9] See James Lovelock, "A physical basis for life detection experiments," *Nature* 207 (August 1965): 568–70.

[10] See Lovelock, "Gaia as seen through the atmosphere."

[11] See James Lovelock, R. J. Maggs, and R. A. Rasmussen, "Atmospheric Dimethyl Sulphide and the Natural Sulphur Cycle," *Nature* 237 (June 1972): 452f.

[12] See James Lovelock, R. J. Maggs, and R. J. Wade, "Halogenated Hydrocarbons in and over the Atlantic," *Nature* 241 (January 1973): 194–96.

[13] Lovelock, "Gaia as seen through the atmosphere," 580.

[14] James Lovelock, *Gaia: A New Look at Life on Earth* (New York: Oxford University Press, 1979), 145.

[15] See Bruno Latour and Timothy M. Lenton, "Extending the Domain of Freedom, or Why Gaia Is So Hard to Understand," *Critical Inquiry* 45, no. 3 (Spring 2019): 659–80. doi: 10.1086/702611