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The shape of Anthropocene: The early contribution of the water sciences

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Abstract

The conceptual history of the Anthropocene is well-known: after a few scattered appearances in Soviet literature, the term Anthropocene was reignited independently by Paul Crutzen during his famous intervention at the IGBP-SC meeting in Cuernavaca in February 2000. The standard narrative of the history of the term emphasizes the role of Earth System Science and geology in institutionalizing the term, and in paving the way for the term's current popularity within and beyond the natural sciences. Yet this standard account misses a third important contribution to the earliest assimilation, spread, and evolution of the term in the scientific literature: the water sciences. The present contribution reconsiders the role of seminal papers, individuals, and disciplinary areas in the water sciences in the early conceptual history of the Anthropocene concept. The analysis draws on three main findings concerning the early appearance, assimilation, and application of the term in water sciences literature which has been largely overshadowed in existing accounts of the history of the Anthropocene concept. Discussing these literary sources at the intersection of conceptual history, history of science, and scientometrics, the research argues that the water sciences were crucial in the early assimilation and application of the Anthropocene as a suitable and useful category in the international scientific community. In doing so, the analysis also advances that the water sciences should be considered as the third vector (together with Earth System Science and geology) in reconstructing the earliest conceptual history of the Anthropocene.

Keywords

Anthropocene, conceptual history, history of science, history of the Anthropocene, water sciences

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Introduction: The missing perspective

Researchers familiar with the "Anthropocene" concept know its history very well. The term has a scarcely documented prehistory in post-WWII Soviet literature, appearing in translated documents as a loose synonym of Quaternary.[1] In February 2000, the term was (re)invented independently by Paul Crutzen during his famous spur-of-the-moment intervention at the International Geosphere-Biosphere Programme Scientific Committee (IGBP-SC) meeting in Cuernavaca. A publication co-authored with limnologist and freshwater ecologist Eugene Stoermer (who had also been using the term independently) on the *IGBP Newsletter* ensued soon after in May 2000 (Crutzen and Stoermer, 2000), followed in 2002 by the seminal and more impactful *Nature* article "Geology of Mankind" (Crutzen, 2002). Since then, the term began to gradually spread across scientific literature mostly gravitating around Earth System Science. Geologists and stratigraphers of the Geological Society of London took notice of the term, and by 2006 they started discussing it on stratigraphic grounds (Zalasiewicz et al., 2018). First, the *GSA Today* article "Are we now living in the Anthropocene?" saw light in February 2008 (Zalasiewicz et al., 2008b). Then, the Anthropocene was discussed in thematic panels during the 2008 December meeting of the American Geophysical Union (Steffen et al., 2008; Williams et al., 2008; Zalasiewicz et al., 2008a). Lastly, an Anthropocene Working Group (AWG) began its operations in the summer of 2009 as part of the Subcommission of Quaternary Stratigraphy (AWG, 2009). In the years that followed, the term witnessed an astonishing growth in interest paralleled by the many applications, interpretations, and debates it instigated across interdisciplinary academic research—from philosophy to ecocriticism and postcolonial theory (Castree, 2017; di Chiro, 2017; Merchant, 2021; Polt and Wittrock, 2018; Yusoff, 2019)—and the general public alike.

This standard (and briefly summarized) account emphasizes the role of two knowledge domains in the early assimilation, spread, evolution, and institutionalization of the Anthropocene as a scientific concept: *Earth System Science*, and *geology.* The former domain represents the birthing pod of the idea, characterizing the Anthropocene as a post-Holocene transition in the functioning of the Earth System determined by global-scale anthropogenic forcings since the Industrial Revolution, and particularly since the beginning of the second half of the 20th century (Hamilton, 2015, 2016; Steffen et al., 2004, 2011b, 2018; Syvitski et al., 2020). The latter domain has crystallized this state shift in the Earth System into the popular geological proposal—the Anthropocene Hypothesis—of ratifying an Anthropocene unit, possibly as a post-Holocene epoch/series, on the Geologic Time Scale and International Chronostratigraphic Chart (Zalasiewicz et al., 2018, 2019, 2021). Earth System Science and geology are commonly considered the principal disciplinary domains wherein the term most latched to; they laid the foundation for the Anthropocene's success not solely in the scientific but also in the broader environmental discourse. Yet this received view of the early history of the term, often epitomized by a handful of influential publications (including also Chakrabarty, 2009; Crutzen and Steffen, 2003), misses a third important contributor to the earliest history of the Anthropocene concept in the scientific literature: the *water sciences*.

This contribution argues that the water sciences were crucial in the early assimilation and application of the Anthropocene as a suitable and useful category in the international scientific community. Water scientists, especially oceanographers, limnologists, and hydrologists, began using the term systematically to characterize a state-shift in the functioning of their epistemic objects, whether oceans, seas, riverine fluxes, coastal zones, or the hydrological cycle. In doing so, they embedded the Anthropocene concept with a strong scientific characterization that, parallel to Crutzen's impetus in popularizing the term, set the premises for its present scientific and broader academic popularity and success. This argument builds on largely neglected literary sources from the water sciences as indicative of the importance of this disciplinary domain for the earliest *conceptual history* of the Anthropocene—which, besides defining the main goal and scientific contribution of this research article, sets also its methodological orientation (Goering, 2013; Koselleck, 2002). These literary sources are characterized by published internal material of water-related research initiatives and projects as well as peer-reviewed literature. Combined, these sources provide a snapshot of the spread of the term across literary mediums during its earliest stages of existence, supporting the argument hereby advanced.

In the following sections, a definition of water sciences is first given. It is recognized that this designation is broad and loosely defined, hence minimal considerations over the meaning and scope of this research area are necessary before discussing its role in the early conceptual history of the Anthropocene. Then, the analysis discusses the place, role, and significance of water in the emergence of Earth System Science by looking at core projects and initiatives placing water as a key epistemic object. This step is particularly important in understanding why and how water sciences assimilated the Anthropocene concept during its earliest stages of existence. Afterward, the analysis inspects three major clues considered emblematic of the early success and farsighted assimilation of the term by water scientists by diving into literary sources. These sources are particularly valuable as they farsightedly anticipated some central themes in ongoing debates surrounding the Anthropocene hypothesis.

Defining the water sciences

Rather than a single discipline, water sciences (or aquatic sciences) is a heterogeneous body of knowledge encompassing disciplines and research areas wherein water plays a decisive role in describing and understanding the functioning of certain natural entities and phenomena. It loosely centers around disciplines such as hydrology, oceanography, and limnology, and more generally encompasses those sciences where water is a defining (though not an exclusive) epistemic component.

The singular chemical properties, range of applications, and value for biological life make water a universal object of interest in the history of scientific, philosophical, and religious thought across human societies (Ball, 1999; Biswas, 1970; Dooge, 2001). Major religions in the world develop symbolic rituals around water, often perceived as a purifier, with some traditions worshipping water bodies such as rivers as sacred (e.g. the Ganges River to the Hinduist tradition, or the Whanganui River to the Māori people. On geomythology, see Bradley, 2012; Chamberlain, 2008; García and Gaviro, 2017). The ancient philosopher and mathematician Thales of Miletus (c. 620 BCE—c. 546 BCE), often regarded among the initiators of the Western philosophical tradition, reportedly considered water to be the first principle or *archê* of all things:

> Thales, the founder of this school of philosophy [i.e., the Ionian School], says the permanent entity is water (which is why he also propounded that the earth floats on water). Presumably he derived this assumption from seeing that the nutriment of everything is moist, and that heat itself is generated from moisture and depends upon it for its existence (and that from which a thing is generated is always its first principle). He derived his assumption, then, from this; and also from the fact that the seeds of everything have a moist nature, whereas water is the first principle of the nature of moist things. (Aristotle, *Metaph*. I, 983b)

Water—both as a resource and a natural agent—has also had a fundamental historical, political, military, and economic role in the history of human civilizations (see for instance Oreskes, 2020). From watermills, aqueducts, and drainage systems to infrastructure and navigation, water management has been pivotal not solely in securing water as a vital resource and fencing from water-related threats such as floods and storms, but also in transitioning humans civilization from nomadic to agrarian societies (Engman, 1996). Very often sustainable water consumption was the discriminating factor between thriving and collapsing societies. Water management, and particularly hydrology, witnessed great advancements during the Industrial Revolution through great technological improvements and increased scientific knowledge. By the beginning of the 20th century, these advancements "allowed for unprecedented growth in the production of agricultural commodities and energy and confirmed the belief that man [*sic*] could fully control water and be the master of nature" (Savenije et al., 2014: 321).

During the late 20th century, water use increased by a staggering 700% (Dooge, 2009). Unprecedented growth in the human population mixed with increasing awareness of the anthropogenic pressures posed to natural systems raised concerns about water security, availability, and accessibility on a local, regional, and global scale. These represent major challenges to human societies, particularly low-income parts of the world, as well as to other species and thus biodiversity (Vörösmarty et al., 2010, 2015). The set of graphs drafted by the IGBP portraying the magnitude of the "Great Acceleration" includes water use and damming as a socio-economic trend, whereas nitrogen to the coastal zone and water withdrawal and ocean acidification are used as Earth System trends (Steffen et al., 2004, 2011a, 2015).[2] This unprecedented increase in water consumption engendered new approaches to studying and managing water, and local as well as international organizations—such as the International Association of Hydrological Sciences, established in 1922—began to emerge. The field of water resources development transformed into water resources management during the 1980s, and following the 1992 International Conference on Water and the Environment in Dublin, water resources management was renamed "integrated water resources management" (IWRM)—namely, the idea that "the water resources system and its variety of users should be studied in an integrated manner, whereby all the costs and benefits of an intervention are assessed and weighed, so as to come to balanced, well-thought-out and equitable solutions" (Savenije et al., 2014: 322). During the 1990s, it became clear that understanding and communicating the importance of water systems necessitated a co-evolutionary approach that integrated ecology as well as the human factor. This led to the formation of eco-hydrology and, notably, socio-hydrology—namely, the "new interdisciplinary but quantitative science of people and water, with the ambition to make predictions of water cycle dynamics, and thus underpin sustainable water management" (Sivapalan et al., 2012: 1272).

Water has also been a central object of concern for the United Nations at least since 1964 when a resolution to start the International Hydrological Decade (1965–1974) followed from the 13th session of UNESCO's General Conference (Britannica, 2016; Kuusisto, 2001). An UN-Water unit—one among over 30 UN entities focusing on water programs—was established in 2003 to support the UN Members States in water management and sanitation.[3] Jointly with the UNESCO World Water Assessment Programme, founded in 2000, UN-Water publishes an annual World Water Development Report addressing water-related themes and issues worldwide. March 22 is celebrated by the UN as World Water Day to raise awareness of the 2.2 billion people lacking access to safe water.

Normative approaches are ingrained in the water sciences, which have historically and epistemically developed not solely as a descriptive "hard" set of sciences but also as a societal response to water-related threats—be it floods, drought, or lack of clean water. Hydrologists and water scientists such as Gilbert White (1945; see also Macdonald et al., 2012)—the father of floodplain management in the USA—spent their careers working at the interface of human action, water science, and aquatic systems. The magnitude and extent of anthropogenic activities on water bodies had been largely documented by the international water science community long before the Anthropocene term—as also testified by Stoermer's informal use of the term during his classes throughout the 1980s and 1990s. As discussed in the following section, the same normative drive characterizing the development of water sciences in the 20th century was also constituent in the emergence of the study of the Earth as a system, where water had a central role too.

Water in earth system science

Water is the defining element of the hydrological cycle—one of the most fundamental biogeochemical cycles determining the functioning of the Earth System. Systematic studies of the Earth as a complex system of interacting biogeochemical cycles began in the 1980s, particularly with the original input of NASA Earth System Sciences Committee's first chairman, Francis Bretherton (Earth System Sciences Committee, 1986, 1988), and the formation of the IGBP in 1986 (Seitzinger et al., 2015; Steffen et al., 2020; Uhrqvist, 2014).[4] The IGBP was one of the four global environmental change (GEC) initiatives that led to the formation of an Earth System Science Partnership (ESSP) in 2001, sponsored by the International Council for Science (ICSU, after its original name, International Council of Scientific Unions).[5] Since its formation, the ESSP included water as one of the fundamental subject areas, together with carbon-related energy, food, and health (Leemans et al., 2009). To consolidate water as a research area, the Global Water System Project (GWSP) was launched by the ESSP in 2004 as a Joint Project following a series of discussions and events on the Global Water System in the preceding years (Alcamo et al., 2005). The project addressed the question of how human actions are "changing the global water system and what are the environmental and socio-economic feedbacks arising from anthropogenic changes in the global water system" (p.10).

GWSP was not the only project with a critical focus on water and water bodies. Within phase one of the IGBP (i.e. between 1986 and the early 2000s), four core projects fostered research in water sciences. First is the Joint Global Ocean Flux Study (JGOFS; 1987–2003), sponsored by the Scientific Committee on Oceanic Research (SCOR) and ICSU (JGOFS, 1988). Its primary goals were to "improve the understanding of the processes related to global carbon cycle processes and flux of associated biogenic elements in the ocean, focusing on the interaction between atmosphere, ocean floor and continents," and to "develop models which enable predictions about changes of biogeochemical processes causing climate changes" (Giese, 1994: 177).

Second is the Biosphere Aspects of the Hydrological Cycle (BAHC; 1990–2003), an initiative in close partnership with the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP), and cooperation with three working groups of the International Association of Hydrological Sciences (IAHS). The project stemmed from the recognition that "the representation of hydrological processes is one of the weakest and most challenging aspects of the present climate models" (IGBP, 1990: 5.1–3). To face this knowledge vacuum, BAHC was launched "to improve our knowledge of how terrestrial ecosystems and their components affect the water cycle, freshwater resources and the partitioning of energy on Earth" (Kabat et al., 2004: 1; see also Hutjes et al., 1998).

Third is the Land-Ocean Interactions in the Coastal Zone (LOICZ; 1993–2014). LOICZ aimed at tackling one of the core questions of the IGBP, namely, "*How will changes in land use, sea level and climate alter coastal ecosystems, and what are the wider consequences?"* (Crossland et al., 2005: vi). This question was addressed by integrating scientific studies on coastal zones with implementations strategies addressing socio-ecological aspects. LOICZ was an extremely prolific initiative: it produced over a thousand publications between journal articles, books, and reports (Ramesh et al., 2015), and included scientists and researchers from more than 80 countries (Buddemeier et al., 2002). Notably, LOICZ hosted its landmark Synthesis and Futures Meeting between 29 May and 1 June 2002, at the Rosenstiel School for Oceanography in Miami, entitling it "Coastal Change and the Anthropocene" (LOICZ, 2002), and named its 2005 synthesis *Coastal*

Fluxes in the Anthropocene (Crossland et al., 2005), witnessing the relevance that the term had so rapidly assumed.

Last is the Global Ocean Ecosystem Dynamics (GLOBEC; 1995–2010), which originated from a joint initiative of SCOR and UNESCO's Intergovernmental Oceanographic Commission in late 1991 and integrated as an IGBP core project. The project focused on global ocean ecosystem dynamics by providing an "integrated and coherent understanding of natural forcing and its interactions with human populations" (Globec, 1997: 5). A fundamental issue addressed by the project was differentiating "anthropogenic from naturally occurring effects in marine ecosystems" (Globec, 1997).

In addition to these core projects, an interdisciplinary Water Group was established by the IGBP in 1998 "*to understand the role of continental aquatic systems – rivers, lakes, wetlands, estuaries, groundwater, and coastal zones – in the biogeochemical functioning of the Earth system*" (Meybeck, 1998: 8). The group catalyzed research elements from core projects of the IGBP, thus reinforcing water as a pivotal theme for the research program. The group set the foundation of the Sustainable Water Future Programme (Water Future) of Future Earth, which emerged after the end of the IGBP initiative in 2015. The Water Group was originally headed by limnologist and water scientist Michel Meybeck. As later discussed, Meybeck has been a key figure in the popularization of the term Anthropocene across water sciences, especially during the term's first decade of existence.

This dense labyrinth of projects (and acronyms) shows that water, as an essential element of oceans, rivers, coastal areas, ecosystem services, climate, and the hydrological cycle, was a central thematic area during the emergence and institutionalization of Earth System Science between the late 1980s and the early 2000s (and beyond). Water was crucial in fostering the international exchange of data and cooperation among water projects and initiatives—which has historically been difficult (Vörösmarty et al., 2001). The cooperation between BAHC and IAHS is an example of this. Each project was invested not solely with the *descriptive* task of understanding water and its role within the Earth System, but also with the *normative* goal of proactively addressing how human societies, and the Earth in general, are threatened by anthropogenic modifications of water bodies (Holligan, 1990). The projects provided guidelines, insights, and possible solutions to prevent or mitigate the extent of humans' impact on the Earth's water cycles and water bodies, and to address issues of water security. More importantly, each project converged in identifying the human factor as a key epistemic parameter in modeling nature's functioning. Naturally, this was achieved not by looking at water in isolation, but as an element permeating the complex interactions of the Earth's features and mechanisms. The Anthropocene idea originated from this pre-existing body of knowledge: as an Earth System Science concept, it navigated across research projects and interacted with water disciplines close to Earth System Science once seeing light in the scientific landscape. Indeed, this was the case.

The Anthropocene in early water sciences literature

How did the water sciences affect, then, the early assimilation, spread, and evolution of the Anthropocene concept in the scientific literature? One way to answer this question is by looking at how water scientists first engaged with the term in literary mediums during the first years of existence of the Anthropocene concept—that is, after the Cuernavaca meeting in February 2000. This approach reveals three major findings surrounding the origins of the Anthropocene concept related to its earliest appearance in public records, the earliest proposal of a 1950 boundary to mark the beginning of the Anthropocene, and the earliest application of the notion as a scientific category. Each of these findings is particularly valuable in reconstructing in detail the conceptual history of the Anthropocene.

The earliest appearance of the "Anthropocene" in published sources

The received view on the early conceptual history of the Anthropocene unanimously considers the Cuernavaca moment to be the beginning of the Anthropocene saga (Davies, 2018; Grinevald, 2020; Malhi, 2017; Schwägerl, 2014; Steffen, 2013). Crutzen's neologism was an immediate success: it was a major topic of conversation during the coffee break, with someone even recommending the Dutch chemist that he patent the term (Kolbert, 2014). Then, this saga often proceeds by implicitly assigning the term's *first appearance* in written records to the *IGBP Newsletter* article by Crutzen and Stoermer (2000), published in May 2000.[6] Surprisingly, however, this version is not entirely true. The term was *introduced*, indeed, by Crutzen and Stoermer in the sense of being *defined* and *characterized* (more prototypically than in a strict sense) for the first time as an alternative terminology to designate the present epoch since the Industrial Revolution. The article undoubtedly deserves this credit. However, the term had already *appeared* in two much less known literary sources—both from the water sciences.

The first source is a candidate statement that appeared in Volume 9, Issue 1 of the *ASLO Bulletin* (today *Limnology and Oceanography Bulletin*), published in March 2000. This was just 2 months before the *IGBP Newsletter* article and only a few weeks after the Cuernavaca IGBP-SC meeting on February 22–24. Running for the presidency of the American Society of Limnology and Oceanography (today Association for the Sciences of Limnology and Oceanography), oceanographer Hugh W. Ducklow's statement included a mention of the Anthropocene:

> In the post-Kyoto era, CO_2 from fossil fuels permeates the depths of the ocean and threatens unprecedented rates of climate change, and the hydrological cycle is dominated globally by human activity. Recently I heard Nobel Laureate Paul Crutzen declare that Earth has passed from the Holocene into the Anthropocene Era – recognizing the dominance of *H. sapiens* in planetary dynamics. (Ducklow, 2000: 3)

To the scientist, Crutzen's declaration was an opportunity for ASLO to "transition to a scientific society more engaged in earth system science, local, national and regional environmental policy issues" (Ducklow, 2000). Ducklow participated in the Cuernavaca IGBP-SC meeting as Chair of JGOFS. He was an attendee of the Past Global Changes (PAGES) panel when Crutzen, then Vice-Chair of the IGBP, reportedly became "visibly agitated" (Steffen, 2013: 486) at the usage of "Holocene" to mark the context of the panelists' work, thereafter improvising the term Anthropocene. It was only a coincidence that Ducklow was invited to run for the ASLO presidency shortly after the IGBP-SC meeting—as he admits (personal communication, 7 August 2019). Intuitively, his short statement for the presidency was not as impactful as Crutzen's article. Yet what is most interesting is neither the content nor the individual impact of this long-buried source. It is its disciplinary context that matters—that is, oceanography and limnology.

The second source is a brief article of unspecified authorship entitled "The Way Ahead—toward an IGBP II & implications for LOICZ" (LOICZ, 2000) that appeared in the *LOICZ Newsletter* No. 14. The article reports some of the themes that emerged during the Cuernavaca IGBP-SC meeting—namely, the importance of water, particularly the "frozen water" (LOICZ, 2000: 6) of the Vostok ice core (i.e. Petit et al., 1999), for the development of phase two of the IGBP, and that "[i] ncreased collaboration with other projects (BAHC, LUCC, GLOBEC) will help address the water continuum as a whole" (LOICZ, 2000: 6). Then, the article addresses the issues that the IGBP will face and how LOICZ should respond to them, stating that

> Earth System Science will have to deal with interfaces and the boundary conditions set by people. The drivers of systems change and change itself will have to be reviewed in a dynamic context: i.e. what are

> the uncertainties, the nonlinearity and the teleconnections we see when applying a truly global perspective. No longer can we neglect the extent of human interference with the earth system – realizing that it is a crucial part, the term "anthropocene" was developed during the meeting to best describe the current geological age. (ibid.)

Once again, it is neither bibliometric scores nor the content that make this literary record particularly valuable: it is the disciplinary context, namely, oceanography. This is yet another sign (one that makes explicit mention of the importance of water in Earth System Science) of the prompt assimilation of the term Anthropocene in the water sciences—preceding the *IGBP Newsletter* article.

Both Ducklow (2000) and LOICZ (2000) are the first of a series of clues indicative of an early acceptance and prolific partnership between the Anthropocene concept and the water sciences—particularly hydrology, limnology, and oceanography. They show that the term had potential: not only did it begin to circulate among water scientists immediately after the Cuernavaca meeting, but it was already being considered a suitable terminological choice to encapsulate much of the current state of knowledge of the anthropogenic impact of the Earth System and its water components. Notably, the term appeared in internal documents before seeing light in peer-reviewed research, showing that the term did not require "academic formalization" (which also follows a longer timescale than internally published documents) for its meaning to be understood by the water scientists as well as the broader scientific community. It was an intuitive, suggestive, and ultimately useful representation of the state of the world by the beginning of the new millenium. Crutzen's call to "stop using the word Holocene" (Steffen, 2013: 486) was being answered, quite literally.

The earliest 1950 boundary proposal

A second clue of the early assimilation of the term Anthropocene by water scientists comes from research material that actively used the term. This material shows that the term quickly acquired academic institutionalization by actively appearing in peer-reviewed journals and volumes. For example, the term Anthropocene appeared in the 85th Dahlem Workshop Report, *Science and Integrated Coastal Management* (von Bodungen and Turner, 2001).[7] The workshop was organized by biological oceanographer Bodo von Bodungen and environmental scientist Kerry R. Turner and was held on December 12–17, 1999. Among the presenters was Michel Meybeck, then Chair of the IGBP Water Group as well as BAHC-SC member and IGBP-SC member. A few months after the workshop, Maybeck also attended the February IGBP-SC meeting at Cuernavaca. He was a direct witness of Crutzen's intervention, noting down the term Anthropocene in his notebook as soon as he had heard it (personal communication, 24 June 2021). Later, Meybeck integrated the recently coined neologism into his contribution to the 85th Dahlem Workshop Report, which became the chapter "River Basins under Anthropocene Conditions" (Meybeck, 2001b).

The chapter discusses "the evolution of riverine fluxes during the Anthropocene" (p.276). Specifically, the contribution engages with how extant knowledge of the past, present, and future of riverine systems are modeled and construed, and how river fluxes operate under substantial anthropogenic forcings (e.g. water use, damming, chemical pollution). To model river fluxes, the author argues, "one must combine hydrological and biogeochemical processes" (p.290) and take anthropogenic factors into account. This necessitates, among others, an enormous input from "economists, policymakers, environmental engineers, and other specialists" in addition to "environmental historians, geographers, archeologists, and paleolimnologists" (pp.291–92). Most notably, in introducing his analysis, the author suggests that

> Although these authors [Crutzen and Stoermer] assign Watts's invention of the steam engine (1784) as the starting point of the Anthropocene, I prefer to refer to 1950 as the key date for its full development, i.e., the point at which many indicators of human impacts (e.g., land use, dam constructions, urbanization, CO_2 increase, waste release) reached a global extension. (276)

This is an important record in the conceptual history of the Anthropocene: it is the first time when the 1950 boundary is proposed as a possible beginning of the Anthropocene in scientific literature, anticipating by approximately a decade the chronostratigraphy-based starting date selected and currently being studied by the AWG (Waters et al., 2014; Zalasiewicz et al., 2019).[8] Notably, the proposal came from a *water scientist* in a *limnological* study—another clue of the prompt assimilation and application of the term Anthropocene among the water sciences. To the French scientist, the year 1950 represented "the height of *Anthropocene* development, that is, the point at which human activities reached a global extension and impact" (Meybeck, 2001a: 14).

The fact that Meybeck's suggestion anticipated the AWG does not mean that its proposal directly influenced the Group. Interestingly, the record does not seem to be mentioned in any major research material authored by the AWG. An exception is Zalasiewicz et al. (2011), which quotes Meybeck (2003a)—a research article where the 1950 proposal is reiterated by the author—as an example of early assimilation of the term in scientific literature. More recently, Meybeck (2003a) is also mentioned by Zalasiewicz (2020), once again as an instance of early adoption of the term rather than a direct precursor of the Anthropocene Hypothesis. The lack of direct recognition in surveyed geological literature, as well as personal email communication with AWG members, seems to suggest that Meybeck's proposal went mostly unnoticed within the stratigraphic approach to the Anthropocene. These facts invalidate a possible direct link between the proposal and the preferred date currently selected by the AWG to define the lower chronostratigraphic boundary of the proposed unit. On the contrary, both proposals seem to have emerged, or rather, *converged* independently from one another toward the same date.

This seemingly fortuitous convergence is not entirely coincidental. The increasing use of chemical compounds, pesticides, and radioactive pollution since the 1950s was already a largely documented fact—not least since Carson's (1962) *Silent Spring* and by water scientists throughout the 20th century. It was not a coincidence that the Earth System Science community (of which Meybeck was a direct member) adopted the 1950s as the beginning of a transitional phase in human societies, namely, the Great Acceleration (McNeill and Engelke, 2014; Steffen et al., 2018; Syvitski et al., 2020). The 24 socio-economic and Earth System trends first developed in 2004 were the product of decades of intensive efforts in understanding the Earth System (Steffen et al., 2004). This research crystallized and unified, via international reach and multidisciplinary cooperation, the emerging body of specialized knowledge of the Earth's functioning—including plate tectonics, climatology, environmental sciences, and ecology (Steffen et al., 2020)—with the increasing awareness and concern of the scale, magnitude, and consequences of humans' environmental footprint. Feasibly, the 1950s represented a known watershed before both the AWG and Meybeck's proposal.

Nonetheless, Meybeck was the first to recognize 1950 as the possible starting date for the Anthropocene. In doing so, he was also the first to suggest an alternative starting date to the Industrial Revolution in locating the beginning of the Anthropocene—anticipating the Ruddiman Hypothesis (Ruddiman, 2003; Ruddiman et al., 2020) as well as several other alternatives that have been proposed in the following two decades (e.g. Certini and Scalenghe, 2011; Doughty et al., 2010; Glikson, 2013; Lewis and Maslin, 2015). This is particularly valuable in reconstructing the earliest conceptual history of the Anthropocene idea.

The earliest applications of the Anthropocene in water sciences

Increasing mentions and applications of the term in the water sciences literature is the third clue confirming the importance of this multidisciplinary knowledge domain in the earliest history of the Anthropocene concept. As observed, the water science community had been well aware of the extent of anthropogenic activities on water systems long before the birth of the Anthropocene concept (L'Vovich et al., 1990; White, 1945), making this disciplinary domain particularly receptive to the neologism. Probing into sample research texts produced by water scientists, equipped with minimal complementary bibliometric information, can grant us a finer-grained understanding of how the term was being used during its earliest years of existence.

After his early encounter with the term, Meybeck continued utilizing the notion of Anthropocene. Together with Will Steffen and Paul Crutzen, he was one of the scientists who most implemented the concept in published research, acting as a vector for the dissemination and popularization of the term across the scientific community. For instance, the term features in the title of his article "Riverine quality at the Anthropocene: Propositions for global space and time analysis, illustrated by the Seine River," published in 2002 on *Aquatic Sciences* (Meybeck, 2002). In 2003, he described a set of "syndromes" characterizing riverine changes during the Anthropocene in a paper for the journal *Philosophical Transactions of the Royal Society B* (Meybeck, 2003a)—with the term once again emphasized in the title. Several book sections (Meybeck, 2003b; Meybeck et al., 2004; Vörösmarty and Meybeck, 2004), further journal articles (Dürr et al., 2005; Meybeck, 2004; Meybeck et al., 2006; Meybeck, 2005a; Meybeck and Vörösmarty, 2005), and also an entry for the *Encyclopedia of Inland Waters* (Meybeck, 2009: the term appears in the abstract of the entry and as a keyword) followed shortly after—with the Anthropocene term consistently surfacing, either marginally or more emphatically, across individual sources. The proposal of dating the beginning of the Anthropocene to 1950 appears in many of these contributions (Meybeck, 2001a, 2002, 2003a, 2004, 2005b; Meybeck and Vörösmarty, 2005).

Notably, Meybeck (2005a)—an invited commentary entitled "Looking for water quality" and published in *Hydrological Processes*—considers "radionuclides since the 1950s" (331) as one of the factors behind the exponential growth in water quality study and monitoring during the 20th-century. This was not the first time he encountered radionuclides for geochronological purposes: as early as 1971, he coauthored a paper studying the presence of four radionuclides (Iron-55, Caesium-137, Lead-210, and Silicon-32) in freshwater lake sediments (Krishnaswamy et al., 1971). The authors noticed that the presence of Iron-55 and Caesium-137 in the atmosphere and hydrosphere "are primarily due to testing of nuclear weapons" (407). Similar radionuclides are currently considered by the AWG the most promising marker to define the lower stratigraphic boundary of the Anthropocene (Waters et al., 2016, 2018; Zalasiewicz et al., 2019). Radioactive isotopes are only marginally mentioned by Meybeck (2005a) as a driver for changes in water studies; yet this chemical signature further consolidates, more or less indirectly, his selection of 1950 as a suitable starting date for the Anthropocene. This makes Meybeck's proposal especially prescient to the current geological proposal—despite the commentary did not receive substantial attention from a bibliometric standpoint.

The proposal did not go unnoticed in the water sciences (e.g. Folke, 2003; McKee, 2003); nor was Meybeck alone in engaging with the Anthropocene concept among water scientists. The term appears in the title of a research article authored by Codispoti et al. (2001), "The oceanic fixed nitrogen and nitrous oxide budgets: Moving targets as we enter the anthropocene?," published in *Scientia Marina*. The article exhibits noticeable bibliometric scores, appearing in 604 citations, 64 of which in the past 2 years according to the publications database Dimensions.[9] Grounding, among others, on pre-existing research data and methods developed by JGOFS and SCOR, the authors discuss the state of knowledge of the oceanic fixed nitrogen and nitrous oxide budgets in light of the massive anthropogenic intervention on the nitrogen cycle since the 1950s. The "*climatic transition from the Holocene to the Anthropocene*" (p. 100) makes estimates on the oceanic nitrogen budget difficult to assess as this represents a moving target. The authors note that "trying to understand how the oceanic source term for N_2O may change as we enter the Anthropocene is more than casual interest" (Codispoti et al., 2001), therefore attributing the Anthropocene an explicit epistemic utility in identifying the set of properties that oceanography and the water sciences must address. The lead author, Louis Codispoti, found the term Anthropocene particularly interesting as it resonated with his youth environmental activism, and it challenged the idea of a balanced marine combined budget—a theory widely accepted in oceanographic studies (personal communication, 25 February 2022; see also Codispoti, 2007).

Another example is an article merging oceanography and atmospheric science by Sabine et al. (2004), published in Science in 2004. The article has been particularly successful in terms of bibliometric score: with 2713 citations (407 of them in the past 2 years) and an altmetric score (i.e. social media and web appearances) of 140,[10] it is one of the most-cited research articles produced between 2000 and 2009 (namely, between the Cuernavaca moment and the establishment of the AWG). The authors estimate the anthropogenic carbon dioxide uptake by oceans from the period between 1800 and 1994—a period they define as the Anthropocene. The term is used several times in the research, providing time coordinates to assess current estimates about the oceanic sink for anthropogenic carbon dioxide—for instance, by stating that "[o]ver the anthropocene, about 244 ± 20 Pg C was emitted into the atmosphere as a result of the burning of fossil fuels and cement production" (p. 370). Technical terminology aside, this application reflects a general trend in early Anthropocene literature, namely, the application of the concept as a *temporal category*. This may appear obvious: it is simply consistent with the nature and common scientific use of geological time units (either formal or informal). However, this nuance is not trivial. It emphasizes temporality over other possible applications of the concept as a *spatial category* (e.g. the geographical extent of the Anthropocene), as a *descriptive category* (e.g. physical or chemical properties of the Anthropocene), or even as a *political category* (e.g. the political implications of entering the Anthropocene), as an *esthetic category* (e.g. how to visualize the Anthropocene), or more. Indeed, many of these nuances only emerged in the following decade and matured as discrete approaches and research trajectories in the "Anthropocene Studies" (Merchant, 2021; Swanson et al., 2015; Toivanen et al., 2017).

A third example is a 2005 research article by Syvitski et al. (2005), also published in *Science*. The research, which estimates on a river-by-river basis the seasonal flux of sediments on the global coastal ocean, has a total of 1800 citations, and an altmetric score of 369.[11] Among the authors are Jaia Syvitski, a water scientist and current AWG member, and Charles J. Vörösmarty, limnologist and environmental scientist then GWSP member. Vörösmarty has been working within water programs and initiatives of the IGBP and often co-authored research with Meybeck. He was among the main figures directly involved in the assimilation and spread of the Anthropocene concept in the water sciences, particularly in limnology and hydrology. An interesting aspect of Syvitski et al. (2005) is that the term is presented as if it was already a *well-established* scientific notion—one needing no direct explanation.[12] There is no mention of Crutzen (2002) nor Crutzen and Stoermer (2000) although the Anthropocene is defined, consistently with Crutzen's proposal, as the "period after the Industrial Revolution" (p. 378). In fact, there is no bibliographic reference remanding to any particular publication emphasizing the Anthropocene in one way or the other. This is peculiar, in that most scientific literature mentioning the Anthropocene produced around that time exhibits a general pattern of either defining, briefly discussing, or referencing sources upon convening the term. The impact of this type of application of the term becomes clear by considering that the term was then very young and that it was appearing in a top-ranked scientific journal like *Science*. Feasibly, these factors may have motivated researchers to assimilate and reproduce the term, considering it an intuitive and scientifically sound designation.

To fully appreciate the value of this early research material one has to imagine the term Anthropocene to be almost virtually unheard of by the vast majority of the international scientific community—with the exception of the few unknowingly lucky attendees of the PAGES panel at the Cuernavaca meeting (and their respective research networks). Web search engines were far from their current levels of performance, and the term was nowhere to be found in dictionaries and encyclopedias. It was a neologism of an explicit geological denotation, and a semblance of environmental warning, defined and characterized by the very scientists using it to articulate their research—chief among them the water scientists. The sample articles surveyed, while only representing a very limited portion of the early application of the Anthropocene, are emblematic of the early application and success of the term in the water sciences. As noted by Zalasiewicz (2020), early scientists were "using the term matter-of-factly, as a vivid and useful conceptual addition to their discourse and wider communication" (Zalasiewicz, 2020: 14). Water scientists were, indeed, among those who found the term a useful conceptual addition to their knowledge domain.

Conclusions

Scientific terms or ideas, just like biological organisms, survive (or perish), spread, and evolve across environments. The Anthropocene idea may as well not have survived, spread, evolved, and thrived in the academic discourse—the apparent fate of concomitant terms such as "Anthropozoikum" (Markl, 1986), "Anthrozoic" (Revkin, 1992), "Quinternary" (Berger and Loutre, 2001; Berger et al., 2003), or "Homogenocene" (Samways, 1999)—if it was not for the direct assimilation and application of the concept by the Earth System Science community, by geological research, and, as argued in this article, by the early impetus of the water sciences. This implies that the contribution of the water sciences to the early assimilation, spread, and institutionalization of the Anthropocene concept as a scientific category should be recognized as important as that of the Earth System Science and geology—especially with respect to the earliest history of the Anthropocene concept. The present article provides three clues supporting this argument, namely, (1) the term Anthropocene began to appear in published material from water scientists as early as weeks after the Cuernavaca meeting; (2) a proposal to date the beginning of the Anthropocene to 1950 had already been advanced by a water scientist as early as 2001—anticipating the AWG by approximately a decade; and (3) water scientists immediately assimilated the term and have since then applied it to frame research material, initiating a successful and still ongoing integration of the Anthropocene concept as a valuable epistemic category. Notably, the (re)discovered research material hereby discussed rewrites our understanding of the birth and evolution of the Anthropocene concept, providing first-hand documents of value for historians of ideas engaged in reconstructing the saga of the Anthropocene idea.

This analysis is necessarily limited. The literature surveyed, especially concerning the earliest applications of the term, provides only a very narrow snapshot of the early history of the Anthropocene concept in the water sciences. This snapshot cannot be considered exhaustive and comprehensive of how this knowledge domain absorbed and applied the term Anthropocene; a discrete, monograph-worthy study of the conceptual history of the Anthropocene in the water sciences would more efficiently cover the subject than a research article. Indeed, this seems to be the most viable option in approaching the conceptual history of the Anthropocene in general: not by focusing on a single, unifying history of the term, but rather on the different histories of the reception, assimilation, and application of the idea across disciplinary domains—within and beyond the natural sciences. Such an effort should also be sensitive to national contexts, namely, how the Anthropocene has been assimilated across national cultures of research in the water sciences and other disciplines alike. This task very well resonates with the duties of historians and philosophers of science.

Moreover, the separation between Earth System Science, geology, and water sciences should not be taken sharply. As seen, water-related projects and programs were structural to the development of Earth System Science as a new paradigm in environmental science (Hamilton, 2015). Similarly, water is a fundamental epistemic object of geological research (Kuusisto, 2001). In several respects, Earth System Science and geology intersect with the water sciences and vice versa. This means, as anticipated, that the water sciences are a transversal body of knowledge rather than a strictly confined disciplinary area. Just like the shape of water depends on the object it fills, approaches in the water sciences depend on the disciplinary stance they adopt—and so does the shape of Anthropocene.

Nevertheless, recognizing the importance of the water sciences in the assimilation, application, and broader conceptual journey of the Anthropocene category renders justice not solely to this specific research area and the history of the concept, but also to the very water scientists that set the premises for the current success of the Anthropocene in the academic discourse. It also outlines a blueprint of a story that began from a simple candidate statement and a farsighted proposal to the Anthropocene as a vehicle and phenomena to reconfigure the epistemology of water sciences. This is, of course, a story whose finale is yet to unravel. Much will depend on the future state of the Blue Marble during, and after, the Anthropocene.

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Notes

1. The term appears, for instance, in the bibliography of Alexander Pavlovich Vinogradov et al, “Radiocarbon dating in the Vernadsky Institute V. Radiocarbon,” (1968) 10(2), pp. 454–64; and in a translation of Paleontologicheskiy Zhurnal, (1966) 1, pp. 1047–49, appearing in the abstract of Vsevolod A. Vakhrameev, “Botanic-Geographic Zonality in Geologic Past and Evolution of Plant Kingdom.” See also E.V. Shanster, “Anthropogenic System,” in Alexander M. Prokhorov (eds.), *Great Soviet Encyclopedia*, New York: Macmillan, London: Collier Macmillan, 1974–1983, pp. 139–44. Notably, when Shanster authored the entry “Anthropogenic System” for the second volume of the *Great Soviet Encyclopedia*, he equaled “Anthropogenic System” with “Anthropocene” (p. 140) because he had used the same “-cene” suffix for two Periods/Systems of the Cenozoic, namely the Paleocene (today Paleo*gene*) and the Neocene (today Neo*gene*). The translation was primarily a matter of terminological consistency, so that from today’s perspective Shanster’s “Anthropocene” should read as “Anthropogene.”
2. The authors also state that the graph of flux of nitrogen into the coastal margin “could be updated in the near future based on global watershed models using databases of observed fluxes of nitrogen through river basins” (Steffen et al., 2015: 85).
3. A brief history of UN-Water is available on the interagency’s website (https://www.unwater.org/about-unwater/, Accessed 17 March 2022).

4. Interestingly, the IGBP webiste and other sources consider 1987 rather than 1986 the year of formation of the IGBP. The date 1986 is stressed by Seitzinger et al. (2015), and is consistent with the first ever IGBP report, “The International Geosphere-Biosphere Programme: A Study of Global Change Final Report of the Ad Hoc Planning Group ICSU 21st General Assembly, Berne, Switzerland 14–19 September, 1986.”
5. ESSP transitioned into Future Earth in 2013. The other ESSP members were DIVERSITAS, International Human Dimensions of Global Environmental Change Programme (IHDP), and the World Climate Research Programme (WCRP).
6. This is true as long as one excludes past occurrences of the term in Soviet geology.
7. The Dahlem Workshop Series (or Dahlem Konferenzen) was a highly prestigious series of workshops that ran from 1974 to 2012. They were hosted in Berlin (in the Dahlem district), and originally funded by the German Research Foundation (Deutsche Forschungsgemeinschaft) and the Donors’ Association for German Science (Stifterverband für die Deutsche Wissenschaft), and later supported by the Freie University of Berlin. The workshops, held in English, had usually around 40 participants of international provenance discussing and working collectively on predetermined topics—originally from the viewpoint of the natural sciences, but later expanded to include the human and social sciences.
8. For the sake of clarity, the AWG has not selected the year 1950 CE *precisely.* Rather, the Group has gathered stratigraphic evidence converging around the 1950s as a promising starting date. Feasibly, Meybeck’s proposal should also be equally interpreted as flexible more that strictly attached to the year 1950 CE in particular.
9. See https://badge.dimensions.ai/details/id/pub.1071806898, accessed 26 March 2022.
10. See https://badge.dimensions.ai/details/id/pub.1029548155, accessed 26 March 2022.
11. See https://badge.dimensions.ai/details/id/pub.1062451569, accessed 28 March 2022.
12. The fact that the term was occasionally presented as a well-established scientific concept is also relevant to ongoing discussions over the suitability of the term “Anthropocene” in chronostratigraphic research. See Zalasiewicz et al. (2017) and Luciano (2022).

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