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THE ANTHROPOCENE REVIEW

Contingencies of the Anthropocene: Lessons from the 'Neolithic'

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Lesley Head

Abstract

The emerging Anthropocene concept contains two conceptual challenges: its developing narrative tends to present a teleological view of history as linear and deterministic, which is at odds with evidence of evolutionary and historical contingency; and the species category at its core sits uneasily with both the causal details of historical changes and the complexity of conceptualizing human–nature relations. We can learn from the ways similar challenges have been dealt with in the long debate over the origins of agriculture. A body of critical and empirical scholarship now conceptualizes agriculture in more dynamic, contingent terms, but has dealt less well with the second, more difficult, challenge. To realize the Anthropocene's potential to suggest restorative and less fatalistic approaches to the future, we need to work as hard on the concepts as on their constitutive empirical evidence.

Keywords

archaeology, capitalism, contingency, dualism, historical process, hunter-gatherer, more-than-human, origins of agriculture

Introduction

The emerging concept of the Anthropocene challenges us to think differently about many things. It challenges the ideal of economic growth that helped propel it, particularly its manifestation over the second half of the 20th century (Steffen et al., 2011: 862). If human impact on the Earth can be translated into human responsibility for the Earth, the concept may help stimulate appropriate societal responses and/or invoke appropriate planetary stewardship (DeFries et al., 2012; Ellis, 2011). Even so, while the concept has emerged out of palaeoecological, archaeological and historical perspectives on Earth systems, there is great uncertainty about the future, and how we can apply any lessons of the past, since 'Earth is currently operating in a no-analogue state' (Crutzen and Steffen, 2003: 253). The evidence of the Anthropocene requires us to rebuild its own conceptual

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scaffolding in order to imagine and enact the world differently (Sayre, 2012). This will be a long-term project.

In this paper I aim to contribute constructively to that project by addressing two connected challenges that hamper the potential of the Anthropocene, as concept, to help us think differently in the necessary ways:

(1) The emerging narrative tends to present human history in a linear, deterministic and teleological frame at odds with both scientific and social scientific understandings of evolutionary and historical contingency. This may be an inadvertent by-product of the geological conversation in which the concept is often discussed, rather than a deliberate strategy, but it needs to be addressed.
(2) The *anthropos* at the core is a slippery concept. On one hand the human is understood as an increasingly dominant force: 'our own species, has become so large and active that it now rivals some of the great forces of Nature' (Steffen et al., 2011: 43). On the other, 'the ancient dichotomy of humans and nature is now empirically false at the global scale' (Sayre, 2012: 63). Is the *anthropos* a separate and definable actor, or a variable force in an assemblage with others, or both? As others have recognized (Malm and Hornborg, 2014), we have conceptualized the Anthropocene with an undifferentiated human, again contrary to the abundant evidence of spatial and temporal differences in influences below the species level. Further, the Anthropocene is depicted as an outcome of human power, yet the assemblage thus created is characterized by surprise, uncertainty and lack of control (G Harris, 2007).

This paper identifies and discusses the insights that the Anthropocene debate might gain from the question of agricultural origins. Much recent Anthropocene debate is reminiscent of earlier discussions over the Neolithic Revolution. When and where did it start? What were the drivers, what were the responses and what are the reliable empirical indicators? In the last two decades such questions have been reframed in new approaches seeking to 'rethink the Neolithic' (Thomas, 1991) – famously as neither Neolithic nor Revolution (e.g. Gamble, in Bellwood et al., 2007). In an ongoing careful exercise, scholars take issue with the questions, examine the empirical evidence more carefully and pay attention to the embedded concepts. I am not arguing that the Anthropocene and the Neolithic are similar, or even equivalent, phases of human history. I am arguing that they both represent pivotal changes in the way we understand and conceptualize human relations with the non-human world. Each discourse has its own distinctive politics, requiring us to consider whose voice counts. There are things to be learned, therefore, if the incipient intellectual community around the Anthropocene reflects on how the transition to agriculture has been debated over recent decades.

The evolution of agriculture has been consistently understood as a threshold moment in human history. It has its own sweeping narrative arc. Agriculture significantly increased the availability of calories per unit of land and labour invested. The storage and trade of significant food surplus paved the way for a transition from hunter-gatherer society to sedentism, in turn providing the necessary population growth for cities and the emergence of civilization. Agriculture led to widespread transformation of the face of the Earth through the processes of land clearing and other ecological changes. Indeed, the early agricultural period is one candidate date for the onset of the Anthropocene (Ruddiman, 2003).

This story is often told in a linear and determinist way that seems to emphasize the inevitability and superiority of agriculture sweeping across human history. However, evidence from the archaeological record over the last several decades, summarized later in the paper, has documented enough spatial and temporal variability in this process to challenge the coherence of the cultural and economic package glossed as 'agriculture'. I particularly draw attention to a set of more critical approaches which have engaged with the implications of this empirical evidence for the concept of agriculture, and its companion concepts (hunter-gatherers, sedentism, civilization, to name a few).

Several authors have argued that the emergence of the Anthropocene concept is also a moment of convergence between 'Earth System natural science and post-Cartesian social science' (Malm and Hornborg, 2014: 1; see also Lorimer, 2012; Oldfield et al., 2014). This convergence is characterized by: seeing outcomes as contingent, acknowledging the demise of nature as a realm separable from culture, emphasizing non-linear changes and uncertainties, and attending to the material basis of interspecies interactions including those within and between humans and others. The convergence thus provides a historical opportunity to challenge the modernist framing of humans as separate from and superior to nature, and of human history as a progress of continuous improvement. In order to make the most of this moment, it is necessary to forestall two attendant risks. The first is abandoning contingency to teleology and essentialism. And second, an Anthropocene that becomes too quickly reified as just another phase in human history will not only be historically inaccurate, but also have limited potential to mobilize the kinds of political action that its constituent evidence demands. It is more likely to lead to fatalistic responses. I argue that we should use the period when the Anthropocene concept is still emergent in the public consciousness, and informal as a geological epoch, to craft an articulation that is more consistent with contingent understandings of history and science, attuned to variability and (as it happens, in the process) generative of political possibility. Understanding causation and more importantly fixing problems requires differentiation along a number of lines instead of, or in addition to, the species level.

The structure of the rest of the paper proceeds as follows. In the following section I briefly review the Anthropocene narrative as expressed in some of its foundational documents, with particular attention to themes of teleology, determinism, dualisms and treatment of the human. Second I show how contingent approaches to the history of agriculture have creatively revised previous deterministic narratives of the early Holocene. I then draw out some 'lessons' from agricultural debates and also identify a set of ways the Anthropocene is new. Some of the lessons can be learned from concepts that remain intractable in archaeological debates over agricultural origins. New approaches to agricultural origins deal well with issues of contingency but less well, I will argue, with the nature/culture dualism and the question of the problematic human category (Head, 2007). Although it is widely argued that the Anthropocene proclaims the death of the Enlightenment human–nature dualism, the modernist vision of nature is in other ways remarkably persistent, for good reasons (Castree, 2014). Anthropocene science scholarship can benefit from greater engagement with critical social sciences scholarship on these questions.

As a caveat, note that I am not primarily concerned here with whether the Anthropocene is named as a geological epoch, nor whether an early (8000 BP), middle (1800 CE) or late (1950 CE) timing is chosen. But, as my argument will show, I am interested in how the debate over when and where the Anthropocene started provides clues to bigger issues and embedded assumptions.

The Anthropocene narrative

To the question, 'what characterizes the Anthropocene?', Zalasiewicz et al. (2011a: 836) start their answer in the deep time of human prehistory:

> The use of tools was once thought to distinguish humans from all other animals, and among the earliest people who lived at 2Ma in Africa were *Homo habilis*, the 'handy man'. From that time, people have been

> modifying the Earth. For much of that human story, these changes were achieved by muscle and sinew, supplemented first by primitive tools, largely for hunting, and later by fire. Traces of humans in the Pleistocene rock record are rare, and stay rare until the Holocene.

For the *anthropos* to hold at a species level, it has to encompass all of the relevant time and space of *Homo sapiens*. This it demonstrably does not do – despite widespread recognition of human influences on fire and fauna in the Pleistocene, there is not a serious suggestion that the Anthropocene is a Late Pleistocene phenomenon (although note Foley et al.'s (2013) argument for a Palaeoanthropocene). Nevertheless. Zalasiewicz et al. in the quote above hark back even further, and to a genus level.

As Malm and Hornborg (2014) have shown, the long evolutionary path is a common trope in the standard Anthropocene narrative. A key component is the manipulation of fire. Even for the most common Anthropocene chronology, attached to James Watt's 18th-century mobilization of the steam engine, the evolutionary precursor of fire is framed as the ultimate cause because the transition to fossil fuels in the Industrial Revolution needs to be

> deduced from human nature. If the dynamics were of a more contingent character, the narrative of an entire species – the *anthropos* as such – ascending to biospheric supremacy would be difficult to uphold: 'the geology of mankind' must have its roots in the properties of that being. (Malm and Hornborg, 2014: 2)

This essentialist view of the human as a fossil-fuel wielding species is for Malm and Hornborg impossible to reconcile with the huge historical and contemporary differentials in access to such resources. Indeed, they argue,

> uneven distribution is a condition for *the very existence* of modern, fossil-fuel technology … The affluence of high-tech modernity cannot possibly be universalized – become an asset of the species – because it is predicated on a global division of labour that is geared precisely to abysmal price and wage differences between populations. (Malm and Hornborg, 2014: 3)

In other words the species is a category mistake in conceptualization of the Anthropocene, and a recipe for political paralysis. Other differentiations that similarly draw attention to more particular social and political drivers include the Capitalocene (Huber, 2008; Malm, 2013; Moore, 2013) and the Econocene (Norgaard, 2013).

Consider the *cene* as well as the anthropos. In the narratives referred to above, the Anthropocene origin is located not only with a human ancestor, but also very deep in time. I agree with Malm and Hornborg that this is more by default than design. The linear view of history and prehistory is inadvertently embedded within the dominant modes of visual representation – timelines and stratigraphic diagrams (Head, 2000). But the result is a teleological view of human history in which the (negative) outcome is inevitable, a visual trajectory further reinforced by the many exponential curves that characterize the Anthropocene (e.g. Steffen et al., 2011: Figure 1).

Many if not most of these foundational documents contain within them the evidence of spatial and temporal variability, for example, in the first articulation of the 'Anthropocene' (Crutzen and Stoermer, 2000), and in the aforementioned exponential curves. Even Ruddiman (2013) – in the process of proposing an agricultural package, and an early Anthropocene – demonstrates how spatially and temporally variable it was. Zalasiewicz et al. (2011b) discuss many variables as a way of working out whether there is a single stratigraphic boundary. But as Sayre (2012: 66) argues, it is precisely this variability that makes the anthropogenic 'too abstract a category'.

Contesting teleology and linear ideas of progress is especially important given that much of the opposition to climate change science, and much of the difficulty people have grasping the complexity of change, stems from public discourses in which humans are understood as separate from the rest of nature, sometimes with status over and above the rest of nature. Further, we have built teleological ideas of destiny and progress into the many national narratives that drive economic growth (Jackson, 2009). Issues of linear time, determinism and dualisms are entwined in complex ways, as are non-linearity, contingency, emergence and relationality (G Harris, 2007).

The evidence of humans and their processes being embedded into Earth systems at all scales is widely understood to represent 'a very public challenge to the modern understanding of Nature as a pure, singular and stable domain' (Lorimer, 2012: 593), separable and separated from humanity (Oldfield et al., 2014). Despite the claims, it seems that such a view of Nature is only half dead since, as Proctor (2013: 90) argues, Nature survives in most invocations of the Anthropocene: 'It appears typical, when confronted with the complexities that are the Anthropocene, to sharpen the conceptual boundary separating these domains [nature and culture] so as to render this complexity understandable'. Robbins and Moore (2012) go so far as to name the scientific anxiety involved as a disorder. The notion of socio-ecological systems, in which the two separate domains are now mixed, is another example of reinforcing rather than rethinking the dualism (Head, 2012). It is not surprising that the human–nature dualism is so deeply embedded in the narrative, given its deep historical roots in Western thought (Glacken, 1967; Sayre, 2012), embedding of the associated concept of nature in contemporary life (Castree, 2014), and the fact that industrial capitalism is itself partly constitutive of both the dualisms that we now wrestle with and the Anthropocene itself (Malm and Hornborg, 2014; Sayre, 2012).

There are insights to be gained here from the collection of social sciences approaches referred to as post-humanist. These contest persistent human exceptionalism by tracing

> the materialities of interspecies interaction – including genetic, microbial, haptic, digestive and ecological connections – to demonstrate the ontological impossibility of extracting a human body, let alone intentional mind, from the messy relations of the world. (Lorimer, 2012: 585, in Haraway, 2008)

As Gibson and I (Head and Gibson, 2012) have argued at greater length, there are both opportunities and challenges here. There is a major and ongoing challenge in elaborating human and non-human continuities and differences (part of which, following Lulka (2009) is to resist homogenizing the non-human). As scholars we need to be eternally vigilant in applying the analytical impulse to questions of human difference and power, and the ways they are conceptualized in climate change debates. Plumwood's (1993) analysis of the deep structures of mastery buried in our intellectual frameworks is still apposite, and her theory of mutuality, which acknowledges both continuity and (non-hierarchical) difference between humans and non-humans, continues to be helpful here. And of course it is in some ways an inescapable dilemma; 'Our life condition appears to be "both/and" rather than "either/or", obliging us to use the contradictory ideas of nature as "external" and "universal" when discussing ourselves' (Castree, 2014: 29). A key point is that these debates and tensions are a fundamental aspect of how and whether we conceptualize the Anthropocene, not concerns to be sidelined as a simple definitional footnote.

Rethinking the origins of agriculture

Archaeologists have been debating the origins of agriculture for a long time, with a fundamental rethink of the Neolithic Revolution, and its Near East centre of origin, in the last few decades (Thomas, 1991). Evidence increasingly showed that the various parts of the Neolithic 'package' did not all occur together, nor necessarily always in the same order. Sedentism sometimes preceded, sometimes followed agriculture. These debates are relevant to the Anthropocene, not so much as part of defining the latter's temporal boundaries, as per Ruddiman, but rather because of the assumptions embedded in the conceptualization of any period of human history. Nor am I concerned here with the specifics of the (considerable) methodological or empirical disagreements in those debates, except insofar as they throw broader interpretive questions into relief. For examples of the broad range of views on both concept and method, see Bellwood et al. (2007).

Phases of pre/history

A central consideration is the concept of phases or periods of history, whether in deep archaeological or more recent historical time. Are these – including the Anthropocene – understood as a convenient shorthand for capturing big picture, long-term change, or do they impose boundaries so strong that they delimit not only time but also our thinking? Gamble et al. (2005), for example, critiqued 'agricultural thinking' because of its in-built assumptions about origins, history and the processes of change.

As the discussion below will show, our understandings of historical 'stages' and phases are themselves influenced by historical processes, and defined contingently in relation to one another. Depending how they are thought about, historical phases can replace one another, transition from one to another (Biermann, 2014), be mutually embedded or just generally be messy. There are many different examples in current debates. For example as Ruddiman (2013) argues, his early Anthropocene model has the additional awkward characteristic of swallowing most of the Holocene. And industrial capitalism is in large part an agricultural enterprise; like the anthropos, agriculture may be too big a category to have much explanatory traction.

Let us focus then on debates about how agriculture came to be a dominant mode of life across much of the planet in the early to mid Holocene. In particular I highlight those aspects of contingent and non-linear approaches (Terrell et al., 2003) – and their critique of grand syntheses and metanarratives – that will assist thinking about the conceptualization of the Anthropocene. Evidence has long shown agriculture to be a contingent emergence in a number of different ways (Davidson, 1989). The literature is much bigger than I can deal with here and this is not a comprehensive review. Such understandings have come not only from rethinking the agricultural part of the equation, but also unravelling the monolithic concept of the 'precursor' hunter-gatherer phases. In the Australian context, for example, both Pleistocene and Holocene archaeological evidence suggest a 'past comprising a mosaic of independent cultural trajectories based on continuous adjustments' (Ulm, 2013: 189) to local physical and social conditions (Hiscock, 2008).

Many agricultural practices existed in so-called hunter-gatherer societies

This example draws attention to the fact that boundaries between historical periods may be more complicated than often recognized. Expanding ethnographic and ethnohistoric research into hunter-gatherer lifeways in the second half of the 20th century revealed many examples of practices previously associated only with agriculture, gardens and cultivation. Australian Aboriginal examples include the encouragement of fruit seed germination on the edge of campsites (Jones, 1975: 24), both extensive and small-scale sites of yam cultivation (Hallam, 1989), and many descriptions of tilling the soil to enhance the flourishing of tuberous food sources (Gott, 1982). A series of influential papers examined subsistence strategies across the boundary zone of Torres Strait, using it as a transect between the hunter-gatherer groups of northern Australia and the agriculturalists of New Guinea (Harris, 1977). Harris expressed this spatial variability as a continuum of human–plant relations (D Harris, 1989, 2007), whereby domesticated species could be important to a greater or lesser extent.

Conversely, stone technologies previously understood to be Neolithic, such as grinding stones, occur both much earlier in time than agriculture, and persist in places where agriculture never appeared (Fullagar, 2006; Fullagar and Field, 1997; Van Peer et al., 2003).

Empirical evidence of hunter-gatherer cultivation processes was often ignored or rendered invisible in the complex process of colonization

This example draws attention to the fact that boundary-making is itself a political process. Influential 18th and 19th century conceptualizations of agriculture arose in the specific historical context of colonialism. The taking of lands was partly justified to the colonizers by framing colonized peoples as those who lacked purchase on the land (Head, 2000). Both Knobloch (1996) and Anderson (1997) point to the ways that 'hunter-gatherer' and 'agriculturalist' were raced and gendered ideas from the beginning. Invisibility of planting and soil practices was partly to do with their gendered nature; the descriptions are overwhelmingly of women's work (Gott, 1982, 1983). In a number of New World contexts, the agricultural metaphor was central to the colonizing culture's vision of itself and its civilizing presence. 'Improvement' of the land was related to the transforming hand of civilized man in the form of land clearing, followed by the plough, the herd and the fence. A process of conceptual dispossession attended the physical dispossession (Anderson, 2003; Head, 2000). Indeed the agricultural package is so variable that it 'is unlikely to have hung together as a concept without the central notion of separating humans/culture/civilization out from nature' (Saltzman et al., 2011: 56). The politics of the Anthropocene are very different in their specifics, but it is important that we are alert to the fact that they exist (Malm and Hornborg, 2014).

Archaeological evidence shows that agriculture emerged differently in different spaces and times

Processes that may or may not coalesce into global patterns start as locally variable ones. Agriculture emerged independently, in different configurations, in different parts of the world. Evidence from yams, taros and bananas, for example (Denham, 2007a, 2007b; Vrydaghs and Denham, 2007), challenged the dominant Near Eastern 'cereal-centric' models. Jones and Brown (2007) show in detail how the morphological changes to plants and animals, and the set of practices documented from the Near East, have come to dominate thinking about the origins of agriculture, arguing that that area has defined the tests for both empirical evidence and the frameworks for thinking about subsistence and food production. For example, the specific morphological changes seen in domesticated plants, particularly gigantism and dehiscence (the spontaneous opening at maturity of a plant structure, such as a fruit, anther or sporangium, to release its contents) in wheat and other cereals, characterize expectations of how domesticated plants could be visibly (and genetically) distinct and different to their wild counterparts. The focus on Eurasian cereal agriculture, which includes the story of the domestication of wheat, is argued to fetishize the significance of morphological changes, at the risk of ignoring or underplaying more significant social and ecological change (Denham, 2007a; Denham and White, 2007; Vrydaghs and Denham, 2007). More nuanced and varied conceptualizations of domestication, as a social and cultural process of relations rather than simply a rearrangement of genes (Barton and Denham, 2011; Denham, 2007a, 2007b; Hodder, 2007; Terrell et al., 2003; Zeder et al., 2006) have been advanced. Plants that reproduce vegetatively can be just as significant as cereals, albeit less materially transformed[1] and hence less archaeologically visible, partners in the socio-ecological processes that Barton and Denham (2011) call 'vegecultures'.

Further, morphological change is an 'artificial' moment in time – a point only along the line of evolving relationships, in this example between the humans and plants. Some relationships might be quick and dramatic; others slow and evolving; some intense or indeed with little commitment from either human or plant partner (Zeder, 2006). Denham et al. (2009) conceptualized human–plant relations over archaeological timescales as constituted by 'bundles of practices', reminding us that close empirical attention to variation in space and time reveals very different patterns to the imposition of pre-constituted categories.

The history of agriculture (and its mirror concept hunting/gathering) bears all the hallmarks of De Landa's (1997) non-linear history, in which humanity 'liquifies' and 'solidifies' in different forms:

> if the different 'stages' of human history were indeed brought about by phase transitions, then they are not 'stages' at all – that is, progressive developmental steps, each better than the previous one, and indeed leaving the previous one behind. On the contrary, much as water's solid, liquid, and gas phases may coexist, so each new human phase simply added itself to the other ones, coexisting and interacting with them without leaving them in the past … at each bifurcation alternative stable states were possible, and once actualized, they coexisted and interacted with one another. (De Landa, 1997: 15–16)

This applies not only to the variable onset of agriculture but also to its later manifestations. For example, Roberts et al. (2011) argue that major transitions within the agricultural Holocene were complex, contingent and non-deterministic.

Conceptual critique of the concept of agriculture

While the archaeological examples above show the complex and appropriate interplay between empirical evidence and conceptual framing, it is useful to draw attention to critiques from outside archaeology that also have implications for understandings of long-term change. Conceptual critiques of the hunter-gatherer/agricultural dichotomy came from anthropology, with Ingold's (2000) articulation of 'dwelling', and from geography with Anderson's (1997) critique of animal domestication. Building on examples of how 'others' conceive of their relationship with plants, Ingold reconceptualized human–non-human relations as being the 'relative scope of human involvement in establishing the conditions for growth' (Ingold, 2000: 86), without making distinctions between the natural and social worlds. Anderson synthesized an 'appeal' to relax rigid oppositions and reframe 'and re-imagine more animal-inclusive models of social relations' (Anderson, 1997: 463). She argued that the 'underpinning moralities and contradictory manifest forms' of domestication are open to 'rupture and reversal' (Anderson, 1997: 481). Scholars across a range of social science and humanities disciplines have taken up this challenge, producing new accounts of human–animal relations in which the boundaries previously drawn are not so distinct, and in which the human cannot be privileged in quite the same way (see, for example, Cassidy and Mullin, 2007). Implications are being explored in a number of areas of natural resource management and biodiversity conservation, in conversation with the ecological sciences (Hobbs et al., 2013; Lorimer, 2012; Ogden et al., 2013; Robbins and Moore, 2012).

Lessons for the Anthropocene

So, what can we learn from all this for thinking about the Anthropocene? I wish to draw here on approaches in both the natural and social sciences that seek contingent, relational, materialist approaches to the relations between human and non-human worlds. These approaches are neither essentialist nor teleological, they are attuned to heterarchical rather than hierarchical difference and they also attend to power. I see three particular implications from the agricultural discussion.

(1) It is a *long-term scholarly enterprise* to classify periods of history in this way, to rework them, to debate their meaning and boundaries. It is not a simple question of definition, to be skipped over to get to core business. We need to be prepared to analyse the process (using appropriate disciplinary tools) rather than impose categories from above, or assume that the question of the Anthropocene is only a geological question. In the process we must be alert to the concepts even as they are becoming embedded, and be conscious of the cultural specificity of the discourse, as well as the cultural specificity of the changes being analysed. As Robin argues in a different context (2013: 332), 'Anthropocene origin stories follow the deep wheel ruts of northern hemisphere history'. There are of course differences between critique of the Neolithic concept and the pace and scale of scholarship around the Anthropocene. The latter has a virtually global multidisciplinary reach and it has been framed in a particular way by the physical sciences.

(2) It is important to be alert to *spatial and temporal variability*, and what it means for phases of history. The process by and rates at which both agriculture and the Anthropocene became global in scale are clearly matters for ongoing empirical analysis. The point is that detailed analysis of such change is important for understanding causal processes, in disentangling drivers and effects, and imagining how and where to intervene. For example Steffen et al.'s (2011) demonstration that the post-1950 Great Acceleration 'was disproportionately driven by consumption patterns in the Global North, *even* in the context of increased population growth throughout the rest of the world' (Ogden et al., 2013: 342) invites interventions around consumption rather than population per se. It is particular groups of humans doing particular things that generate particular historical processes, in assemblage or constellation (Ogden et al., 2013) with many non-human others, whether we are talking about Pleistocene fire and megafaunal hunting, methane emissions from rice agriculture in China, Watt's steam engine and the parallel engines of industrialization and colonization, or the post-Second World War great acceleration.

(3) We need to be careful with *the category human.* This is really a lesson from what the agricultural origins debate has never quite done, and there is considerable scope to draw the post-humanist social sciences into further conversation with the natural sciences. But it is also the case that this challenge is the most difficult one. It is no accident that related origin stories and conceptualizations of human–nature relations have emerged as part of two key constituent phases of the Anthropocene, agriculture and industrial capitalism. 'The demise of the human–nature dualism and the tenacious hold it nonetheless maintains are both strongly linked to industrial capitalism' (Sayre, 2012: 58), in that ideals of pristine nature somewhere else were strengthened during the brutal urban expressions of the Industrial Revolution. Similar arguments have often been made about colonialism, with the noble savage standing in and for nature (Anderson, 1997, 2003). If the Anthropocene is to fulfil its promise to do things differently, a lot of conceptual labour will be needed.

Let me be clear – this is not an argument to get rid of the concept of the human, but to consider more carefully differentiations of concept and practice both within this category, and between it and others. We have to think differently about how human and other life and materials are mutually embedded, while at the same time accounting for clear evidence of different power relations within such assemblages (Head and Gibson, 2012). Archaeological investigations into the constitution of modern human behaviour are also relevant here. Evidence indicates that there is no set package of human traits, and they are not patterned in predictable ways; if anything 'flexibility' is the characteristic of modern humans (Balme et al., 2009; Davidson, 2013).

Conclusions: Generating political possibility

This paper has sought to address two significant conceptual challenges in the way the Anthropocene is emerging. First, that linear, deterministic and teleological conceptualizations will prevail over the empirical evidence of historical contingency, and second that an unexamined *anthropos* is too large and slippery a concept to be at the heart. The paper has drawn on debates over the origins of agriculture to show how similar challenges have been grappled with over more than two decades. Discussions of agricultural prehistory have dealt well with the first challenge, a variety of alternative conceptualizations emerging that more realistically accommodate spatial and temporal variability, and resist the imposition of totalizing labels. To my mind the same debates have dealt less well with the second challenge, perhaps partly because the *anthropos* remains a key constitutive concept of both archaeology and anthropology. Preparedness to rethink the human has been rather more evident in geography (e.g. Lorimer, 2012), a discipline which has always had to address human–nature relations.

The Anthropocene also poses new and different challenges. We are living in it as we work on it. We necessarily have to work all this out as we go along, only partially with hindsight. We are discussing a category, built out of a body of evidence, that demands that we also engineer political, social and economic change. As it happens, a contingent, messy, non-linear view will likely serve us better politically, given the failure so far of large governance categories such as nation states and intergovernmental agreements to curb emissions.

The Anthropocene concept already has a number of different lives, not all of which scholars will control, but all of which should be monitored. We do not yet know whether Anthropocene will become a culturally embedded key word (like nature) rather than an ephemeral buzzword (like post-modernism). Castree (2014: 9) draws on Williams' (1976) argument that keywords have three characteristics; they are ordinary, enduring and have social force. This outcome will not be in scholarly control, but we need to be alert to and participative in the process. Cultural studies scholars and others who focus on text and discourse will make very important contributions.

Finally, consider the implications of my argument in the context of the future orientation of this journal (Oldfield et al., 2014). As scholars we are in and of this history, and need to attend to the processes of category and thought construction just as much as the historical evidence of concern. A more contingent understanding of the Anthropocene is not only more historically accurate, it also provides more realistic and less fatalistic pathways to the future. If we are assuming humans will be part of the future, how can we articulate and enact the necessary creative human interventions – the creative destruction of dismantling the fossil-fuel economy, and a variety of restoration and repair activities? It may be out of the practice of these interventions that new concepts of the *anthropos* emerge.

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Note

1. That is, unless and until new techniques (e.g. genetics and residue analysis) tell us more about the specifics of hunter-gatherer interaction with and transformation of species.

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Humans and technology in the Anthropocene: Six rules

Peter Haff

Abstract

Humans play an essential role in creating the technological systems of the Anthropocene, but, nonetheless, large-scale technology – the 'technosphere' – operates according to a quasi-autonomous dynamics, summarized by six rules: (1) the rule of inaccessibility, that large components of the technosphere cannot directly influence the behavior of their human parts; (2) the rule of impotence, that most humans cannot significantly influence the behavior of large technological systems; (3) the rule of control, that a human cannot control a technological system that expresses a larger number of behaviors than he himself; (4) the rule of reciprocity, that a human can interact directly only with systems his own size; (5) the rule of performance, that most humans must perform at least some tasks that support the metabolism of the technosphere; and (6) the rule of provision, that the technosphere must provide an environment for most humans conducive to their survival and function.

Keywords

Anthropocene, coarse-graining, complexity, control, technology, technosphere

Introduction

The argument that we are living in a new geologic epoch, the Anthropocene (Crutzen and Stoermer, 2000), is usually supported by reference to the many ways in which humans appear to be impacting the planet, potentially challenging through their activity the major forces of nature (e.g. Crutzen, 2002; Steffen et al., 2007). The aim here is to emphasize another factor at play in addition to direct human impact and intentionality. This factor is large-scale technology, summarized here under the concept of the technosphere (Haff, 2012, 2013). The focus of the present paper is on the dynamics of this newly emerged Earth system (Haff, 2013), and the consequences for humans of being numbered among its parts.

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The technosphere includes the world's large-scale energy and resource extraction systems, power generation and transmission systems, communication, transportation, financial and other networks, governments and bureaucracies, cities, factories, farms and myriad other 'built' systems, as well as all the parts of these systems, including computers, windows, tractors, office memos and humans. It also includes systems which traditionally we think of as social or human-dominated, such as religious institutions or NGOs. The Haber-Bosch process and associated technologies, responsible through synthetic fixation of nitrogen and distribution of resulting fertilizers for providing about 40% of the world's dietary protein (Smil, 2002), is a specific example of a globally distributed component of the technosphere.

In the following paragraphs we abandon the apparently natural assumption that the technosphere is primarily a human-created and controlled system and instead develop the idea that the workings of modern humanity are a product of a system that operates beyond our control and that imposes its own requirements on human behavior. The technosphere is a system for which humans are essential but, nonetheless, subordinate parts. As shorthand we can say that the technosphere is autonomous. This does not mean that humans cannot influence its behavior, but that the technosphere will tend to resist attempts to compromise its function (which is defined below). The emergence of autonomous technology is a topic that has been much discussed earlier in political and social terms; see for example Winner (1977) and Ellul (1967), and, more recently, Arthur (2009) and Kelly (2010), whose works go a long way toward disabusing the notion that humans operate as independent agents in the modern technological world. Our contribution to the discussion on technological autonomy is to attempt to put certain aspects of the human relationship with technology, especially large-scale technology, on a more physical basis.

It has been argued elsewhere (Haff, 2012, 2013) that the technosphere represents a new stage in the geologic evolution of the Earth. It is a global system whose operation underpins the Anthropocene and therefore merits special attention in our attempts to understand the role of humans in a nascent geologic epoch. The property of technological autonomy relocates the basis for thinking about problems such as environmental degradation from a human-centric to a system-centric perspective. The emphasis shifts from focusing only on the human side of the equation to a consideration of the demands of the technosphere itself. We say 'demands' because autonomy has its own necessities and an autonomous system must operate in a way to ensure that it can satisfy them. Thus, an autonomous system must be able to self-solve problems that would otherwise oppose or terminate its function. For example driverless cars must be able to brake, swerve and perform numerous other maneuvers of self-control in order to navigate an urban environment (Benenson et al., 2008). At the large scale, the unplanned, undesigned and spontaneous crystallization of diverse and previously disparate elements of technology into the networked, global system called the technosphere meant there was a new player at the table whose interests would have to be considered in tandem with human interests. This is the point at which the technosphere escaped human control. We analyse the role of technology in the Anthropocene by examining basic physical principles that a complex dynamic system must satisfy if it is to persist, i.e. continue to function, and then interpret these principles as they apply to the technosphere and its human components.

Pursuing this line of reasoning may appear to drift from a direct analysis of problems of the Anthropocene, but an understanding of the underlying physical nature of the technosphere vis-à-vis its human components can help address salient problems of an Anthropocene Epoch that are mediated by technology, such as global warming. The present work does not attempt the difficult task of prescribing solutions for these problems, but focuses as a necessary first step on dynamical questions concerning the relation of humans to technology. Such analysis is timely, as the Anthropocene is being considered for official acceptance with full geologic stature (e.g. Zalasiewicz et al., 2010).

The aim here is to determine a set of basic physical rules that are expected to be true for large complex systems – and for their components, including any human components – regardless of detailed system construction or function, and on the basis of these rules to gain insight into the relationship between the technosphere and its human components. These rules do not include an equation of state; they contain no reference to the specific constitution of any system (or part) – they are not constitutive – and in consequence are not predictive except that, like conservation laws in physics, they impose constraints on system behavior. They are therefore informative about conditions humans face as they attempt to navigate the Anthropocene. Note that the rules invoked here, although general, are less crisp than principles or laws of physics, deriving more from qualitative observation than from precise quantitative experiments. They are, however, more useful descriptors of the systems to which they apply, even if at the same time more subject to revision.

Organization and constraint

As considered here a system is a collection of parts. These parts may themselves be systems. A system is *dynamic* if it does something, or equivalently, if it consumes energy. A dynamic system of many parts is *organized* if the system function can be described succinctly. Organization means that many parts work together. The collectivity of actions reduces the number of words (or bits) needed to describe what the system does, making a succinct description possible. For example, an automobile can be described as an (organized dynamic) system whose function is to transport people and goods quickly and safely along highways. For the moment we skip over the level of detail that one might employ in such a description. The implication of organization for most parts that belong to an organized, persisting system is that their behavior be consistent with the function of the system to which they belong. The qualification 'most' means that we make allowance for an occasional broken part whose inutility does not significantly impair system function – as a wobbly leg on a table does not cause a restaurant to go out of business, This requirement of consistency implies strong constraints on the behavior of system parts.

Constraints applied to non-human parts are often hard or mechanical, such as the flanges that ensure that a train remains on the tracks. Constraints applied to humans can be hard or soft. A company employee experiences the hard constraints of his office, whose walls resist penetration. The door is open, but the soft constraint of fear, for example the implicit threat that he could lose his job, suffices to keep him confined for much of the day. If he is lucky, he is subject to the softer constraint provided by incentives, for example the prospect of higher pay or, better, the implicit incentive offered by a rewarding job – he wants to be in the office because he loves what he does. Enjoyment of or pleasure in an activity may have an internal, human source, but technology often provides the means necessary for self-satisfaction, for example in the supply of materials and studio space for an artist. A host system may also offer disincentives or punishment for wayward behavior that obstructs or interferes with system function – the implicit threat of job loss for a lazy worker, execution for a murderer, court martial for a deserter from the army, suspension for a disruptive student and so on. From the point of view of the host system, the purpose of such constraints, incentives or deterrents is, in the end, to keep its human parts locked into the system so that the system can continue to function.

This line of argument can be applied to the technosphere itself. A succinct description of this system can be based upon the observation that in the pre-Anthropocene, pre-technological world the human population was perhaps 10 million (US Census Bureau, 2012). The ramp-up of technology from pre-history through, e.g., dynastic China, Rome and medieval Europe to today's global technology has led to the expansion of this population to a level approaching 10 billion today (7.2 billion in 2014), suggesting that on the order of 999 out of every 1000 humans owe their existence and their wellbeing to technological systems. A compact description of the technosphere is that it is a global apparatus that searches for, extracts, and does work with (mostly) fossil energy resources to provide support for its own existence as well as that of its essential parts, including members of the world's human population. This description partly reflects the fact that every dynamical system that has a long lifetime as measured in multiples of the timescales of its major components, such as the cycle times of corporations or governments or the usable life of buildings and other capital, must be organized or configured in such a way as to reliably find and use high quality energy to support its metabolism. Otherwise the system would have run down in a few cycle times and would not be available for us to discuss. These conditions are expected to apply to most large technological systems, as well as to the composite technosphere itself. In the following section we develop the argument that, in the technological world of the Anthropocene, most people are subject to the rules of – are essentially captives of – large systems that they cannot control – a corporation, a State, transportation networks, the technosphere as a whole. This state of human affairs is not meant as a metaphor or analogy, but as a physical necessity, a reality. We understand intuitively that we must often respect seemingly impersonal rules imposed by faceless entities, but may resist the conclusion that this condition is not curable and that it is the necessary status of most small parts of large systems. Addressing the question of how size affects the interaction between systems and between systems and their parts, the topic of the following section, makes it possible to explicitly state some of these rules, which are based on requirements of scale and organization.

Coarse graining

The adoption of a particular level of resolution or scale in describing the components of a system is called *coarse graining* (e.g. Gell-Mann, 1995). Thus, in analysing transportation systems, which play a key role in the technological processes that help define the Anthropocene (Haff, 2010, 2012), we have a choice of different levels of description depending on what question is being asked. For example, the description of traffic in terms of all the manufactured components that make up each vehicle down to the bolts that hold the wheels on, and the description of traffic in terms of density of cars on the road, represent two different levels of coarse-graining the highway-and-traffic system. The description of traffic in terms of individual cars on the highway is an intermediate level of coarse graining. At this level the details of each automobile are abstracted away, whereas in the density description of traffic only the collective effect of individual automobiles remains. The selection of a coarse-graining scale specifies the components that we can use to describe the system, allowing some and hiding others. If we are interested in timing of stop lights to minimize stop-and-go traffic we might coarse grain at the level of individual cars and ignore the smaller details of each automobile. If we are investigating regional traffic flow on major expressways we might choose a density description, ignoring the discrete nature of each automobile. We are guaranteed that there exists a coarse-grained description that will have a correspondence to the real world at the chosen scale, even though it discards much information about smaller scales, because real-world behavior at the coarse-grained scale is what suggests the coarse-grained description in the first place.

Humans and the technosphere: Six rules

In order to place ourselves, and other systems of interest, in perspective as components of the technosphere, we imagine the world to be coarse grained at the scale of a system S, which might, for example, be a human. In the three-stratum picture, similar to a concept sometimes employed in analysing the structure of biological systems (e.g. Salthe, 1985), the environment of a system S is divided into three levels or strata, Stratum I, II and III, relative to that system. Stratum II is occupied by S as well as by all other components of the environment that are resolved at the scale of S, i.e. that have a similar size. If S represents a person, then other people also occupy his Stratum II. Whatever their actual size, components that are spatially much smaller than S, such as blood cell or a transistor, occupy Stratum I (relative to S), and similarly all components, whatever their actual size, that are much larger than S, such as an office building, a city or an ocean, occupy his Stratum III. It is essential to bear in mind in the subsequent sections that, whatever the size of system S, the three strata are defined relative to that system. Using the three-strata parsing scheme, six rules are developed that govern the relation between different systems or between a system and its parts. These rules apply to humans considered as parts of the technosphere and help inform us about our place in that system, and thus in the Anthropocene.

The rule of inaccessibility

Our own Stratum I incorporates small components of our environment that normally we do not have to think about in daily life, such as a nematode or soil grain. Stratum I also includes many small technological parts, such as transistors and synthetic nanoparticles. Stratum I contains those components that are blurred away when the environment is coarse grained at our own scale. Individual transistors in a laptop might as well be atoms as far as accessibility by the user is concerned. We cannot interact with most Stratum I components directly. This is the rule of inaccessibility. The rule of inaccessibility applies in a similar way to the technosphere with respect to its Stratum I parts, such as individual humans, whom it is not able to affect directly.

One explanation for the rule of inaccessibility is that a significant difference in size between two systems implies that the larger system cannot directly influence the smaller system without also affecting many other small systems or parts that are nearby. If your hand tries to grasp a single cell in a leaf lying on the ground, the whole leaf ends up in your hand instead. The collection of affected Stratum I parts, the leaf, is in effect a Stratum II system relative to the probing system, your hand, so what began as an intended direct Stratum II effect on a Stratum I system ends up as a Stratum II effect on another Stratum II system

The rule of inaccessibility does not mean that we cannot affect a specific system or part that resides in our Stratum I, but only that we cannot do so directly in terms of variables defined in Stratum II. Two systems in each other's Stratum II can potentially interact with one another directly because their dynamics are based on the same coarse-graining scale that resolves their stratum. Indirect access to Stratum I is possible because the Stratum II levels for two systems, each of which resides in the other's Stratum II, are generally not congruent, but overlap. Overlap or fuzziness of stratum boundaries is essential for function in a world of many scales because it allows indirect communication between parts whose respective Stratum II layers do not overlap. For example, a transistor inside a computer lies deep within our Stratum I layer, where it is not directly accessible by us or by other systems in our Stratum II. To manipulate a given transistor mechanically requires the intermediary of another system or set of systems, for example a microscope equipped with a manipulator arm. The microscope and the human end of the manipulator are systems in our Stratum II. The series of linkages that transmit a human reaching motion to arm to hand to finger motion (a cascade that accomplishes hand-off of scales via overlapping strata within a single organism), and then on to the microscopic motion of a probe at the other end of the manipulator arm, work by sequential interactions between one system in its own Stratum II with a smaller system whose Stratum II overlaps that of the first.

When the chain of connections mediated by overlapping strata is clear, it may be convenient to attribute direct agency to the large system rather than to articulate in detail the chain of causation. For example, rather than running through the sequence of events from brain to grasping action, we simply say that 'he' picked up the leaf. We similarly understand that cancellation of an insurance policy has a higher source than the letter announcing the cancellation. Nonetheless, from our perspective as Stratum I parts of the technosphere, the rule of inaccessibility distorts our perception of the Anthropocene. According to the rule, the effects of large-scale technology are transmitted to us indirectly through a hand-off of scales, finally resolving into technospheric agents such as cell phones, salesmen, police, utility bills and so on, each of which lies within our Stratum II layer. The consequence for humans is that the clarity and immediacy of our experience with these Stratum II parts, with which we interact directly, tend to overshadow the importance of the more diffuse and harder-to-visualize Stratum III technosphere (see Tversky and Kahneman, 1974, for a discussion of the related phenomenon of *availability bias*). The popular concept of technology is reminiscent of the way biology was viewed prior to the conceptualization by Vernadsky ([1926] 1997) of the biosphere, i.e. that it was mainly an organismal phenomenon. For humans, the upshot of the rule of inaccessibility is to draw attention toward what we are familiar with and thus towards local cause and effect, and away from one of the principal paradigms of the Anthropocene world, namely that humans are components of a larger sphere they did not design, do not understand, do not control and from which they cannot escape.

The rule of impotence

Stratum II systems are generally unresponsive to the behavior of most of their Stratum I parts by virtue of constraints applied to enforce organization of the parts. This is the rule of impotence. If the behavior of Stratum II systems were sensitive to the individual behaviors of most Stratum I parts, then a Stratum II system would be continually buffeted by large, essentially random, forces, and would lose its ability to behave coherently and to fulfill its function. This is the physical reason that a bureaucracy does not often change a policy because of the complaint of an individual, or a highway is not usually shut down, except briefly, as a consequence of an accident. Large companies, armies, tax collection agencies and other bureaucracies seem indifferent to or uncaring about a typical individual human because such indifference is a requirement of their own continued function.

There are some exceptions to the rule of impotence. Thus, every system of many parts is a network, in the sense that there is always a set of links, however indirect, between any two of its parts. In a tightly coupled system (Perrow, 1999), a failure of a small part can under certain circumstance generate a cascade along the network, causing large-scale failure. For example, in 2003 power lines in the US state of Ohio sagged into a tree causing a power blackout across northeastern USA and southeastern Canada that affected 50 million people (Minkel, 2008). Such failures must be infrequent compared with system cycle times if the system is to persist. By contrast, in some systems a few select parts can generate a sequence of events that propagates through the network to aid system function. These parts, for example a building thermostat, can be called leader-parts or, if they are humans, simply leaders. The role of leaders is discussed in the following section. Most small parts of large systems, however, including human parts of the technosphere and its large components, are subject to the rule of impotence. The rule of impotence helps enable a key phenomenon of the Anthropocene, the appearance of large technological systems that tend to resist human objections to or interference with their function.

Leadership and the rule of control

The rule of impotence does not gainsay that certain atypical humans may significantly influence a host Stratum III system. Similar to the way in which Stratum II influence may be projected downward to Stratum I scales, the overlapping of strata provides a path by which the action of some Stratum II parts can be projected upward to the Stratum III level above. Leaders can have large effects at the Stratum III level, and for many large systems leadership is essential to system survival. A company, army or country would not last long in the absence of decisions by leaders.

Although it is sometimes convenient to view a leader as someone who causes the system he leads to behave in a manner that he himself determines, i.e. to control the system, from the point of view of the Stratum III system the function of a CEO, a naval captain or any successful leader is to more effectively enable the system to do what it needs to do to maintain viability – to be able to navigate the complex terrain of the environment within which it operates, to react to competition, to secure resources required for its metabolism and to evade or counter threats to its existence. These proclivities are by necessity built into any large-enough dynamic system if it is to survive. Leadership is one mechanism used by the system to help satisfy its survival requirements.

Leadership is possible only when the system to be led has certain simplicities that a human leader can comprehend and make use of – for example an organizational structure that is accessible through a chain of command (the embodiment of a series of overlapping Stratum II levels). The technosphere in general does not offer such simplified structure. Thus, a large naval vessel sailing alone across the sea under the watchful eye of a captain might seem a representative microcosm of a planetary technosphere sailing alone through space under the guidance of a world leader ready to take corrective actions against external threats or internal malfunction. However, there can be no such leader. The technosphere is not a giant version of a navy ship. The latter is purposefully designed according to engineering specifications to suppress as many undesirable degrees of freedom as humans can think of, and in the process to provide the captain with specified lines of control. A central purpose of the ship design process, beyond providing for suitable military capabilities, is to simplify the complexity of the machine by providing an interface so that its *apparent* or *interface complexity* does not exceed that of the captain. This is a requirement that follows from the so-called Law of Requisite Variety (Ashby, 1957; Fransoo and Wiers, 2006; Luhmann, 2012), here renamed, for clarity, the rule of control.

According to systems theory, if a system is potentially subject to N disturbances or challenges to its function and if it possesses M ways of responding effectively to those disturbances, then to regulate or control the state of the system, that is, to ensure desired functionality, M must equal or exceed N. Roughly speaking, a controller (e.g. the captain) has to be complex enough to mimic (react to) the behavior of the system that is to be controlled (the ship), a condition that can be achieved in designed systems by simplifying the system sufficiently to match the capabilities of the controller. However, the technosphere is not an engineered or designed system and during its emergence has not relied on nor required an overall leader, and in consequence lacks the infrastructure needed to support leadership. In this regard the technosphere resembles the biosphere – complex and leaderless.

Finally, if a leader of a system with built-in leadership infrastructure, such as the CEO of a corporation (e.g. Steve Jobs) or the president of a country (e.g. Xi Jinping), or an engineer or a scientist (e.g. Isambard Kingdom Brunel or John Bardeen, the products of whose genius are directly appropriated by governments or corporations), is termed a cooperative leader (i.e. supportive of the function of the system), there remains the category of uncooperative, or adversarial, leader, who opposes and is able to significantly influence one or more key elements of system function (e.g. Nelson Mandela or Mahatma Gandhi in effecting major social change).

The effectiveness of an adversarial leader, who is a malfunctioning part as far as the system is concerned, is made possible by the same kind of cascading network effects that underlie the potential failure of strongly coupled systems such as the power-grid. Strong-coupling between a large number of parts in a large system cannot be created directly or on demand by a prospective leader, but it may emerge as a system-wide (i.e. Stratum III) response to a Stratum III scale force (such as widespread political repression). The emergence of strong-coupling stimulated (say) by Stratum III level stresses due to climate change might represent a first step in the appearance of self-limiting ('thermostatic') behavior in the technosphere.

The rule of reciprocity

The rules of inaccessibility and impotence have been discussed separately to clarify the relation between a Stratum II system and much smaller or much bigger systems. These rules together with the fact that two Stratum II systems may affect one another directly imply a single rule of reciprocity that limits direct mutual interactions between two systems to those and only those that have reciprocal membership in each other's Stratum II layer. Reciprocal membership means that if one system is in the Stratum II layer of a second system, then the second system is in the Stratum II layer of the first. This relation also follows from the nature of coarse graining. The rule of reciprocity re-emphasizes the point made above, that the physical restriction imposed on humans that they can deal directly only with other Stratum II systems, many of which such as automobiles or cell phones are products of human design, encourage the anthropocentric misconception that we created and control large-scale technology.

The rule of performance

According to the rule of performance, at least some of the actions of most system parts must support the function of the system to which they belong. We recall the function of the technosphere – to extract high quality energy from the environment and to do work with that energy to sustain its own existence and that of its parts, including humans. If too many parts failed the rule of performance, then the technosphere could not function according to its description. The effect of the rule of performance is that most humans must support this functionality, for example by holding a job, reproducing, being sufficiently sociable to help sustain a human network of knowledge and cooperation, paying taxes and supporting activities such as education, without which efforts the technosphere would eventually collapse.

There are penalties for flouting the rule of performance. With regard to the technosphere, humans are not voluntary members of a system whose goods and services they use for convenience and from which they could resign if they 'wanted to'. Technology provides not just luxuries such as bath powder and steak knives, but essentials of life such as food and water, which, for the billions of humans alive today, are available only as a consequence of the function of the technosphere (e.g. fertilizers, mechanized farm equipment, efficient long-distance transportation, pesticides, medicines and so on). The technosphere locks humans into service not only by giving them what they need and want, but by the implicit threat to withdraw perquisites or even necessities of life for those who leave. A few individuals may occasionally withdraw from the technosphere voluntarily to become hermits, or fail to work in its support because of mental or physical incapacity, e.g. the sick and the homeless. From the point of view of the technosphere the latter are broken parts, and are in effect discarded from the system unless they can be repaired, i.e. made serviceable again. Humans remaining on the outside often suffer accelerated ageing

(Hahn et al., 2006), the same fate that faces other kinds of technospheric parts discarded because they no longer 'work', such as the once shiny automobiles rusting in a junkyard. The rest of us perform support tasks for the technosphere not because we know about the rule of performance, but because of incentives or constraints that lead us to participate or because of punishments that come to bear when we stray from regular performance of our tasks. Most of the time, most of us work to support the technosphere whether we know that it exists or not, and whether we want to or not.

The rule of provision

It is necessary that the parts of a system experience an environment that makes it possible for them to perform their support function. The host system contributes to maintenance of a suitable environment for its parts according to the rule of provision. A railway car is able to move easily from origin to destination because the tracks are smooth and well secured and the wheel bearings are maintained in a well-lubricated condition. The railroad system, which lies in the car's Stratum III, must provide these and other support services for its rolling stock and other components in order to be able to function itself. For its human parts the technosphere provides essential support in many different ways, for example by supplying food and fresh water to population centers, medicines to keep us healthy, the tools, systems and knowledge we need to do our jobs, and the time and recompense needed for us to be effective consumers.

The type and rate of provision are responsive to human needs and desires, the latter of which, in their acquisitive form, have no known upper bound. A consequence is that the rules of provision and performance together create conditions conducive to positive feedback. The provision of gadgets, services and systems that people want, or discover that they want, can enable or encourage new modes of human performance that support further production of these and other desiderata. In this way technology creates its own niches and subsequently expands into them, as, for example, in the recent emergence of a pervasive app market (e.g. Abowd et al., 2005) in the wake of expanding adoption of smart phones.

The stability of these growth conditions is not, however, guaranteed. Environmental degradation, global warming, a world population that continues to rise and many other developments that are driven by a high-metabolism technology, raise the question of whether the technosphere may eventually fail the rule of provision, on which civilization and its own existence depend. The rules of provision and performance, even if adhered to, do not guarantee indefinite longevity for the technosphere. The rules are only minimal requirements that must be met if a metabolizing system is to endure through many internal cycle times. A system's environment poses external challenges, some of which are generic, and point to an additional set of rules that must be followed for a system to survive long enough to overcome the challenge. Perhaps the most fundamental of these is a consequence of the second law of thermodynamics – namely, that an enduring system must eventually begin to recycle whatever fraction of its mass waste products is not recycled by other environmental systems. In the case of the technosphere, these 'other systems' are those that embody the shrinking resource called natural capital (Daily, 1997) (e.g. undisturbed soils, which can function as a carbon sink). The question of recycling and other issues pertaining to the dynamics of the technosphere that are not treated here are discussed in Haff (2010, 2012, 2013, 2014).

We note that, although the above discussion outlines six rules, logically they reduce to only four, since the rule of reciprocity implies the rules of inaccessibility and impotence. However, because our approach is physical rather than axiomatic, it is more appropriate to view the rule of reciprocity, which is not derived here from first principles, as a deduction from the rules of inaccessibility and impotence, which are physically based. The listed rules are thus not all independent, but, because each is informative, we refer here to all six rules.

Summary

The Anthropocene is a product of human activities and of technology. Creation of technology is usually considered to be a consequence of those activities and therefore a derivative phenomenon. From a large-scale perspective a different picture emerges of the relation of humans to technology, that humans are parts of a dynamic and uncontrollable Earth system from which they cannot escape and in whose service they labor. The vision of Man as a cog in a wheel, subject to a dominating and impersonal technology, has long been a trope in popular culture (e.g. the film *Modern Times*: Chaplin, 1936). The main point of the present argument is to go beyond the use of metaphor (except where it clarifies ideas) and to show from a physical point of view how certain conditions deriving from requirements of scale and organization reinforce the idea of humans as parts of, rather than simply creators and users of, modern technology.

We have outlined a set of basic dynamical rules that apply to human interactions with the technological world of the Anthropocene – the rules of inaccessibility, impotence, control, reciprocity, performance and provision. Tracing out possible consequences for human wellbeing of our asymmetrical relation to the technosphere, as described by these rules, lies substantially beyond the scope of this work. However, whether or not these rules can in themselves answer questions we have about technology and the human future, the hope is they may suggest new questions that would not be asked from a worldview in which technology was seen as simply a product of human ingenuity.

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Vernadsky's philosophical legacy: A perspective from the Anthropocene

Bertrand Guillaume

Abstract

Vernadsky is rightly associated with the seminal contemporary concept of the 'Biosphere', which acknowledges that the world we belong to is a functionally integrated, global phenomenon. Beyond this fundamental idea (that ecology should be thought of at the planetary scale, presaging the concept of Earth System Science), Vernadsky also anticipated the idea of the so-called Anthropocene, i.e. the recent geological era dominated by the global environmental impact of human expansion and activities. Yet, this two-fold legacy of Vernadsky seems still underestimated when it comes to its philosophical implications. In this paper, I explore more particularly three philosophical implications of the planetary and cosmic view that Vernadsky had of the role of ecological/biological organization (including that of humankind) in the great chemical cycles of the Earth, with regard to epistemology, ethics and (in a more speculative way) metaphysics.

Keywords

Anthropocene, Biosphere, environmental humanities, history, philosophy, Vernadsky

Vernadsky: Precursor of the notion of the Biosphere

Vernadsky is rightly associated with the seminal contemporary idea of the 'Biosphere', which rests on the realization that the world to which we belong must be studied and understood at a global scale. His eponymous book is indeed the first modern scientific contribution on the biogeochemical cycles of the Biosphere seen as a holistic concept (Vernadsky, 1929, 2007). For having forged this very concept and established its underlying basis, Vernadsky should be viewed today as the founder of global ecology in the later sense of Bolin (1979) or Budyko (1980).

In 1911 in Vienna, Vernadsky had met with Suess, who initially had coined the term biosphere (Suess, 1875) yet suggesting a different interpretation, that is, the unified sum of the living systems on Earth in the tradition of biology as 'living bodies theory' derived from Lamarck (see, e.g.,

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Polunin and Grinevald, 1988). Despite speculations on more complex interpretations (Ghilarov, 1998), we owe to Vernadsky in the 1920s the idea of the Biosphere in the sense that Hutchinson (1970) would subsequently develop and 'ecologize', and which is now widely admitted within the international scientific community, that is 'the thin external layer of our planet [where] life is concentrated' such that the latter – life – 'can be conceived of as an indivisible set in the mechanism' of the former – the Biosphere – (Vernadsky, 2007: 150–152).

The story is well known (see, e.g., Bailes, 1990; Deléage, 1991; Grinevald, 1987), and the history of the development and subsequent dissemination of the biogeochemical Vernadskian renderings of the Biosphere concept has recently been highlighted again (Oldfield and Shaw, 2013). At the dawn of the 1920s, Vernadsky began to write in Ukraine on the relationships between geochemistry and what he called 'living matter' at the planetary scale. Invited by the Rector of Sorbonne University (Paul Appel), he came to Paris in the summer of 1922 and stayed there until the end of 1925. In Paris, Vernadsky met Teilhard de Chardin and Edouard Le Roy through whom he broadened his scientific concepts to a truly cosmic view of life on Earth. In 1924, he published in French *La géochimie* (Vernadsky, 1924, 2007) and in 1926, back at the Saint Petersburg Academy of Sciences, *The Biosphere* in Russian (French and German translations are from 1929 and 1930, respectively), which established the importance of an inquiry into the phenomena of life in the Biosphere with its indissoluble links to both cosmic and planetary geochemical processes.

Vernadsky: Precursor of the notion of the Anthropocene

Beyond this fundamental idea that ecology should be thought of at the planetary scale, Vernadsky also anticipated, among other things, the idea of an 'Anthropocene' as recently formulated as a label for the distinctive current geological epoch increasingly dominated by the geochemical actions of humankind (Crutzen, 2002; Oldfield et al., 2013; Steffen et al., 2007; Zalasiewicz et al., 2010).

Vernadsky's role may be placed within the contemporary history of the first genuine scientific considerations on the growing influence of humankind on the environment (Steffen et al., 2011), that is about five decades after Marsh (1864, 1874) in the USA or Stoppani (1873) in Europe, but about three decades before the international interdisciplinary symposium of the Wenner-Gren Foundation held in Princeton on the evolution of the 'face of the Earth' as transformed by human impact (Thomas, 1956).

Chronologically, the latter, famous conference led to around three decades of global environmental scientific assessments (see, e.g., Turner et al., 1990) – including the International Geophysical Year (1957–1958) and subsequent satellite observations – which ultimately laid the foundations for the International Geosphere-Biosphere Program (see, e.g., Steffen et al., 2004), promoting in turn the 'Anthropocene' concept (Crutzen and Stoermer, 2000).

From this point of view, the concept initially proposed by Crutzen and Stoermer to capture the idea of our species now so active and powerful that it rivals some great forces of nature (Crutzen, 2002) is clearly echoing a striking intuition of Vernadsky (1924, 2007: 219–221):

> But in our geologic era, in the psychozoic era – the era of reason – a new geochemical factor of paramount importance appears. […] Man has introduced into the planet's structure a new form of effect upon the exchange of atoms between living matter and inert matter […] With man, an enormous geological power has appeared on the surface of our planet'.

In philosophy, it is difficult not to think of Bergson – quoted by Vernadsky in the original French text of *La Géochimie* – for at least two reasons: first Vernadsky's core argument is nothing more than the role of Bergsonian Homo Faber in the transformations of the Biosphere; second, Bergson himself had explicitly prophesied this very consequence of the industrial revolution:

> A century has elapsed since the invention of the steam engine, and we are only just beginning to feel the depths of the shock it gave us […] but the steam engine, and the procession of inventions of every kind that accompanied it, will perhaps be spoken of as we speak of the bronze or of the chipped stone of prehistoric times: it will serve to define an age. (Bergson, 1907, 1911: 153)

Philosophical implications of Vernadskian thought: Epistemology

This two-fold legacy of Vernadsky's thought, underpinning the concept of the Biosphere and anticipating the dawn of the Anthropocene, seems today underexplored when it comes to its philosophical implications. I shall here consider briefly the issue of epistemology associated with the planetary and cosmic view that Vernadsky had of the role of ecological and biological organization in the great geochemical cycles of the Earth (including the role of humankind).

In the reference book of the Soviet Academy of Science, one can read the following terms next to the name of Vernadsky in the column 'area of research': geochemistry; mineralogy; biogeochemistry; geology; radio-geology and meteoritics. Each term already suggests a broad area of knowledge in Earth Sciences, but the list is still incomplete, for Vernadsky deployed an even broader and more multiform range of scientific concerns (Baranovskaya, personal communication, 2013).

Against reductionism, Vernadsky developed a systemic approach through pedology, the general science of soil conceived by his former mentor Dokuchaev as a 'natural body'. In the framework of the holistic philosophy of nature characteristic of global ecology, he examined the 'mysterious circle of organic life at the surface of the globe' considered by Dumas and Boussingault (Dumas, 1842: 7). He immediately embraced the reciprocal interrelationships of both inert and living matters in the metabolism of the Earth within the solar system, as well as the bonds unifying the 'wonderful circulation between the three kingdoms' (animal, mineral and vegetal) so important to Lavoisier (Berthelot, 1890: 168) and humankind as a framework for understanding key aspects of the Earth System's functioning.

One could say that while the biosphere of Suess (1875) allowed the switchover from a natural trinity (mineral versus vegetal versus animal) to a binary world (organic versus inorganic), the Biosphere of Vernadsky (1929, 2007) aspired to re-establish the 'unity of nature' in the great tradition of Humbolt, whose well-named *Kosmos* (von Humbolt, 1845–1862, 1866) Vernadsky had read as a teenager.

As Deléage (1991) noted, Vernadsky was probably able to integrate such different disciplines because he was himself at their intersections, allowing him to deploy an unprecedented vision of a terrestrial and cosmic mechanism that gathers together the biological and the geological, and would later open the road to both the contemporary 'ecologized' Hutchinsonian interpretation of the Biosphere and the Lovelockian view of a living 'super-ecosystem' deeply intertwined with its abiotic environment. From this point of view, the conception of Vernadsky was a genuine scientific revolution (Grinevald, 1998). His elaboration of the concept of the biosphere opened a new paradigm in ecology and life sciences (Smil, 2002), and in this respect we may view his key ideas as a breakthrough of equal significance to that of Darwin. As Margulis and Sagan (2000: 51) suggested: 'Vernadsky did for space what Darwin had done for time: as Darwin showed all life descended from a remote ancestor, so Vernadsky showed all life inhabited a materially unified place, the biosphere'.

Vernadsky decided – as stated in his preface to the Russian edition of *The Biosphere* (Vernadsky, 1998: 39–41) – not to choose between, on the one hand, different and complex geological phenomena conceived simply as 'a string of accidents', that is to say, singularities that can only be studied with a situated casuistic approach and, on the other hand, general theories insufficiently based on empirical results therefore prone to 'philosophical and cosmogonal hypotheses that cannot be founded on facts'. To resolve this dilemma, and embrace the functionally integrated nature of what we now term the Earth System in a trans-disciplinary – yet truly scientific – manner within which it is possible to identify some regularity in the interrelation of complex phenomena and their organization, Vernadsky recommends a methodological approach of scientific generalizations founded on facts and empirical evidence, and not assumptions and theories. This, he suggests, would allow for an holistic view of the phenomena connected with life by regarding as a scientific phenomenon the systemic mechanism underpinning their detailed operation.

Eventually, while mostly 'invisible' before its revival with scientific and philosophical discussions about the Gaïa hypothesis (see Lovelock and Margulis, 1974 and e.g. Lovelock, 1979), the so-called Vernadskian revolution (Grinevald, 1998) seems quite obvious today. It appears, retrospectively, as having allowed a modern macroscopic look at the Earth (Schnellnhuber, 1999), so as to perceive its specificity, complexity and unique dynamics as a 'living planet' within the solar system.

In a conference at the French Society for Astronomy, Poincaré (1903) claimed that astronomy 'gave us a soul capable of understanding nature'. Long before pictures were taken from space by man-made devices, Vernadsky gave a new impetus to this assertion when, using the power of his imagination, he stepped outside the terrestrial globe to provide a panoramic view of it – as Suess (1883, 1904: 1) had done earlier in describing the 'peak shape of continents'. Consequently, in his evocation opening the first part of *The Biosphere*, Vernadsky offers the vision of a unique planet, separated from the endless space of the cosmos by its atmosphere. With an operating procedure of his own, this would allow him to develop a trans-disciplinary analysis, such as the one now widely used in Earth System Science based on advanced observation, modelling and computation techniques. For this reason, The Biosphere is, as Deléage (1997: 22) rightly argued 'a magnificent example of the trans-disciplinary widening necessity to reveal issues properly invisible in a narrow disciplinary operation'. A remaining challenge for the most recent international initiatives (e.g. 'Future Earth') that have followed in the wake of Vernadsky's pioneering vision is to better integrate the humanities in their programmes.

Philosophical implications of Vernadskian thought: Ethics

Any inquiry into the facts–values articulation in Vernadsky is a difficult task, for he seems to make every effort to maintain a distance between the two. It seems, however, possible to sketch the essential elements of his personal journey via his scientific ecology to a general ethics of science and technology, and to provide a modest comparative historical perspective. What should one conclude from 'the extreme increase of the pressure of life in the biosphere caused by the appearance of the evolved homo sapiens' emphasized in the appendix to the French translation of *The Biosphere* entitled 'The evolution of species and living matter' (Vernadsky, 1929) when it comes to the moral responsibility of humanity?

On reading Vernadsky, it becomes clear that he believed humans had come to bear some (new) responsibility, but he did not subscribe to the type of environmental ethics based on the 'rights' of the Biosphere that the US tradition would later develop. His views appear to have been closer to humanistic anthropocentrism and resonate with the Jonassian *motto* of the future of humankind as a 'primary obligation', for he actually attributes to science a truly social function for the good of humanity. There is obviously not complete convergence between the views of Vernadsky the geochemist and Jonas the philosopher: the former held to an optimistic view of progress, whereas the latter was more pessimistic. Vernadsky is not satisfied with pollution from the productive activities needed for the economical modernization of his country (with which purpose he was so strongly engaged), and he highlights unfortunate delays between scientific developments and the social and political understanding required to deal with their consequences (Deléage, 1997). However, his whole research orientation is largely turned towards the study of natural resources and their productive use for his people (Deléage, 1997), and is convinced of the inescapable potential of science and knowledge to point civilization in the direction of universal progress.

Yet he seems to take for granted that the required level of human responsibility will occur as a natural consequence of scientific progress, because of the immanent direction of the biogeological processes themselves towards the advent of the Noösphere – a term that Vernadsky coined along with French colleagues Teilhard de Chardin and Le Roy to suggest a Biosphere in which not only human action, but also human thought would come to play a critical role (see Vernadsky, 1945, 2007: 161–190). He considered that this creative development in the Biosphere called the Noösphere 'in the form of scientific knowledge and its technological application, is – like its parent stock, living matter – a planetary phenomenon' (Callicott, 2013: 193). This optimist philosophy of the future goes along with a proportionate attachment to constitutional freedoms and to the democratic value of science, confirming the hostility of Vernadsky to autocracy, though Jonas (1979, 1990) later suggests that, with regard to ecology, autocracy can have its advantages as a counter to liberal capitalism.

Likewise, for Vernadsky, the diffusion and multiplication of terrestrial life do not operate 'in the abstract and unbounded time and space of mathematics, but in the finite dimensions of the planet and the boundaries imposed by the physical and chemical constitution of its living environment' (Deléage, 1997). Yet he shows a strong belief in the power of adaptation, an ability he judges 'immense' for living organisms, and whose limits 'are unknown, but are increasing with time on a planetary scale', all the more for man 'endowed with understanding and the ability to direct his will', so that 'the question of unchanging limits of life in the biosphere must be treated with caution' (Vernadsky, 1998: 118–119).

In the context of the Biosphere and the Noösphere, Vernadsky (2007: 414) therefore favoured a future of growing creative possibilities rather than of self-destruction. His diagnosis again echoes the Bergsonian one. As the French philosopher puts it: 'What we need are new reserves of potential energy – moral energy this time [for] the body, now larger' of humankind (Bergson, 1932, 1935: 268) 'half crushed beneath the weight of its own progress. Men do not sufficiently realize that their future is in their own hands' (Bergson, 1932, 1935: 275). In the words of the Russian scientist: 'If man understands [that the strength of mankind is derived from its brain] an immense future is open before him in the geological history of the biosphere. […] we may face the future with confidence. It is in our hands' (Vernadsky, 1945).

Vernadsky took here a risky gamble, convinced that human wisdom and joint solidarity, as a planetary phenomenon, would inevitably and irreversibly unfold from globalized progress in the Noösphere. Certainly, the worst threats of our actions were not completely known to him, neither in the form of occasional surges of concentrated power (he died in January 1945, before Hiroshima, but long after the horrors of the Second World War had become well known, yet even these failed to damp his optimism right up to the time of his death), nor in the form of the more gradual accumulation of diffused pollution – e.g. the depletion of the ozone layer the role of which he understood as including protection 'from the harmful short-wavelength radiation of celestial bodies' (Vernadsky, 1998: 118–119), or the anthropogenic forcing of the climate.

It was only with Hutchinson (1970) that the metabolic, evolving vision of Vernadsky became more troubled by acquiring a physiological, functional component (Callicott, 2013: 196) which, in turn, provided the basis, within global ecology, for the 'ugly questions' of Fosdick (1928), which Millikan (1930) had previously caricatured: 'Is man to be the master of the civilization he has created, or is he to be its victim? […] Have we spiritual assets enough to counterbalance the new forces?'.

Definitely, Vernadsky realized that technology would exceed all that people had previously done to the natural world around them, as a result of which they would necessarily bear some responsibility for its consequences. Yet, from this point of view, and with regard to the consequences of its action, the Noösphere – as 'the latest and greatest morphological development in the evolution of living matter' (Callicott, 2013: 191) – should, by its nature, necessarily promote the emergence of an awareness of human responsibilities in such a way as to regulate its activity within the Biosphere. Vernadsky did not (and maybe could not) see the Jonassian ethical turn, namely the idea that technology, if prone to swing towards either the good or the bad, could inherently be transformed into a bad only through its growth:

> Modern technology […] has enhanced human power beyond anything known or even dreamed of before. It is a power over matter, over life on earth, and over man itself […]. Its unfettered exercise for about two centuries now has raised the material estate of its wielders and main beneficiaries, the industrial 'West,' to heights equally unknown in the history of mankind. […] But lately, the other side of the triumphal advance has begun to show its face, disturbing the euphoria of success with threats that are as novel as its welcomed fruits. […] The net total of these threats is the overtaxing of nature, environmental and (perhaps) human as well. Thresholds may be reached in one direction or another, points of no return, where processes initiated by us will run away from us in their own momentum – and toward disaster. (Jonas, 1979; 1990: ix)

As now illustrated by the case of climate change, the always enlarged nature of human action, with the magnitude of its works and their impact on the global future have new implications for ethical reflection. As stated by Krakoff (2011), the implications of human action in the Anthropocene are 'quite different than in previous eras, when human activity was capable only of the most ephemeral effects on the world'. Yet, while some facts he had himself established were about to become sources of worry and pessimism for the future – obviously illustrating the excess of our power with regard to our capacity of prevision – Vernadsky wrote:

> We are entering this new spontaneous process at a terrible time, at the end of a destructive world war. But the important thing for us is the fact that the ideals of our democracy correspond to a spontaneous geological process, to natural laws –the noösphere. So we can look at the future with confidence. (Vernadsky, 2007: 417)

Philosophical implications of Vernadskian thought: Metaphysics

With regards to Vernadsky's legacy, and in a more speculative way, let me now explore some of his 'metaphysical passions' (Callicott, 2013: 186). This dimension could appear surprising for such a realist scientist as Vernadsky. One can nonetheless, I believe, raise the issue of the metaphysics of his philosophy of science and technology at two different levels (Bailes, 1990 ignores Vernadksy's religion philosophy, but see, e.g., Valliere, 2007 and Hagemeister, 1997).

The first level involves the transformative power of the 'living matter' – for which Vernadsky had a 'quasi-religious veneration' according to Callicott (2013: 186) – and the question of the direction in which evolution must proceed. In an already well-established Russian tradition (see, e.g., Timiriazeff, 1903–1904), he conceived of the Biosphere not as an accidental phenomenon but as a mechanism or a process of cosmic essence which changes only in form, the unalterable function of life on Earth being to transform the solar energy flow into terrestrial active energy and, simultaneously, to increasingly expand the biogenic migration of atoms in the Biosphere. This ultimately led Vernadsky to speculate on metaphysical features inherent to life by suggesting a direction for evolutionary processes (Clark et al., 2004). Life expands its domain not only through the processes of evolution 'in quantity' – as a colonizing force into inert matter – but also 'in quality' – towards higher levels of consciousness. From this point of view, the Noösphere 'in the form of scientific knowledge and its technological application' (Callicott, 2013: 193) would appear as a 'strategy' of life, and the emergence of 'civilized' man as the result of paleontological evolution (Deléage, 1997: 28).

We know also that Vernadsky believed in the principle of a strict biogenesis. Following Pasteur, whose works on so-called chirality (a property of asymmetry of objects or systems, see, e.g., Flack, 2009, for an inquiry into the discovery of this property for natural molecules) perfectly matched his asymmetrical conception of the world – gravitational in (physical) space, and thermodynamic in (biological) time – Vernadsky proposed a fundamental antithesis between 'inert matter' and 'living matter'. He also attributed differentiated geometries to them, Euclidian and Riemannian, respectively (Callicott, 2013: 182–183). Indeed, Vernadsky always thought that life existed in the universe from all eternity, and – as far as both ideas rely upon the same foundations – did not preclude speculation on its possible extraterrestrial origin, meteorites having for instance brought life from deep space onto Earth, before it develops there, thrives and evolves finally according to the universal laws of evolution towards the Noösphere.

The proximity to Bergson is here again striking, for in the Bergsonian view of evolution, on the one hand, chance is replaced by the invention of life, whose essence 'is everywhere the same, a slow accumulation of potential energy to be spent suddenly in free action', and on the other hand 'the appearance amid the plants and animals that people the earth of a living creature such as man […], while not predetermined, was not accidental either' (Bergson, 1932, 1935: 219). In the same strand, clearly echoing Vernadsky and the Russian philosophical thought at that time, Bergson (1932, 1935: 218) finally claims: 'And it is to this very conclusion that the philosopher who holds to the mystical experience must come. Creation will appear to him as God undertaking to create creators'.

This brings us to the second metaphysical aspect of the Vernadskian legacy, which consists of wondering where the flow of this biogeocosmic evolution leads us. While a more ecological interpretation would authorize another option (e.g. rediscover, as anthropology teaches us, the wisdom of 'cold societies' living without disturbing the great cycles of nature, see Lévi-Strauss, 1965), Vernadsky seems to suggest more frankly that there is no such alternative: our destiny is to be Promethean.

In his most elaborated version of the Noösphere notion, Vernadsky (2007) accordingly emphasizes the development of humanity on Earth since the inaugural mastery of fire, even going as far as indicating new options in the universe, namely to extend the realm of human activity into space. One can see here another echo of Bergson (1932, 1935: 268), that

> mechanism should mean mysticism. The origins of the process of mechanization are indeed more mystical than we might imagine. Machinery will find its true vocation again, it will render services in proportion to its power, only if mankind, which it has bowed still lower to the earth, can succeed, through it, in standing erect and looking heavenwards.

This famous look at the sky, announced by both Bergson and Vernadsky (however in a different style), prefigures the notorious conclusion of *The Two Sources*, which ultimately raises today the fundamental issue underlying the thought of these two giants: that of a mysticism deifying humankind. The wonderful words of Bergson (1932, 1935: 275) sound at first as a warning, but then offer a choice:

> Theirs is the task of determining first of all whether they want to go on living or not. Theirs the responsibility, then, for deciding if they want merely to live, or intend to make just the extra effort required for fulfilling, even on their refractory planet, the essential function of the universe, which is a machine for the making of gods.

Reading Vernadsky again, it seems clear that he had made his own choice in the direction of technical development (regarding biogeochemistry and genetic engineering, see e.g. Vernadsky, 1925). Indeed, Vernadsky doubtless conceived of the co-evolution of humankind with the Biosphere on an inevitable, irreversible and extreme process, that of building the world and mastering nature. As Vernadsky (2007: 414) puts it, presaging the notion of the Anthropocene: ‘Mankind taken as a whole is becoming a powerful geological force. Humanity’s mind and work face the problem of reconstructing the biosphere in the interests of freely thinking mankind as a single entity’.

At a time when there is serious consideration of geoengineering as a response to the threat of climate change, Vernadsky’s concept of the future role of humanity vis-a-vis the Earth System is not the most implausible one. It underlines, retrospectively, the potentially hubristic tendencies already embedded in the pioneering programs promoting the idea of so-called ‘rational’ management of nature and ‘sustainable development’, such as the MAB programme (*Man and the Biosphere*) established by UNESCO in 1971. As a warning, one may recall that Queen MAB – referred to in Shakespeare’s *Romeo and Juliet* – used to be the fairies’ midwife, who brought dreams to men, but delusional dreams, because her name is derived from the old Irish and means inebriety.

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Perspectives and controversies

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Does pre-industrial warming double the anthropogenic total?

William Ruddiman,[1] Steve Vavrus,[2] John Kutzbach[2] and Feng He[2]

Abstract

According to the early anthropogenic hypothesis, land clearing and agriculture caused emissions of greenhouse gases to begin to alter climate as early as 7000 years ago (Ruddiman, 2003). Climate-model simulations based on the CO_2 and CH_4 concentrations proposed in the hypothesis suggest that humans caused a global mean warming of 0.9 to 1.5°C before the start of the industrial era. Additional pre-industrial effects on land surface reflectance (changes in albedo resulting from forest clearance) may have cooled climate enough to cancel 0.2 to 0.3°C of this warming effect, leaving a net early anthropogenic warming contribution of between 0.7°C and 1.2°C. This proposed early anthropogenic warming is comparable with, and likely larger than, the measured 0.85°C warming during the last 150 years. If the simulations based on the early anthropogenic hypothesis are correct, total anthropogenic warming has been twice or more the industrial amount registered to date.

Keywords

early Anthropocene, global temperature, greenhouse gases, industrial era

Instrumental measurements of temperature currently indicate a global warming of 0.85°C from the mid 1800s to the early 2000s (Intergovernmental Panel on Climate Change (IPCC), 2013), an interval when ice core and instrumental measurements show atmospheric concentration increases from 280 to 400 ppm for carbon dioxide, and from 750 to 1800 ppb for methane. These and other greenhouse-gas increases, along with climate feedbacks, would have produced a considerably greater global warming if the climate system had come into full equilibrium, but two factors have muted part of the industrial warming. First, the large thermal inertia of the ocean has slowed the global warming response to greenhouse-gas increases in recent decades (Meehl et al., 2006).

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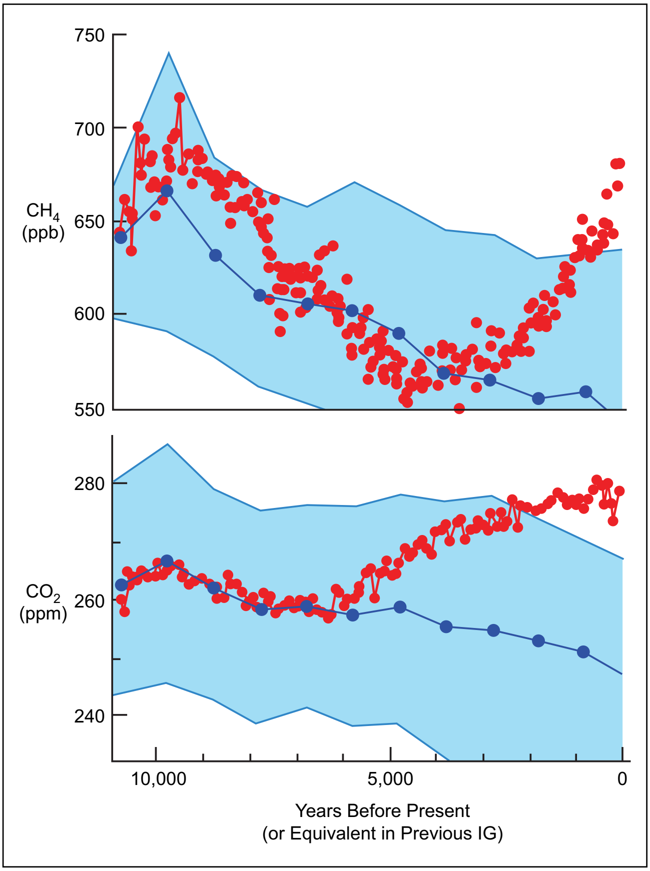

Figure 1. CO_2 and CH_4 trends during the current Holocene interglaciation (red) compared with the average (dark blue) and standard deviation (light blue) of previous interglaciations (Ruddiman et al., 2011).
Source: CO_2 and CH_4 values taken from publications of EPICA Community Members (2004).

Second, industrial-era aerosol emissions have produced a net cooling effect that has opposed some of the industrial warming (Meehl et al., 2012).

Several lines of evidence now support a sizeable pre-industrial greenhouse-gas increase over many millennia. Atmospheric CO_2 concentrations have been increasing during the past 7000 years, in contrast to the mean downward trend during equivalent intervals of previous interglaciations over the last 800,000 years (Figure 1). Similarly, the Holocene CH_4 trend has risen since 5000 years ago, but the same interval in previous interglaciations shows a downward average trend. Because the upward trends during the last several thousand years are anomalous compared with the natural decreases during previous interglaciations, anthropogenic interference in the operation of the climate system during the Holocene is a plausible explanation.

During the interval that these anomalous Holocene CO_2 and CH_4 trends developed, agriculture was gradually spreading across the arable regions of the continents (Figure 2). Forests cleared to grow crops and create pasture for livestock emitted CO_2 to the atmosphere. Paddies flooded to grow irrigated rice emitted CH_4, as did growing livestock herds. Seasonal burning of crop residues and weeds also contributed to the early greenhouse-gas increases.

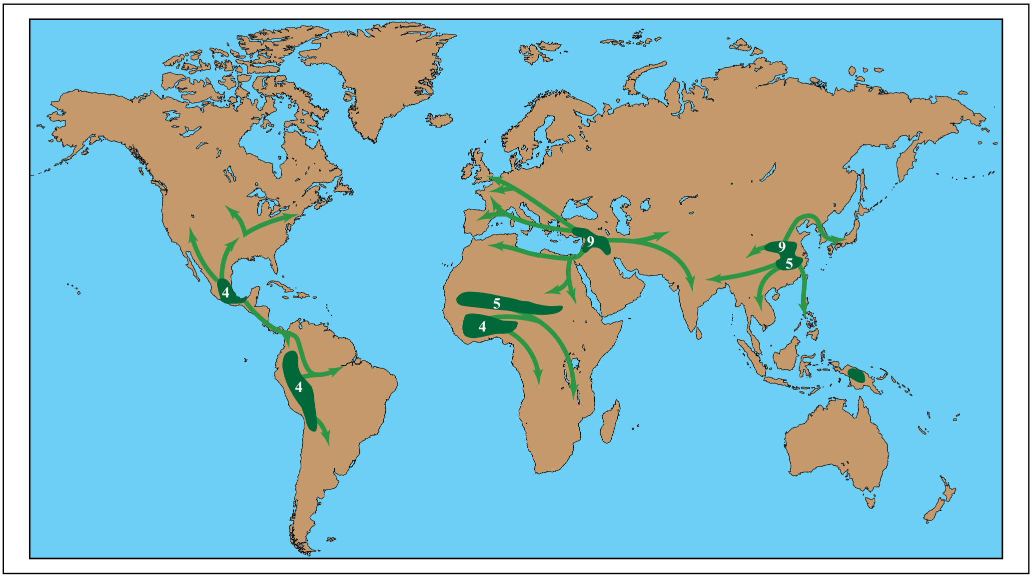

Figure 2. The spread of agriculture during pre-industrial time. Numbers in white indicate the time of initial dispersal from areas of domestication in thousands of years. Light green arrows show the major pathways.
Source: Adapted from Bellwood (2004) and Purugganan and Fuller (2009).

In recent years, accumulating evidence from historical land-use studies and from archeology has begun to provide insights into the quantitative impact of agriculture on greenhouse gases and climate. Ellis et al. (2013) summarized the extensive literature documenting large-scale pre-industrial land use by early agriculturalists. Kaplan et al. (2009) used historically documented land-use trends in Europe spanning the last 2000 years to model the extent of pre-industrial deforestation there, and by extension in other agricultural regions (Kaplan et al., 2010). By their estimate, pre-industrial deforestation released some 343 Gt (billion tons) of carbon C into the climate system, enough to cause a 24-ppm rise in CO_2, similar to the increase measured in ice cores (Figure 1).

Fuller et al. (2011), using archeological evidence to map the spread of irrigated rice agriculture across southeast Asia, estimated that the resulting CH_4 emissions would have been sufficient to explain 70% of the 100-ppb CH_4 increase between 5000 and 1000 years ago measured in ice cores (Figure 1). They also mapped the spread of livestock across Asia and Africa, but did not attempt to estimate the resulting CH_4 emissions, which are likely to have been substantial.

The Kaplan et al. and Fuller et al. efforts were pioneering studies that will be refined in the future, but in both cases per-capita land use millennia ago was much larger than it was during the centuries just before the start of the industrial era (Ellis et al., 2013; Kaplan et al., 2009; Ruddiman and Ellis, 2009). Because inefficient early farming required large amounts of land, total clearance was surprisingly extensive relative to the small populations existing at the time. Later population increases resulting from agriculture gradually reduced the easy availability of land and drove adoptions of technological innovations that allowed intensive farming and the extraction of more food per hectare (Boserup, 1965).

As part of the early anthropogenic hypothesis, Ruddiman (2003) proposed that agricultural greenhouse-gas emissions accounted for total pre-industrial gas anomalies of 40 ppm for CO_2 and at least 250 ppb for methane. These anomalies were calculated as the sum of the observed increases in gas concentrations during the middle and late Holocene, combined with the gas decreases evident during the previous interglaciations when significant anthropogenic emissions from agriculture could not have occurred (Figure 1). Without early anthropogenic emissions, he estimated that the CO_2 level would have fallen to approximately 240–245 ppm and the CH_4 concentration to 445–450 ppb.

Several climate-model experiments have simulated the climatic effects of the difference between the greenhouse-gas values for 1850 measured in ice cores and the lower concentrations proposed for 1850 in the absence of pre-industrial anthropogenic emissions. The models in these experiments have used two kinds of representation of the ocean: (1) simplified versions with the ocean represented as a shallow 'mixed layer' heated by the Sun, cooled by overlying air masses and mixed by winds, and (2) more complete versions that also simulate the full circulation with deep ocean mixing, including sinking of cold dense water in polar regions.

Simulations using the Community Climate System Model, Version 3 (CCSM3) coupled to a wind-mixed ocean layer indicate a net warming of ~1.0°C (Vavrus et al., 2008), but the warming increases to ~1.5°C with the deep ocean included (Kutzbach et al., 2011). Similarly, simulations using CCSM4 with a mixed-layer ocean indicate a net warming of ~0.9°C (He et al., 2014) but the warming increases to ~1.5°C with the deep ocean included (Kutzbach et al., 2013). Both kinds of models incorporate high-latitude albedo feedbacks that amplify polar responses, but the simulations with a deep ocean also include the additional feedback effects of poleward heat transport in the three-dimensional ocean circulation.

Kutzbach et al. (2013) analysed the response of the CCSM4 model with a deep ocean to a wide range of greenhouse-gas concentrations and found that the temperature change for a specified increase or decrease in greenhouse-gas concentration is greater for cold climate states than for warm climates. This result, which takes into account that greenhouse-gas radiative forcing is a logarithmic function of greenhouse-gas concentrations, also confirms earlier findings of Manabe and Bryan (1985). Enhanced cold climate sensitivity has important implications for comparing pre-industrial and industrial-era effects of greenhouse gases on global mean temperature (Figure 3). As shown by the stippled triangles in Figure 3, the increase in global annual-mean surface temperature (SAT) is 1.5K for the relatively small increase in greenhouse gases in the colder climate (NA to PI, 200 to 245 CO_{2eq}), and a nearly identical 1.6K for the larger increase in greenhouse gases in the warmer climate (PI to PD, 245 to 355 CO_{2eq}). The term CO_{2eq} (ppm) in this plot incorporates both the change in CO_2 and also the change in CH_4 quantified as an equivalent change in CO_2.

Some of the early greenhouse-gas warming may have been offset by other kinds of anthropogenic activity. One significant factor was the biogeophysical effect of early land clearance (mostly forests) on surface albedo. Pongratz et al. (2010) estimated a total pre-industrial global-average cooling of 0.06°C based on a land-use model with relatively small pre-industrial deforestation resulting from the low levels of per-capita clearance assumed. He et al. (2014) simulated a larger average cooling of 0.17°C by using Kaplan's land-use reconstructions based on historical evidence of much greater early deforestation resulting from higher per-capita clearance. This cooling effect would have been larger, perhaps ~0.3°C, if this simulation had included a representation of the additional feedbacks associated with the deep ocean rather than just a shallow mixed-layer ocean. Still, this counteracting cooling was much smaller than the simulated early warming from greenhouse gases, giving a net warming of about 1.2°C (Figure 3).

Changes in atmospheric aerosols tied to anthropogenic activities could also have potentially altered pre-industrial climate. Prior to the onset of mechanized agriculture in semi-arid prairies and steppes during the early–middle 1800s, farming was restricted to regions with abundant natural rainfall or

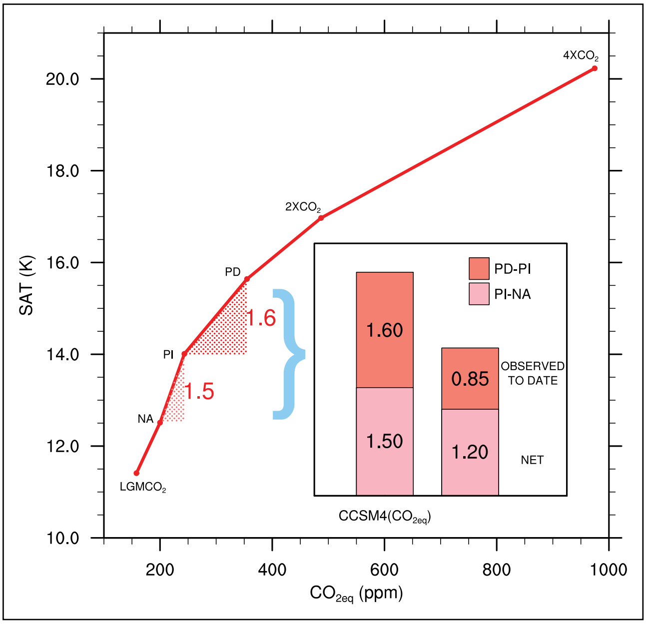

Figure 3. Main graph: Equilibrium annual-average global surface air temperature (SAT) as a function of CO_{2eq} (ppm), the equivalent value of CO_2 with changes in other greenhouse gases taken into account (after Kutzbach et al., 2013). CCSM4 simulations relevant to this paper are: PD ('Present-Day': Year 1990 gas levels), PI (Pre-Industrial: Year 1850 gas levels) and NA: hypothetical 'no-anthropogenic' gas levels based on previous-interglacial concentrations (Figure 1). The stippled triangles highlighting the different slopes of the SAT/CO_{2eq} relation between PI and NA, and PD and PI indicate that climate sensitivity to greenhouse-gas changes is larger for colder climate states. The simulated equilibrium industrial-era warming of 1.6K from PI to PD (left inset) is reduced to the observed 0.85K warming (right inset) by ocean thermal inertia and aerosol emissions. The simulated equilibrium pre-industrial warming of 1.5K (left inset) is reduced to 1.2K (right inset) by albedo-cooling effects from land clearance. The total anthropogenic warming is estimated as ~ 2K.

reliable sources of irrigation (Bellwood, 2004). Pre-industrial agriculture in these well-watered regions probably did not send large amounts of mineral aerosols to the atmosphere. Even today, mineral aerosols from arid and semi-arid regions are a very small source of climatic forcing (IPCC, 2013). Sulfate aerosol emissions have been a modest source of cooling in the industrial era (IPCC, 2013) but in pre-industrial times emissions were likely restricted to localized impacts from small furnaces (Williams, 2003). The other major candidate for pre-industrial aerosol effects on climate is biomass burning. Black carbon from biomass burning has had several opposing effects on estimated industrial-era climatic forcing (IPCC, 2013). Direct aerosol effects are thought to have produced a warming, but opposing cloud-adjustment factors are estimated to have caused a nearly offsetting cooling so that the net effect of pre-industrial biomass burning on climate is difficult to predict.

As summarized in Figure 3 (inset histograms) the net early anthropogenic warming of 1.2K is slightly larger than the instrumentally observed 0.85K warming of the industrial era to date. The total anthropogenic warming to date of ~2K is more than double the observed instrumental warming during the industrial era. Note that this revised view does not alter the widely accepted interpretation of a 0.85K temperature increase since the mid 1800s. It simply places the recent warming atop the different baseline established by the previous early anthropogenic warming (Figure 3).

These two phases of warming occurred within different contexts. The industrial-era warming has rapidly driven global temperature to a level that is poised to escape the top of its natural range over the last several hundred thousand years. In contrast, the early anthropogenic warming acted to offset part of a natural cooling but kept climate within the high end of its natural range. This natural cooling, most clearly evident at high northern latitudes, is generally ascribed to reduced summer insolation. The net effect of the natural Holocene cooling and the partially offsetting early anthropogenic warming was a small global cooling (Marcott et al., 2013).

In summary, the large per-capita footprint of early agriculture boosted the greenhouse-gas releases from relatively small pre-industrial populations (Kaplan et al., 2009, 2010; Ruddiman and Ellis, 2009), and the greater global climate sensitivity during cold climatic states (Kutzbach et al., 2013) further enhanced the warming caused by early greenhouse-gas releases. As a result, the early anthropogenic warming rivaled or exceeded the industrial warming that has been realized to date.

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Perspectives and controversies

THE ANTHROPOCENE REVIEW

Anthropocene Futures

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Abstract

Much of the debate about the Anthropocene has been concerned with global-scale change and with the past. This short paper argues that there is a need for a greater focus on Anthropocene Futures that are relevant to societal actors now and in the relatively near-term future. It suggests that social science perspectives will play an important role in translating insights emerging from the Anthropocene analysis into knowledge that resonates with the lived futures of real people and organisations.

Keywords

Anthropocene, futures, scenarios, social science

The idea of the Anthropocene

The idea of the Anthropocene is a compelling reframing of the relationship between people and nature. If people, through their social, economic and technological activities, have become a geological force, this gives us a new view of ourselves, of our power and perhaps a new sense of responsibility. By embedding people into Earth systems, the idea of the Anthropocene appears both to weaken or even eliminate the classical distinction between Man and Nature (Lorimer, 2012), while giving people a greater role in shaping the direction of change in the biophysical and biological systems that are the basis of all life on Earth. It clearly argues for a closer collaboration between the natural and social sciences in working towards sustainable Anthropocene Futures.

The need for Anthropocene Futures

But what can we say about these Anthropocene Futures? In particular, what predictions does this idea make about the conditions that will affect human development in the coming decades? And what kinds of action by people, organisations and countries does it suggest? Specifically, what choices are there for the 'planetary stewardship' (Steffen et al., 2011a) that the idea of the

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Anthropocene appears to evoke? Does the Anthropocene analysis give us new insights about where the priorities lie, and at what speed and scale to start the work? Are there 'good' Anthropocenes, or only varieties of 'bad' Anthropocenes? Are we already describing a world which is devalued by being seen as dominated by human action, or might new forms of stewardship emerge based on a new Anthropocene consciousness and ethics? On what basis would we be able to judge good and bad outcomes? And who would judge? No idea is ever innocent. Any perspective implies a certain distribution of responsibility and a certain course of action. The Anthropocene is no different.

Much of the emphasis in the debate so far has been on the past. In order to make the claim that people, acting collectively and over long periods of history, have become a dominant force in influencing and shaping the state and dynamics of the atmosphere, hydrosphere, lithosphere and biosphere, much analysis has looked back, seeking to establish a point at which the distinct conditions described by the Anthropocene began. Steffen et al. (2011b) provide a revealing historical survey of the origins of the idea of a distinct epoch in the natural history of the Earth, driven by humankind. From among a number of alternatives, they argue for a start of the epoch at the beginning of industrialisation in England around 1800, but other dates have also been suggested. Ellis (2011: 1029), for instance, emphasizing the differential rates at which different ecosystems have been transformed by human action, suggests that the global terrestrial biosphere made a transition from being shaped primarily by natural biophysical processes, to an Anthropogenic biosphere shaped primarily by human systems in '… the latter half of the twentieth century'. One of the issues for the International Commission on Stratigraphy, in making a decision on whether to adopt the Anthropocene as a new epoch, is to judge when the epoch began. Part of this task may also be to consider when the Anthropocene might end. Rull (2013) suggests a number of possibilities: the next glaciation (in from 1500 to more than 10,000 years time); a catastrophic event (natural or human-induced) that would radically curtail human influence on Earth; or the 'evolutionary disappearance' of humans.

The Anthropocene and (un)sustainable development

One of the main claims about the Anthropocene is that the new epoch raises profound questions about the sustainability of human development (Crutzen, 2002). To begin with, human populations have grown dramatically, especially over the past century, and these people have grown on average wealthier, drawing on massively greater natural resources and environmental services (Steffen, 2011a). A beginning has been made in defining 'planetary boundaries' (Röckstrom et al., 2009), which point to the most urgent dimensions of the global sustainability problems that flow from the scale and scope of human appropriations and interventions in biophysical systems. These include by now familiar changes and impacts associated with climate change, ozone depletion, biodiversity loss and land-use change. In addition, a number of other problems associated with access to resources have been pointed to: peak oil, peak phosphorous, and the resilience of ecosystems services (Steffen, 2011a). Beyond this, there is the growing awareness of 'systemic risks' to global economic, financial and political systems linked to the degradation, failure or transformation of key biophysical and ecological systems. Perhaps one of the most striking claims is that an epoch of relative stability in Earth systems (the Holocene) has been replaced by a new period of rapid change, instability and continuing transience, with growing risks of thresholds and tipping points (Lenton et al., 2008)

An integrated analysis of global changes and the sustainability challenges which flow from them is vital. To make sense of the actions, we need an analysis of problems. But an analysis of problems begs the even larger question: what will people do in response to their new awareness of the Anthropocene and their experiences of it? What will it do to their view of the future and how they plan and act in response? And, given that we are talking here about the long run, what will future people think and do? An Anthropocene framing of global sustainable development problems seems to invite planetary-scale responses, such as geo-engineering and appeals for the global governance of planetary boundaries. But there are obvious questions about whether the global political coordination needed to achieve planetary political and economic responses is plausible, in the absence of a quite dramatic global emergency. Even advocates of a World Environmental Organisation admit that today's reality is otherwise (Biermann, 2000).

First thoughts on Anthropocene Futures

For the time being, the right question to ask is how the Anthropocene analysis may influence the perceptions, norms, plans and actions of people, organisations and governments, now and in the future. Clearly social science can play a major role here. For the most part, social scientists will tend to be cautious in making predictions and forecasts for the future. This is partly because futures, including Anthropocene Futures, will not be universal – just as there are multiple realities in the present, so there will be multiple realities in the future – and partly because there remain deep uncertainties about what the future will look and feel like. The future is not a stable object of study – awareness of it leads immediately to changed expectations and behaviour, changing the stream of events that shape the future.

Bearing these limitations to all futures scenarios in mind, here are some predictions about Anthropocene Futures:

1. There are both costs and opportunities presented by the global sustainability problems presented by the Anthropocene analysis. Costs and opportunities are the drivers of innovation. For instance, peak oil presents opportunities for non-oil energy sources. The remarkable story of global unconventional gas reserves as a result of the fracking revolution demonstrates this clearly. As oil prices have risen, partly as a result of concerns about global reserves, so the economic viability of alternatives has changed, aided in the case of shale gas by a number of technological developments. The fracking example also shows that transitions will not always be smooth and rapid. They are messy and confusing processes, bearing the marks of what went before, but also generating surprising new configurations of habits, institutions and technologies. We may speculate that growing systemic risks to food security as a result of climate change, growing pressure on global land resources and the desire to protect biodiversity will generate the search for new, more diversified but intensified global food production systems. Changing relative prices and preferences will change the role of meat in the diets in unpredictable directions. Even a looming limit to phosphorous production is likely to lead to innovations in low-P agriculture. Access to resources is not a static zero-sum game. Relative prices, geopolitics and ingenuity reshape technologies, and supply and demand continually. Scarcity and crisis lead to new strategies among producers and preferences among consumers, and this in turn leads to the emergence of new scarcities, crisis and innovation in patterns that can only be guessed at. It is true that fossil carbon-based energy has been at the heart of economic development for the past 200 years or more, but if the renewables options grow and prices fall, and if the problems of energy storage can be solved in coming decades, there is no reason to believe that absolute decoupling of carbon from growth will not occur. There is therefore a major

research task in seeking to understand not only the connectedness of global change and sustainability problems, but also how interactions are shaping the social, cultural and economic responses.

2. While there is consensus that in the long run and at the global level, the consequences of scarcity of key resources and more rapidly changing global environmental systems will be severe, the way in which these costs and opportunities will unfold over the coming decades and in particular places is still not well established. The Anthropocene analysis, with its emphasis on the global and the long run, may be an obstacle here. It appears to leave the predicaments faced by people at a distance. This is not to say that social and economic actors do not act on the long run – we save for pensions and companies invest in infrastructures with lifetimes of many decades – but there is still much to learn about precisely when, where and how serious risks will turn out to be for cities, infrastructures, water services, food security and so on. Bringing the Anthropocene into focus over the coming decades, and at spatial and social scales that matter to people remains a formidable analytical task.
3. The costs and opportunities of new planetary risks will be highly unevenly distributed – there will be winners and losers – and this affects the capacity to 'act globally'. Global responses to global risks are most likely when powerful economic and political interests are at stake. Risks tend to be shifted to the weakest and this will continue to be the case, even as more global and connected challenges to sustainable development emerge. Just as global environmental change is an outcome of past inequities of access to natural, economic and human resources, so global environmental change has often acted to exacerbate social inequities in access to resources and environmental services. It may even be argued that the greater the intensity of global competition for resources and services, the less likely is international cooperation to achieve their stewardship, especially where the victims are weak. The experience of the United Nations Framework Convention on Climate Change may bear this out. A study of the geopolitics of the Anthropocene would seek to understand these dynamics of power and seek to inform the development of new institutions that can foster planetary stewardship. These will include unlikely configurations of public, private and citizen initiatives at the global level.
4. The capacity of people and organisations to deal with constraints on access to resources and to cope with transient environmental services will continue to vary in the future. Much of people's resilience and adaptive capacity will be expressed across social scales, at regional, national and local levels, often down to the level of individuals and households. Economic growth will provide greater capacities, while distributive policies, nationally and internationally, will aim to build capabilities to achieve sustainable development. But there are also likely, perhaps sooner rather than later, to be limits in these capacities to adapt (Dow et al., 2013). Conversely, new capacities and resilience will also develop at the global level. For instance, there is already evidence of a growth in the management of catastrophic risks through insurance, allowing for a pooling of risk internationally and the build-up of capital buffers to compensate losses at the global scale. While Hurricane Andrew (1992) caused bankruptcies among insurance companies, by the time of Superstorm Sandy (2012) changes in the industry had allowed it to absorb similar losses more easily (Changnon et al., 1997; Reuters, 2012). There is also evidence of new forms of hedging and diversification in industries with global production networks perceived to be vulnerable to resource scarcities or to the degradation of environmental services (Turral et al., 2011). The disciplines of risk management which financial markets expect, backed by global regulations and emerging private-sector norms and certification schemes, are transforming patterns of investment

and production, and the resilience in key global industries. Despite all this, the world will continue to be deeply unequal and many will be denied the capacity to respond positively to the growing risks to their wellbeing.

5. Finally, we can predict that there will be multiple Anthropocene Futures – it depends on who you are and where you stand. And perhaps this is the most confusing aspect of the idea of the Anthropocene. Tickell (2011: 931) suggests that, '… humans can be regarded, like certain species of ants, as a super-organism'. This is an arresting metaphor because it suggests an emergent global collective action of individuals and societies. But there is unlikely to be a single perspective or consciousness through which to view the predicaments that are presented by the Anthropocene. Short of a real cataclysm, it is likely that 'good' and 'bad' Anthropocenes will continue to exist side-by-side.

We are living through a time of great transformations towards sustainability in energy, food, transport and urban systems. The Anthropocene provides one of the underlying narratives propelling these transformations. The influence of the 'Anthropocene narrative' in shaping expectations and rationales – for investment, for regulation, for lifestyles, for a planetary ethics – are hard to measure and disentangle from the many other influences on social action. The role of programmes such as Future Earth will be to continue to support research on the long run and the global. But we also have a charge to do science that connects to the knowledge and actions of social actors as we find them; in the boards of corporations, in government ministries, in households and in civil society. Connecting to these lived futures challenges us to think again about how we pose questions and how we seek to answer them.

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Review

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Translating science for decision makers to help navigate the Anthropocene

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Abstract

Although scientists typically regard their work as finished with publication in an academic journal, in fact that is just the beginning if the goal is to help society solve problems. This is particularly true for the environmental sciences, in which a generation of scientists has documented that five interacting human impacts are causing undesirable planetary changes: climate change, extinctions, loss of ecosystems not dominated by humans, pollution, and over-population and consumption. Dealing with such issues requires active engagement of scientists with politicians and other leaders as well as the public-at-large. Here we report on the positive outcomes of one such engagement, *The Scientific Consensus on Maintaining Humanity's Life Support Systems in the 21st Century: Information for Policy Makers* (http://consensusforaction.stanford.edu/), which was published in a previous issue of *The Anthropocene Review*. We suggest that effective communication outside the academic sphere will be increasingly important in navigating environmental challenges in the Anthropocene.

Keywords

Anthropocene, climate change, ecosystem loss, extinctions, pollution, population growth, science communication

A defining reality of life in the Anthropocene is that humans exert an inordinate amount of influence on the biosphere. Numerous researchers have documented that as a result of people's activities climate is changing faster and reaching higher temperatures than species have experienced in millions of years (Diffenbaugh and Field, 2013; Intergovernmental Panel on Climate Change

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(IPCC), 2007, 2013); extinction rates are elevated far above background rates (Barnosky et al., 2011; Dirzo and Raven, 2003; GBO3, 2010; Pimm et al., 2006); nearly 40% of terrestrial ecosystems and much of the oceans have been transformed to service humanity at the expense of other species and often with the loss of critical ecosystem services (Cardinale et al., 2012; Daily et al., 2000; Ehrlich et al., 2012; Foley et al., 2005, 2011; Jackson, 2008; Tercek and Adams, 2013; Tyrrell, 2011; Vitousek et al., 1986, 1997); and environmental contamination is causing widespread health problems for people and other species (Diaz and Rosenberg, 2008; Hayes et al., 2003; Lim et al., 2012; Newbold et al., 2009; Staff, 2012). People have fundamentally changed such basic processes of the biosphere as the carbon cycle by adding CO_2 to the atmosphere about 200 times faster than was normal in pre-anthropogenic times (Archer et al., 2009; Berner, 2003; DePaolo et al., 2008), and increasing emissions of nitrogen five-fold, which leads to deposition up to an order of magnitude greater than prior to nitrogen production via the Haber-Bosch process (Erisman et al., 2008). In addition, humans have altered the amount and flow of energy and materials through the global ecosystem by co-opting for ourselves about one-third of the net primary productivity produced through photosynthesis (Grosso et al., 2008; Haberl et al., 2007; Running, 2012; Smith et al., 2012; Vitousek et al., 1986, 1997). At the same time, anthropogenic burning of fossil fuels releases huge amounts of 'fossil' energy into the biosphere (The Oil Drum, 2012; US Energy Information Administration (USEIA), 2013); the amount we add in this way is roughly equivalent to adding two-thirds as much energy as is produced by photosynthesis on land annually (Smith et al., 2012), all for use by a single species, *Homo sapiens*. All of the impacts are ultimately driven by ever-growing human populations, which in many parts of the globe also consume natural resources at a pace that some researchers suggest now requires about 1.5 Earths to sustain, and (assuming no changes) would require the equivalent of two Earths to sustain by the year 2030, and three Earths by 2050 (Rockström et al., 2009; World Wildlife Fund (WWF), 2012; Global Footprint Network (GFN), 2013).

These pressures mean that if society is going to continue to receive the basic services from the biosphere that it has come to take for granted – for example, clean air and water, adequate food, a climate that varies within expected limits – scientifically informed management and governance will be essential. Yet, bringing science to bear on policy decisions in both government and business is a difficult task, as illustrated all too well by such political and economically motivated controversies that surround climate science, environmental contamination, and even teaching such basics as evolution (Aviv, 2014; Oreskes and Conway, 2011).

In view of that, the question of how to effectively inject sound science into the decision-making process looms large in guiding the Anthropocene. Up to now, most scientists have not seen that as a key part of their job, nor has it been significantly rewarded in many academic institutions. In addition, tangible results of science communication efforts are often difficult to see. All of these considerations lead many scientists to the conclusion of 'Why bother?'. The answer is because when scientists are effective at communicating their discoveries outside academia, the science becomes an important component in determining the directions of global change. But, what leads to a successful science communication effort?

Here, we retrospectively examine one effort that, although still in early stages, has already been useful in engaging scientists and policy makers in a productive manner, with the goal of highlighting the ingredients that led to success. The vehicle for dialogue has been the *Scientific Consensus Statement on Maintaining Humanity's Life Support System in the 21st Century: Information for Policy Makers*. The full document was published in a previous issue of *The Anthropocene Review* (Barnosky and Hadly, 2014; Barnosky et al., 2014). Basically, it lays out the science-based consensus on the advisability of mitigating climate change, extinctions, ecosystem loss, widespread pollution, and population growth and overconsumption, and as of this writing has been endorsed by more than 1400 practicing scientists and nearly 1800 people from other walks of life (business people, NGO representatives, graduate students, undergraduate and high school students, and other concerned citizens) (http://consensusforaction.stanford.edu/index.html).

We emphasize that there are numerous other such documents that have been exceptionally useful in developing dialogues between scientists and other constituencies (Crowder et al., 2012; GBO3, 2010; IPCC, 2007, 2013; IPCC-SREX, 2012; Molina et al., 2014; Society for Conservation Biology (SCB), 2013; Union of Concerned Scientists (UCS), 1992; United Nations Environment Programme (UNEP), 2012; WRI, 2005; World Science Academies, 1994), to name but a few. We focus on the *Scientific Consensus Statement* simply because we have been involved from the outset with creating it and using it to engage with policy makers, and thus are well versed in its development and in the process that led to its widespread use. Our hope is that the lessons we learned will be useful in stimulating other scientists to effectively engage with people outside academia who need to understand and use what science has to offer. We begin with a brief summary of what the Consensus Statement accomplished, then dissect what led to its widespread use, and conclude with our views on how consensus statements such as this one fit into the broader spectrum of making decisions in the Anthropoocene.

Background of the *Scientific Consensus Statement*

The effort began in 2010 as scientists from many research institutions located in the USA, Canada, Europe and South America met at a University of California-Berkeley Initiative for Global Change Biology workshop to identify major biological problems arising from the many ways people are now changing the Earth. The result was a publication in a peer-reviewed journal, produced after more than a year of follow-up work by 22 biologists from four countries (the USA, Chile, Finland and Spain) (Barnosky et al., 2012). The publication presented evidence that Earth had seen major ‘state-changes’, in its past; that such transitions are rapid on the scale of geological time and radically transform the biosphere with respect to the previous state; and that the magnitude of human impacts was now great enough to initiate another planetary state-change in the foreseeable future – not over geological time, but within human lifetimes. A key point of the paper was that such a rapid transition at the global level would be disruptive to present societal functions. This is because societal stability relies on the expectation that environmental fluctuations in the near future will not exceed those considered normal for the past couple of centuries and that any future changes will proceed linearly with ample warning for adaptation. In reality, biological systems (and complex systems in general) often change rapidly and in unanticipated directions as critical thresholds are crossed because of either gradual or sudden forcings.

The results presented in that publication were picked up widely in the popular media. California’s Governor Jerry Brown also became aware of the study, and contacted the participating scientists to ask, in effect: ‘If these are such big problems, why aren’t you scientists shouting it from the rooftops? And why are you scientists only talking to each other? Why don’t you give policy makers and the general public something we can use?’.

Following that, a group of 16 global change scientists from seven research and teaching institutions (UC Berkeley, Stanford University, University of Washington, University of New Mexico, University of Helsinki, University of Oslo, and Environmental Health Sciences) continued a dialogue with the governor and his staff about how to deliver scientifically accurate information in a form that world leaders could easily digest and use. The interaction led to the production by the scientists of the document: *Scientific Consensus on Maintaining Humanity’s Life Support System* *in the 21st Century, Information for Policy Makers*. The goals were to: (1) crystallize the science that documented that climate change, extinctions, ecosystem loss, pollution, and human population overgrowth and overconsumption were proceeding unusually fast with respect to the history of life on Earth; (2) point out scientifically grounded potential societal impacts; and (3) highlight broad-brush solutions to the problems. The scientists' role was to present accurate information. The role of the governor's office was to tell scientists what policy makers would find most useful to know, and what styles of communication were most effective.

Once the drafting scientists completed the document, it was e-mailed to researchers respected for their work in the global change community with the request to endorse it. Within less than month, 522 scientists from 41 countries throughout the world had signed the statement. At the same time, a multi-stakeholder collaborative organization, Sustainable Silicon Valley (SSV), invited the scientists coauthoring the statement and the governor to release it at SSV's annual summit, which SSV independently organized. This collaboration brought the business and NGO community into the communication effort. As a result of SSV's involvement, the Consensus Statement was jointly released by participating scientists and Governor Brown on 23 May 2013, at the 2013 SSV Water-Energy-Smart Technology Summit, held at the United States National Aeronautics and Space Administration Ames Research Center at Moffett Field, California.

Uses of the *Consensus Statement*

Upon its release, Governor Brown promptly started using the *Consensus Statement* and the information therein in policy discussions with political leaders nationally and internationally, as well as with US governors and California business people and local officials. Sustainable Silicon Valley began using the statement to engage business and technology leaders, and participating scientists continued to distribute it internationally, not only to academic leaders, but also to those in a variety of decision-making positions and the general public. The distribution included translating the statement into Chinese and Spanish (with the realization that translation into other languages is now needed – presently the Executive Summary is also available in French and Portuguese), and presenting the statement to summarize the issues in wide variety of venues, including policy meetings among high-level officials; direct contacts between scientists and decision makers; seminars and classes in academic settings in the USA, Canada, Mexico, Costa Rica, Finland, Norway, Austria, Germany, Switzerland and Kenya; and public lectures, op-eds and news stories, to name the chief ones. Recently a web-based effort also was launched (http://consensusforaction.stanford.edu/).

As a result, within a year the statement was delivered to many world leaders, among them: US President Barack Obama and many of his staff, including Secretary of State John Kerry; China's President Xi Jinping and Vice Chairman of the National Development and Reform Commission Xie Zhenhua; Japan's Governor Ichiro Matsui of Osaka Prefecture; the United Kingdom's Energy & Climate Change Minister Gregory Barker; Mexico's Governor Eruviel Avila, José Sarukhán (President of Mexico's National Commission on Biodiversity) and Julia Carabias (Mexico's former minister of the Environment); Malaysia's Right Honourable Datuk Seri Panglima Musa Haji Aman, Minister of the State of Sabah; the leader of the Othodox Christian Church His All Holiness Bartholomew I, Archbishop of Constantinople, New Rome, and Ecumenical Patriarch; a Wadaonai chief from the Yasuní region, Ecuador; governors of several states in the USA and ministers from Canadian provinces; selected congressional representatives in the USA; and mayors of several major cities in California and elsewhere. The nascent web-based distribution effort has also helped to bring the *Consensus Statement* to the general public, although much work remains to be done in that arena.

Did providing this information to policy makers make any difference? Only time will tell the full story, but already there are encouraging reports. Within the first six months of its release, the *Consensus Statement* helped inform policy discussions that led to two international agreements between California and other entities to cooperate on reducing greenhouse gas emissions and developing green technology. On 13 September 2013, California and China signed a Memorandum of Understanding that committed both parties to: 'Mitigating carbon emissions; strengthening performance standards to control greenhouse gasses; designing and implementing carbon emissions trading systems; sharing information on policies and programs to strengthen low-carbon development; exchanging personnel and jointly organizing workshops and training; and researching clean and efficient energy technologies' (http://gov.ca.gov/news.php?id=18205). The *Consensus Statement* was translated into Chinese and presented by Governor Brown to President Xi Jinping and National Reform and Development Commission Vice Chairman Xie Zhenhua (the signatory on behalf of China) in meetings that preceded the signing of the MOU (http://gov.ca.gov/news.php?id=18086).

The second international agreement came on 28 October 2013, with the signing of the Pacific Climate Pact by the governors of California, Oregon, Washington and British Columbia's Minister of the Environment (on behalf of the Premier of British Columbia). That agreement includes: 'accounting for the costs of carbon pollution in each jurisdiction; harmonizing 2050 targets for greenhouse gas reductions and developing mid-term targets needed to support long-term reduction goals; taking steps to expand the use of zero-emission vehicles, aiming for 10 percent of new public and private fleet vehicle purchases by 2016; enlisting support for research on ocean acidification and taking action to combat it; adopting and maintaining low-carbon fuel standards in each jurisdiction; and continuing deployment of high-speed rail across the region' (http://gov.ca.gov/news.php?id=18284). More broadly, the agreement commits the parties to:

> Cooperate with national and sub-national governments around the world to press for an international agreement on climate change in 2015. The governments of California, British Columbia, Oregon and Washington will join with other governments to build a coalition of support for national and international climate action, including securing an international agreement at the Conference of Parties in Paris in 2015. The governments of California, British Columbia, Oregon and Washington will coordinate the activities they undertake with other sub-national governments and combine these efforts where appropriate. (http://gov.ca.gov/news.php?id=18284)

And, relevant to scientists' efforts to communicate science such that it helps guide global change, the agreement includes the following language:

> Affirm the need to inform policy with findings from climate science.
>
> Leaders of California, British Columbia, Oregon and Washington affirm the scientific consensus on the human causes of climate change and its very real impacts, most recently documented by scientists around the world in the Intergovernmental Panel on Climate Change's Fifth Assessment Report released in September 2013, as well as other reports such as the Scientific Consensus on Maintaining Humanity's life Support Systems in the 21st Century. Governmental actions should be grounded in this scientific understanding of climate change. (http://gov.ca.gov/news.php?id=18284)

The California-China MOU and the Pacific Climate Pact are significant in three respects. First, they clearly incorporate the scientific realities into developing policies aimed at guiding the future, and benefited from dialogue between scientists and policy makers. Second, within the USA, they mark a watershed in how subnational entities can move forward with important international cooperation, despite political gridlock in Washington, DC. Third, they have economic as well as scientific impacts on the world stage: China is the world's second largest economy, California the world's eighth largest, and the combination of California, Oregon, Washington and British Columbia would equate to the fifth largest in terms of Gross Domestic Product.

Ingredients of successful engagement

Despite having been in circulation only a year, and being forged and disseminated only through the grass roots efforts of scientists without funding by outside organizations, the *Consensus Statement* is now in the hands of political and other leaders in many nations, has led to direct dialogues between scientists and policy makers, and has proven useful in discussions that produced tangible international climate policies. To what can this high level of rapid engagement be attributed and are there general lessons for communicating science that can be extracted? In examining the process retrospectively, we identify the following key ingredients.

Sound science

The key ingredient, of course, is sound science, around which consensus actually exists. In the case of the *Consensus Statement*, the science conveyed about its five focal issues is the result of decades of research by hundreds of scientists, vetted and refined through the years in the form of thousands of peer-reviewed publications. Each of those publications, however, typically focused on just one of the five key environmental problems. An important trigger for developing the new dialogue with policy makers seemed to be a synthetic peer-reviewed study, coauthored by 22 investigators from seven countries and three continents representing a variety of related disciplines. That study treated the issues not as discrete, but as an interconnected set of problems that by interacting had the potential to cause abrupt, societally relevant changes that would likely manifest themselves within decades.

Media coverage and timing

There is no doubt that science reporters have an important role to play in translating the work reported in peer-reviewed scientific publications to wider audiences. Scientists can actively contribute to this process through working with their university press offices to prepare accurate press releases about their scientific work, as several of the authors of the synthetic paper noted above did, and by responding quickly, clearly and accurately to reporters when interviews are requested. If the issue is deemed newsworthy by the popular press, it can reach a broad audience rapidly through print, television and internet-based reporting.

Whether or not a scientific article will be picked up by the popular media depends in part on how it relates to current 'news hooks', that is, what people tend to be concerned with at the moment. In the case of the article that awakened interest in the issues that eventually were summarized in the *Consensus Statement*, the timing was fortuitous. The publication appeared just as the Rio +20 meetings were convening, so environmental issues were generally in the news. Whatever the reasons, considerable media attention ensued and brought the scientific issues covered in the paper to the attention of the general public, including the policy-making community.

Commitment from the policy-making community

Among those who saw reports about the peer-reviewed study was California Governor Jerry Brown. Recognizing the relevance of the study's conclusions to ongoing dialogues about climate change and other environmental issues, he initiated conversation with the scientists about the key environmental issues that policy makers face. In the course of these conversations, it became apparent which information that is essentially taken for granted by the environmental science community had not effectively percolated outside academia, and that an important way to fill the information gap would be to develop a scientific consensus statement designed specifically to convey the issues to the policy-making community. After the *Consensus Statement* was released, Governor Brown integrated it into a wide variety of meetings with other high-level politicians to elevate the visibility of environmental issues that need to be addressed. The importance of such commitment by a politician to engage with scientists and advocate for including science into the decision-making process cannot be overemphasized, since it is in the political arena that policies are actually developed.

Ongoing dialogue

Communicating science to policy makers is not a one-off occurrence, and requires commitments by participating scientists to continually engage after the initial release of information. One of the lessons learned from our *Consensus Statement* experience is that successful communication requires an ongoing dialogue that involves not only telling the policy makers about the science, but learning from the policy makers what scientific information is most important to them in a given circumstance, and what constraints besides the science must also enter into the decision-making process. An important part of the engagement is the willingness of scientists to respond to immediate needs, which come up suddenly in the political arena.

Avoiding prescriptive advocacy

Elsewhere we have noted that efforts to communicate science generally fall into three basic categories: general interest communication, prescriptive advocacy and informative advocacy (Hadly and Barnosky, 2014). The first is simply communicating scientific discoveries that are likely to catch the public's interest but with no decision-making goal in mind (for example, the finding that crows can accomplish some tasks that require causal understanding similar to that of a 5- to 7-year-old child (Jelbert et al., 2014) (and see the Science Daily report at http://www.sciencedaily.com/releases/2014/03/140326182039.htm). The other two, as their names imply, involve advocating that the science be considered in making a policy decision. The difference between the two kinds of advocacy was the focus of a previous article, from which we extract the following relevant passages:

> Informative advocacy … uses scientific knowledge to foretell the environmental (in our case) changes of probable societal relevance that lie ahead. It differs from pure science communication, which is simply to inform, in having an important goal of injecting the scientific realities into the many different categories of information that decision makers must take into account when formulating policy. Informative advocacy also has a second goal that is critical: learning from decision makers about the kind of information they need. This back-and-forth dialog ultimately opens new doors for decision makers to formulate solutions to complex problems, and new doors for scientists to understand how their science is socially relevant.
>
> Prescriptive advocacy, in contrast, means using your position as a scientist to push for a particular policy action, which can do just the opposite of science communication or informative advocacy. We have found that prescriptive advocacy narrows choices for the decision makers, and often ignores harsh realities that especially elected officials face: a wide spectrum of societal views on what constitutes the most pressing needs, and economic and technological feasibility.

> In essence, communicating science involves boiling down the discoveries of the practicing scientific community to their accurate bullet points, and highlighting the societally relevant impacts. Informative advocacy involves taking that science to decision makers (and the general public), and pointing out scientifically sound paths to desired destinations. But it is left to the decision makers (often our elected officials) to decide which of the multiple pathways to solving a particular problem are the most practical to pursue, taking into account the layout of the entire constituency landscape.
>
> Communicating science and informative advocacy identifies destinations and available paths, but does not barricade some paths in favor of others.
>
> Prescriptive advocacy, on the other hand, is all about making arguments that your path is better than any other one. The problem with prescriptive advocacy is that you can tie the hands of decision makers, making it more difficult for them to find the best route through what is usually a complex maze of needs and opportunities.

While all three kinds of science communication can play a useful role in helping to guide the future, it is critical that scientists recognize which kind of communication they are using in a given instance. The Consensus Statement falls in the category of informative advocacy, in that while it specifies the needed destinations and their feasibility, it does not argue that policy makers should implement one specific solution over another. It makes clear that the science indicates that actions are needed to avoid certain future scenarios, but leaves it to policy makers to determine which future scenarios are most desirable, and exactly how to get there.

A challenge for scientists

Our engagement with policy makers in the context of developing and using the *Scientific Consensus on Maintaining Humanity's Life Support Systems in the 21st Century* has convinced us that such science communication efforts are both rewarding and productive. The experience has also demonstrated to us that, while communicating science to policy makers will be essential in helping to formulate a future in which society thrives, a reality is that effective engagement takes time. It adds yet another job to the other three that are usually expected of scientists in many institutions: doing cutting edge research that leads to new breakthroughs published in peer-reviewed journals; teaching; and the administrative duties essential to running both individual research programs and the employing institution. We suggest, however, that the task of making the science useful to those who need it most – political leaders, business leaders, and the public-at-large – is at least equally important as the basic research, teaching, and administration scientists are usually involved in. That means that no longer is a scientist's project finished when results are published in a peer-reviewed paper, especially with regards to critical global problems such as climate change, extinctions, ecosystem loss, pollution, and population overgrowth and overconsumption. The next step, communicating that knowledge to those who need it outside academia, will be what ultimately helps chart the course for navigating the Anthropocene. In our experience, taking that next step is well worth the effort.

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Review

THE ANTHROPOCENE REVIEW

Redefining historical climatology in the Anthropocene

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Franz Mauelshagen

Abstract

Historical climatology is commonly defined as the study of past climates based on 'documentary evidence' before the establishment of modern networks of meteorological measurement, which excludes the last two centuries of recent global warming. This article reviews historical climatology with regard to the Anthropocene. In the Anthropocene the dynamics of climate change are essentially anthropogenic. The term 'sociosphere' will be advocated as a terminological improvement over existing attempts to define the place of human activities in Earth System Analysis. Theoretical and empirical advances in the study of social ecodynamics are called for. Historical climatology has a capacity to contribute making such advances, but a redefinition is inevitable for this potential to be realized: (1) historical climatology needs to expand temporally into the 19th and 20th centuries; and (2) it has yet to adjust to an important conceptual transition in climatology: from a descriptive (meteorological) concept of climate to climate dynamics.

Keywords

anthroposhpere, climate dynamics, climate forcing, Earth System analysis, historical climatology, social ecodynamics, sociosphere

Introduction

For more than a decade, the idea of a geological 'age of man', in which human action has become the driving force of global environmental change, has been discussed under the term 'Anthropocene'. In 2014, the *International Commission on Stratigraphy* (ICS) is expected to decide whether it is now time to officially add it to the stock of stratigraphic terminology. Independent of the outcome, it seems likely that both the term and the idea connected with it will gain more ground in the continuing debate about global change, its causes and consequences. If this is true, academic disciplines and subdisciplines (inside or outside the earth sciences), or any research involved with global environmental change (e.g. the loss of biodiversity or global

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warming), will be faced with the challenge to reflect about their potential for improving our knowledge of the Anthropocene on all levels of understanding.

It has been pointed out before that the proposal to establish a new geologic epoch, the Anthropocene, not only affects geology or the earth sciences, but also our understanding of history in general and climate history in particular (Chakrabarty, 2009, 2010, 2011; Mauelshagen, 2012). Anthropogenic climate change has been one of the main features to define the Anthropocene and its chronology. It is, therefore, obvious to ask for the concrete implications the Anthropocene may have for disciplines involved in climate science today, especially those dealing with climate history. One such discipline is historical climatology. What is its potential contribution to improving our knowledge and understanding of the Anthropocene? And what are the implications of making such a contribution for the future of historical climatology? Historical climatology has been part of the study of past climatic changes on a centennial and millennial scale, which has been relevant to confirming the fact of recent global warming. But it is yet to get involved in discussing the Anthropocene or in writing its climate history.

The first part of this article provides a critical review of the field, focusing in particular on the definition of historical climatology and, to some extent, its research history. This will help to detect the limits of research that have kept historical climatology so far from entering 'Anthropocene territory'. At the end of the review section of this article, two problems will be identified for further discussion in the two sections that follow: (1) the problem of periodization, which is the result of a tradition in historical climatology to exclude the most recent era of global warming from its territory; and (2) the problem of climate dynamics and the share human activities have in it in the era of global warming. Historical climatologists have made some contributions to improve our knowledge of past climate dynamics, though much more could be done in this area, but they have yet to include anthropogenic forces. This gap is paralleled by difficulties in Earth System Analysis to integrate society as the driving force of anthropogenic climate change. These difficulties will be addressed in the third part of this article, which includes a review of concepts that have been proposed to define the place of society in the Earth System. Any conceptual decision will affect how well the study of the Anthropocene connects with the social sciences and humanities. Improving our understanding of the societal dynamics that drives global change in the Anthropocene is of paramount importance. The proposition made towards the end of this article to build future research in this area on the concept of the sociosphere may be regarded as a contribution to the theory of Earth System science, which has provided the framework for most interdisciplinary research on global change in the past two or three decades. In this article, the concept of the sociosphere and its ecodynamics will help defining a new research branch in historical climatology, which will be redefined in the conclusion.

Historical climatology: A critical review

From its beginnings, historical climatology has been an 'interdiscipline' combining approaches (i.e. theories and methodologies) from both sides of the divide between the 'two cultures' (Snow, 1959) of the natural sciences and the social sciences/humanities. The majority of historical climatologists share a scientific background in physical geography with specializations in meteorology and climatology, while historians form the minority. Despite its overall success, interdisciplinary cooperation has raised some terminological questions, which still cause problems of understanding in- and outside the two cooperating disciplines. For example, historians (and other scholars in the social sciences and humanities) often use 'climate history' as a

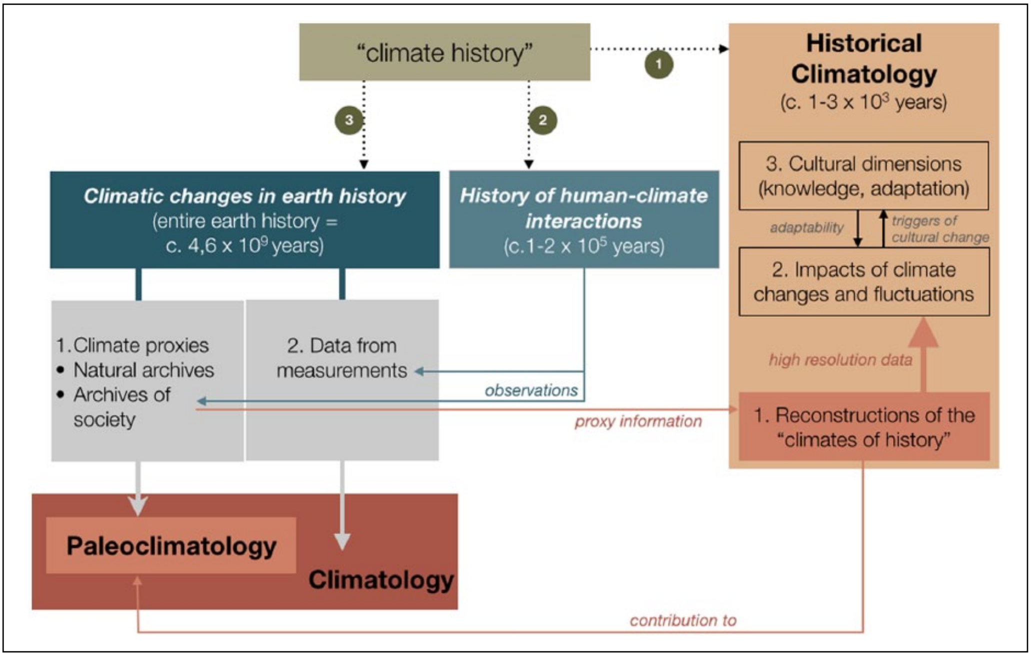

Figure 1. Three common meanings of 'climate history'. They are referring to entirely different timescales and rely on different types of evidence. The graph further illustrates how historical climatology is connected with paleoclimatology and what type of proxy information it relies on in the area of climate reconstruction.

synonym for 'historical climatology', mainly because they feel uncomfortable with the term 'climatology'. Yet, consensus about the meaning of 'climate history' will be difficult to achieve, even among historians. Forty or fifty years ago, many would probably have agreed that it denotes the study of climate and its impact on human affairs for those periods and those parts of the world for which written record exists. This is precisely the traditional line of thought from which historical climatology has emerged. However, this is only the first among three fairly common ways of speaking of 'climate history'; the second parallels the temporal scope of climate history with the history of the human species. Recent examples are Wolfgang Behringer's and John L Brook's monographs (Behringer, 2010; Brook, 2014), which also include brief surveys of climatic changes in Earth history prior to the appearance of biologically modern humans (*Homo sapiens sapiens*) – which already refers to the third meaning of 'climate history', i.e. the course of climate through the history of the Earth, a definition (palaeo-) climatologists most likely prefer over the other two (see Figure 1).

In sum, climate history is not a clearly defined subject of research; nor does it represent a research branch or discipline with a specific set of methodologies and theories. Instead, its scope varies with disciplinary contexts in both temporal depth and thematic range, either limiting itself to reconstructing past local or global climates, or including the study of climate impacts on the biosphere and/or on human populations as well as the study of cultural adaptations.

Contrasting these ambiguities, historical climatology has been established for decades as a field of study placed at the intersection between (palaeo-)climatology and (environmental) history.[1]

Scholars working in this field have reached a consensus to subdivide historical climatology into three study areas or domains:

(1) reconstruction of past climates based on documentary evidence (written records),
(2) the study of climate impacts on societies, and
(3) the study of cultural dimensions of society–climate interactions such as perception, knowledge, ritual and science.

However, the latter two domains were included by historical climatology only after some hesitation, to which the evolution of its definitions bears witness. It is important to sketch this evolution first – also with regard to the novel definition proposed in the conclusion of this article. A survey of developments and achievements in the area of climate reconstruction will follow. This is the domain focused on in this article for practical reasons, mainly because a comprehensive review of all three branches of historical climatology would at least double its length. Even with regard to climate reconstruction the purpose is not to give a complete state of the art summary, but to familiarize the readers of this journal with the character and scope of contributions historical climatology has made so far to improve knowledge of past climate variability and recent global warming, which is, in the end, what links historical climatology with the Anthropocene.

Definitions of historical climatology

When the contours of historical climatology began shaping around 1960 (Le Roy Ladurie, 1959, 1961; Manley, 1958; Utterström, 1955) the traditions of geographic determinism in general (Semple, 1911), and climatic determinism in particular (Huntington, 1915, 1917), had made historians and geographers very sceptical about any too direct causalities between climatic changes and the history of humanity (Febvre, 2009, first edition 1922; Vidal de La Blache, 1922). However, climate determinism was a problem not only when it came to assessing the impacts of climate variability on past economies and societies. Determinist assumptions about the traces left by climatic fluctuations in social and economic history and their record (e.g. price series for wheat, rice and other agricultural products in pre-industrial agrarian societies) had also taken a hand in the area of climate reconstruction. In other words: the spirits of determinism had also had an influence on the documentary evidence selected as climate proxy (Brooks, 1922, 1949). Consequently, reorganizing the distinction between reliable and unreliable documentary proxy information was necessary. With this objective in mind, Emmanuel Le Roy Ladurie suggested suspending impact research, prioritizing the reconstruction of historical climates and, thus, creating a branch of historical research – ‘climate history’, as he called it – in which humans only featured in the role of direct or indirect observers of the weather (Le Roy Ladurie, 1959, 1961, 1967, 1972). He provokingly described this new territory of study as a form of ‘history without human beings’ (Le Roy Ladurie, 1979a, 1979b; Le Roy Ladurie and Rousseau, 2013; Mauelshagen, 2009). Forty years later, it is only too obvious that this expression was based on the tacit assumption that climatic changes were unaffected by human activities, at least in periods of climate history prior to the 20th century. In our day, anthropogenic climate change has been established as a scientific fact almost beyond doubt, and Le Roy Ladurie himself has taken note of it in his late work on climate history (Le Roy Ladurie, 2004/2006; Le Roy Ladurie and Rousseau, 2013).

The temporary suspension of historical climate impact research, until the knowledge of past climates was better prepared to meet its challenge, may be termed the ‘climate-first approach’, which established a lasting special relationship between historians and physical geographers

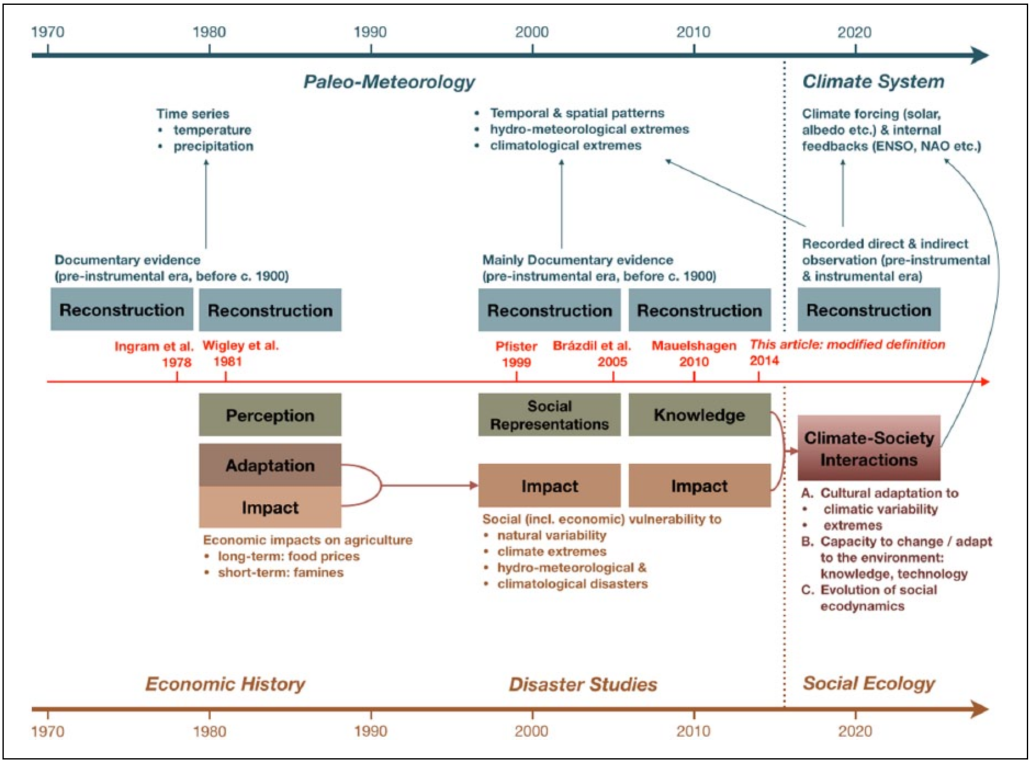

Figure 2. Evolution of definitions of historical climatology since 1978. The timeline (red) splits this graph into two halves, which represent methods and paradigms adopted by historical climatology from its twofold scientific environment: climatology in the upper area (blue colour range), history/the social sciences in the lower area (brown colour range). This graph already includes the redefinition of historical climatology suggested in the conclusion of this article.

(meteorologists, climatologists). Transdisciplinary cooperation between them left traces in attempts to define 'historical climatology', which began effectively with a 1978-article published by Ingram, Underhill and Wigley in *Nature* (see Figure 2). The authors recognized that 'descriptive documentary evidence' was

> an important source of detailed information on past climates, particularly for the period between the eleventh century and the beginning of the era of instrumental meteorology. [...] The successful exploitation of this material demands a varied range of skills and techniques which effectively define specialised subdisciplines of climatology. Historical climatology is best thought of as one such subdiscipline, which focuses on the study of written materials (excluding records of modern standardised instrumental observations) which bear on past climate. These materials include, not only meteorological information, but also data on such phenomena as glacier movements, phenological events and other more or less indirect indicators of climatic change. (Ingram et al., 1978: 329)

Following Ingram et al.'s 1978 article in *Nature*, new dimensions entered the field quickly in the early 1980s (Rotberg, 1981). In their introduction to *Climate and History*, Ingram, Framer and Wigley considered four aspects of study: 'climate reconstruction; the identification and measurement of impact; adaptation and perception' (Wigley, 1981: 4). Later definitions of historical climatology condensed these four aspects into three more or less canonized study areas, while they continued agreeing with the temporal limitations suggested for historical reconstructions in 1978 (e.g. Brázdil, 2000; Mauelshagen, 2010: 20). The now 'classical', most widely accepted version described historical climatology as

> a research field situated at the interface of climatology and (environmental) history, dealing mainly with documentary evidence and using the methodology of both climatology and history. It is directed towards the following three objectives:
>
> (1) It aims at reconstructing temporal and spatial patterns of weather and climate as well as climate-related natural disasters for the period prior to the creation of national meteorological networks (mainly for the last millennium).
> (2) It investigates the vulnerability of past societies and economies to climate variations, climate extremes and natural disasters.
> (3) It explores past discourses and the social representations of climate.
>
> (Brázdil et al., 2005: 365–366)

These three domains to some degree mirror general study areas of climate science today, as may be gathered from the IPCC's subdivision into Working Group 1 on the Physical Science Basis and Working Group 2 on Impacts, Adaptation, and Vulnerability. Yet, research in those domains has not developed homogeneously; the systematic links between them are relatively loosely defined; and there are few empirical studies that have successfully combined them (e.g. Pfister, forthcoming; Pfister et al., 2010; Rohland, 2011, 2013). While the connections between reconstructed climatic fluctuations and (more long-term) changes with impacts on and adaptive processes in society seem obvious, the history of climate perceptions and knowledge in particular is badly integrated (Mauelshagen and Pfister, forthcoming).

Early attempts at reintroducing climate impact studies were made in the later 1970s, when subjects then popular in historical demographics (the study of populations), economic and agrarian history (poverty, famine, prices for cereal crops) promised good connectivity between climate history and human history (Pfister, 1975; Post, 1977, 1984). Famine in particular had captured the attention of economic historians. However, this was short-lived. Notice of the relevance of climate in the history of famines declined rapidly in the 1980s, when new famine theories discredited any approach that would place famines anywhere close to 'natural disasters' (Fogel, 1992; Sen, 1981). The focus of historical climatologists on reconstruction was questioned once again in the late 1990s, when (historical) studies of natural disasters discovered the relevance of climatico-meteorological extremes and anomalies. From here, new links between history and other disciplines from the social sciences and the humanities spectrum were established. Historical climatologists adopted concepts of vulnerability and resilience, and they learned about coping and adaptation strategies that were culturally specific. Concepts and methodologies from the social sciences and humanities helped to better grasp the complexity of climate–society interactions (Mauelshagen, 2009; Mauelshagen and Pfister, forthcoming; Pfister, 2005).

There is an alternative meaning of 'historical climatology' that is often ignored. Let us call it 'HistClim-METEO' as opposed to 'HistClim-PALEO' wherever both meanings need to be kept in mind. Since the 1990s, the US National Climatic Data Center (NCDC) established two data sets called 'Global Historical Climatology Network (GHCN)': one set of monthly data (GHCN-M), the other of daily data (GHCN-D) of temperature (Lawrimore et al., 2011; Peterson and Vose, 1997), precipitation and pressure records from land surface stations across the globe. For the daily resolution data set, more than 75,000 stations from 180 countries provided data exchanged under the World Weather Watch Program of the World Meteorological Organization (WMO) (Menne et al., 2012). Weather stations with the longest record history cover intervals ranging up to more than 175 years. What defines these data sets as 'historical' is not merely the temporal range of the oldest data they contain, but also 'non-climatic influences such as changes in instrumentation, station environment, and observing practices that occur over time',[2] which require application of homogenization methods to assure data quality. This applies to all recent efforts in data rescue (DARE). Among the benefits of high-resolution, long-term quality data Brunet and Jones have emphasized their 'paramount importance' for regional climate change detection and modelling, the reconstruction of past climates from proxy records, and improved impact studies (Brunet and Jones, 2011: 30, 37). The demand for high-quality historical station data also applies to reconstructions in HistClim-PALEO. At least in the service area of data support HistClim-METEO connects with HistClim-PALEO, although the latter defines its territory outside the realm of meteorological station data. As we shall see in the second part of this article, there is more reason for reintegrating HistClim-METEO and HistClim-PALEO under one umbrella, i.e. one definition that includes both (see also Conclusion).

Reconstructing climates of the past

As illustrated in Figure 1, the reconstruction part of historical climatology (= HistClim-PALEO, now and in the following) may be treated as a subdiscipline of paleoclimatology, i.e. 'the study of climate prior to the period of instrumental measurements' (Bradley, 2014; Hagedorn and Glaser, 1990). Alternatively, historical climatology is sometimes distinguished from paleoclimatology based on the difference between 'human archives' (preserved human record) and 'natural archives' (proxies preserved in nature), which leads to a trichotomy of climatological subdisciplines: paleoclimatology, historical climatology and instrumental climatology (Pfister et al., 2008). However, historical climatology shares the same standard procedure with other branches of paleoclimatology (see Figure 3), e.g. dendroclimatology, and it applies more or less the same statistical tools (correlations, regression analysis) in deriving time series from proxy information (Brázdil et al., 2010a). Considering the two principal types of information that can be extracted from documentary sources, i.e. direct observation of meteorological parameters (be it measured or not) and indirect observation of climatically influenced processes in nature (observed natural proxies), historical climatology does indeed hold an intermediary position between paleoclimatology and instrumental climatology (see Table 1).

What distinguishes historical reconstructions most clearly from other reconstructions in paleoclimatology is

(1) the type of proxy information, i.e. human direct and indirect observations of weather and climate as recorded in written or graphic documents (paintings, drawings, maps, photographs; e.g. representations of glaciers and their extension), nowadays often in the form of digitized copies made available by libraries and archives. This type of information poses specific methodological challenges and has specific uncertainties (Brázdil et al., 2005; Pfister et al., 2008);
(2) the expertise required to access that information: knowledge of cultures of written record and graphical representation, and their conservation in archives and libraries; and
(3) methodologies to transform (often purely) qualitative information into quantitative time series (content analysis, indexing), which allow derivation of meteorological time series (e.g. temperature or precipitation series) by statistical means (correlations, regression analysis).

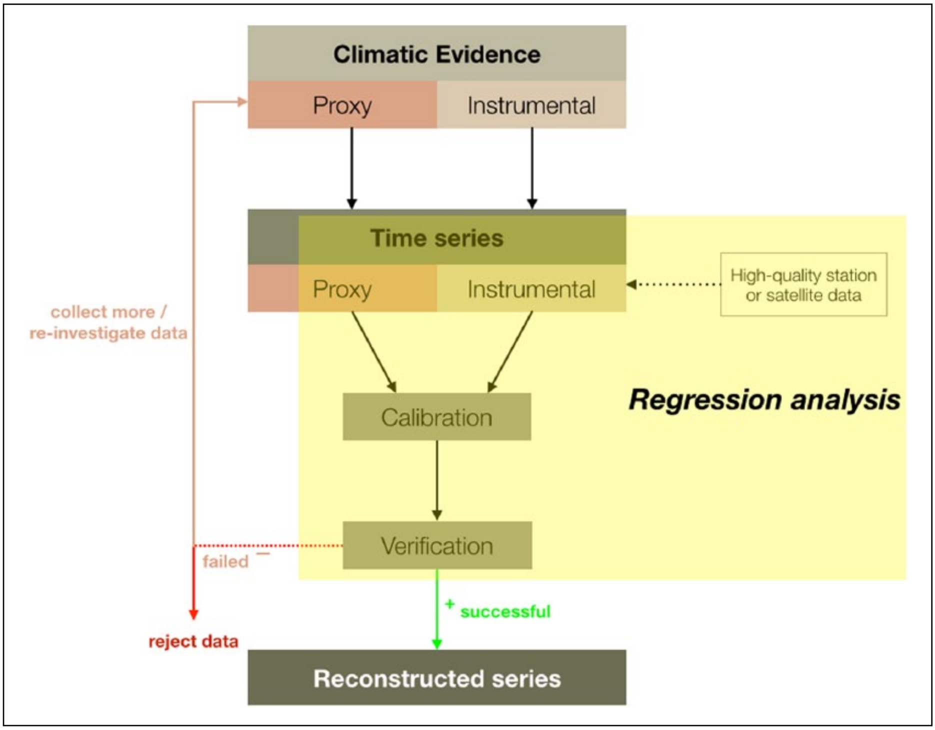

Figure 3. Standard procedure in palaeoclimate reconstruction.
Source: Slightly modified scheme from Brázdil et al. (2010a).

Precise dating of documentary information may be tricky or impossible in some cases, but it never requires anything equivalent to the complex dating methods without which data derived from natural proxies cannot be plotted.[3] Plotting historical data is comparatively simple. Moreover, they allow the highest temporal resolution for a great variety of relevant information (see Table 2), which is particularly valuable when it comes to paralleling climatic changes with changes in society. Weather observations preserved in historical records are often available on a daily, sometimes hourly resolution (e.g. in ship logbooks or weather diaries). Other than dendroclimatological reconstructions they are not limited to information on the growing season. Within the spectrum of available sources of information for palaeoclimatic reconstructions, documentary evidence is particularly valuable for its high-resolution information on the winter season (Dobrovolný et al., 2010). Thus, historical climatology is the only branch of reconstructive climatology capable of designing centennial- to millennial-scale high-resolution time series (i.e. monthly, seasonal or annual resolutions) by calculating averages of even higher-resolved sets of data that span around the year. In that regard, historical climatology resembles modern meteorology more than any other branch of paleoclimatology and might, therefore, be aptly termed ‘palaeo-meteorology’.

As historical climate reconstruction depends on the availability of written record, its scope is limited temporally and geographically to periods and cultures where such record was kept and passed on. Generally speaking, record keeping was most common in agrarian civilisations across Eurasia (the Middle East, China, Japan, Europe), where concerns about the effects of climatic fluctuations on crops were reason enough to observe the weather. Meteorological extremes and hazards were the greatest concern almost everywhere, which explains why the record of such

Table 1. Survey of types of data for reconstruction of past climates.

Archives				
Direct observation			Not measured	Measured
Of meteorological parameters			anomalies climatological and meteorological hazards weather patterns daily weather	air pressure temperature precipitation water levels
Indirect observation	Organic	Inorganic	Organic	Inorganic
Evidence of climatically influenced processes	tree rings fossil pollen remains of animals and plants fossil wood	ice cores varves terrestrial sediments lake and see sediments speleothems moraines borehole temperature profiles, etc.	plant phenology animal phenology distribution of crops yield of crops: sugar content (vine) *Cultural* reported rogations	water levels (flood marks) snow and ice cover and duration first and last frost glaciers (pictorial evidence)

Source: Modified from Pfister et al. (1999, 2008).

Table 2. Comparison of maximum resolution, temporal range, and potential information of different sources for palaeoclimatic reconstructions.

Archive	Minimum sampling interval	Temporal range (order/year)	Potential information derived[a]
Historical records	Day/h	$\sim 10^3$	T, P, X, B, V, L, S
Tree rings	Year/season	$\sim 10^4$	T, P, B, V, S
Lake sediments	Year (varves) to 20 years	$\sim 10^4–10^6$	T, B, M, P, V, C_w
Corals	Year	$\sim 10^4$	C_w, L, T, P
Ice cores	Year/season	$\sim 10^6$	T, P, C_a, B, V, M, S
Pollen	20 years	$\sim 10^6$	T, P, B
Speleothems	Year	$\sim 5 \times 10^5$	C_w, T, P, V, B
Palaeosols	100 years	$\sim 10^6$	T, P, B
Loess	100 years	$\sim 10^6$	P, B, M
Geomorphologic features	100 years	$\sim 10^6$	T, B, V, L, P
Marine sediments	100 years[b]	$\sim 10^7$	T, C_w, B, M, L, P, S

Notes:
[a]*T*, temperature; *P*, precipitation, humidity, or water balance (*P–E*); *C*, chemical composition of air (C_a) or water (C_w); *B*, information on biomass or vegetation patterns; *V*, volcanic eruptions; *M*, geomagnetic field variations; *L*, sea level; *S*, solar activity; *X*, meteorological or climatological extreme events.
[b]In rare circumstances (varved sediments) ≤ 10 years.
Source: Bradley (2014), slightly modified: category X for 'extremes' was added.

short-term, strong impacting events has the greatest temporal depth of all pre-instrumental record. Generally, the spatial and temporal density of weather records increases the closer one gets to the present; time is the great enemy of archival preservation.

Traditions with long-term written record exist(ed) in Europe, China, Japan, Korea, parts of the Middle East, Persia, and India. To date, the potential of documentary evidence in those regions for historical climate reconstructions has been exploited very unevenly. It has been exploited most intensely in Europe (surveys: Brázdil et al., 2005, 2010a), China (Chu, 1973; Ge et al., 2013, 2005, 2008, 2010; Wang, 1979; Wang and Zhang, 1988) and Japan (Mikami, 2008; Zaiki et al., 2006). The potential value of Arabic chronicles has been discussed recently, but detailed results are yet to be published (Domínguez-Castro et al., 2012; Vogt et al., 2011). In Europe, climate reconstruction has produced data series dating back more than 500 years for temperature, precipitation and air pressure. Temperature and ground air pressure data are available in seasonal resolution starting from 1500, and in monthly resolution from 1659 onwards (Luterbacher et al., 2002, 2004; Xoplaki et al., 2005); reconstructions of precipitation are available for all seasons starting from 1500 (Pauling et al., 2006). These data have been displayed in high spatial density in grids of 0.5 × 0.5 (approximately 60 km × 60 km), which contain a total of 5000 data points. Recently, some time series for Europe have been extended back as far as the Middle Ages through work carried out in the framework of *The Millennium Project* (Dobrovolný et al., 2010; Glaser and Riemann, 2009; Kiss et al., 2011; Leijonhufvud et al., 2010; Loader et al., 2011). Besides this temporal expansion, efforts in historical climate reconstruction are currently shifting southward into the Mediterranean (Lionello, 2006: 32–57, 2012: 91–98).

Historical climatology is globalizing. This has been the most obvious trend in the last decade – a trend largely founded on documentary evidence preserved in colonial records. The merchant fleets of European colonial powers, that began to sail the world oceans from the 16th century onwards, produced enormous amounts of written record, mainly in the form of ship logbooks, containing valuable information about wind directions and speed, ocean currents and ice cover (García-Herrera et al., 2005; Wheeler, 2009; Wheeler et al., 2006). Recent studies are exploring new territory, as they are expanding into tropical and subtropical parts of the globe, as well as from the Northern Hemisphere into the South (Nash and Adamson, 2013; Neukom and Gergis, 2012). Documentary evidence of climatic fluctuations in South America is beginning to be explored (Neukom et al., 2009; Prieto and García Herrera, 2009; Prieto and Rojas, 2012). There is likely much more to discover in the colonial archives of Spain and Portugal. The value of documentary records for the knowledge about Australia's climate in the past two centuries, after the arrival of First Fleeters in 1788, has also been recognized. Logbooks, governors' correspondences, early settler's diaries and newspapers are among the most valuable sources before systematic meteorological observation began.[4] Reconstructions of strong La Niña (1788–1790) and El Niño (1791–1793) events have helped explain the struggle of early Australian settlers to adapt to an unfamiliar and hostile climate (Gergis et al., 2010). In Canada, daily records exist in Quebec from the mid 18th century, nearly continuous from the late 18th century.[5] Researchers involved in extracting and digitizing the Canadian data are members of Working Group 5 (on documentary evidence) in the multidisciplinary research consortium ACRE (Atmospheric Circulation Reconstructions over the Earth).[6]

For several decades, historical climate reconstructions used to focus almost without exception on temperature, precipitation or air pressure. One reason for this is that early modern and medieval documents in Europe and China (the two principal research areas of historical climatology in the first 40 years) provide ample information on these meteorological factors, particularly rainfall, cold and heat, because pre-industrial economies were dominated by the primary sector, i.e. agriculture, and concerns over food production. Another reason was the dominating meteorological concept of climate, which favoured averages over variability and extremes. It was adopted by historical climatology in its founding years (e.g. Flohn, 1949), and has hardly been seriously questioned since then. However, new developments in climate impact research, namely the study of climatological and meteorological disasters (e.g. Groh et al., 2003; Juneja and Mauelshagen, 2007; Mauelshagen, 2009, 2010; Pfister, 2002; Schenk, 2009), inspired new reconstructions in the area of extremes and natural hazards such as tropical cyclones, hurricanes, other types of windstorms, etc. (Chenoweth et al., 2007; Dupigny-Giroux, 2009; Lamb and Frydendahl, 1991; Mock, 2004).

Preliminary summary

Reconstruction of past climates was clearly the principal focus of historical climatology until the early 1980s (Carey, 2012), and it remained dominant until the present (Mauelshagen, 2011). By improving our knowledge of the climate history of the last 1000 years, historical climatologists have contributed data confirming the fact of global warming in the 20th and 21st century. Though historical climatology has been involved only with the pre-industrial years of climate history, the 'Little Ice Age' (LIA, approximately 1300–1850) and the 'Medieval Climate Anomaly'(MCA), its contribution to our understanding of recent climate change is far from negligible. Particularly since the 1990s, research into both periods became significant for the debate on global warming, thus securing historical climatologists a place in it. While the potential of documentary evidence for climate reconstruction and impact research in regions on which attention almost exclusively focused in the early decades of historical climatology, Europe and China, is by no means exhausted, historical climatology has shown a globalizing trend in the last decade, expanding into the climate history of the world oceans, arctic, tropical and subtropical parts of the world. Another trend is that the spectrum of reconstructions has been broadened, particularly in the area of extreme events and natural hazards.

All this is good news for the future of historical climatology and its potential contribution to the study of the Anthropocene, which certainly asks for a global perspective on climatic changes and a better understanding of the impacts of extreme events. Yet, reviewing historical climatology also has revealed two major problems in existing definitions of the field that hamper connectivity with the study of the Anthropocene. These obstacles will be discussed one after the other, below.

1. The problem of periodization. From the perspective of climate history, the Anthropocene began when anthropogenic climate forcing started to overwhelm natural forcings on a global scale. According to the most widely accepted chronology this was not the case before industrialization (see below for a more detailed account). However, in state of the art definitions of historical climatology industrialization roughly coincides with the onset of systematic meteorological measurement, or the 'instrumental period', which historical climatologists have long accepted as a frontier beyond which they claim no territory. In effect, historical climatologists exclude the era of global warming (and the Anthropocene) from their study and reduce themselves to making only indirect contributions to its understanding. This problem of periodization is also reflected by the discrepancy between two competing definitions, referred to in the above account of the evolution of definitions of historical climatology: in the dominating one, HistClim-PALEO, proxy information extracted from documentary evidence plays the defining part, at least in the area of climate reconstruction; in the other one, HistClim-METEO, established by the NCDC when creating the GHCN data set, historical climatology deals with 'historical data' from weather stations that require homogenization. This discrepancy calls for a more consistent definition of the 'historical' in historical climatology.

2. The problem of (anthropogenic) climate dynamics. Anthropogenic climate change plays a key role in the Anthropocene. Yet, human activities as climate forcing have no place in existing definitions of historical climatology. One reason for this is that historical climatology formed as a discipline under the influence of climate concepts that prevailed in the 1950s and 1960s. The greenhouse effect gained ground in the ensuing decades, but it was still far from the level of scientific and public recognition it has received since the creation of the Intergovernmental Panel on Climate Change in 1988. This leaves the question of why definitions of historical climatology have not been adapted since then. What helps explaining this oddity is the other reason why (anthropogenic) climate dynamics did not become a research interest of historical climatology, which is – once more – that historical climatology limited itself to the 'pre-instrumental period'. This meant practically that it ended before industrial release of anthropogenic GHGs into the atmosphere accelerated. In this way, the problem of periodization is interwoven with the problem of climate dynamics.

No end of history: The problem of periodization

In the decades after 1950, when historical climatology took shape as an interdiscipline, state of the art climatology suggested that it be limited to periods before the availability of instrumentally measured data. While this makes sense from the perspective of climate reconstruction and data accessibility, it does neither from the perspective of any of the other two study areas of historical climatology, nor from the point of view of history in general. What is the meaning of 'historical' if the most recent period of human and climate history is being excluded by definition? Limiting the temporal scope of historical climatology in this manner was obviously influenced by a positivistic view of instrumental measurement, as if measurement was immune to the impacts of time and change. In the last decade or so, studies in the history of meteorology and climate science have uncovered all the necessary detail to prove how misleading this idea really was.

Classic definitions of historical climatology take the reality of an 'instrumental period' in meteorology and climatology for granted, as in fact many definitions of paleoclimatology do. There are two ways of dating the instrumental period: one spells its beginnings with the invention of technologies of measurement in the mid 17th century (Ingram et al., 1978: 329), the other with the establishment of national meteorological networks (Brázdil et al., 2005; Mauelshagen, 2010). The latter periodization recognizes that the instrumental record lacked density and standardization in its early days. Indeed, the enormous effort that had to be undertaken by Gordon Manley and others to establish the Central English Temperature Series from fragmented and shattered records in the 17th and 18th centuries resembles the complexity of palaeo-reconstructions (Manley, 1953, 1974; Parker and Horton, 2005; Parker et al., 1992). The same could be said about similar series of early temperature measurement, for example in France (Le Roy Ladurie and Rousseau, 2013: 169–207; Rousseau, 2009). Only after national meteorological networks had been created in the 19th century, marking the beginning of a truly instrumental period in the USA and Europe, historians and their knowledge of archives and documents no longer seemed to be required.

Maps indicating the geographic density of stations feeding the GHCN-Daily data set confirm that the profile of an instrumental period indeed began shaping in Europe and the USA in the second half of the 19th century (see Figure 4). However, these maps also show (1) that station-based meteorological measurement reached global dimensions only after 1950; and (2) that the density of weather stations continues to be greater in the Northern Hemisphere compared with the global South. Moreover, they do not show the availability of station data for other meteorological factors than temperature and precipitation, which have the longest record.

There is more inhomogeneity to discover. While the establishment of national weather services in many industrializing countries, and some of their colonies around or after 1850, marks a caesura in data production, it must also be pointed out that 'each national weather service created its own

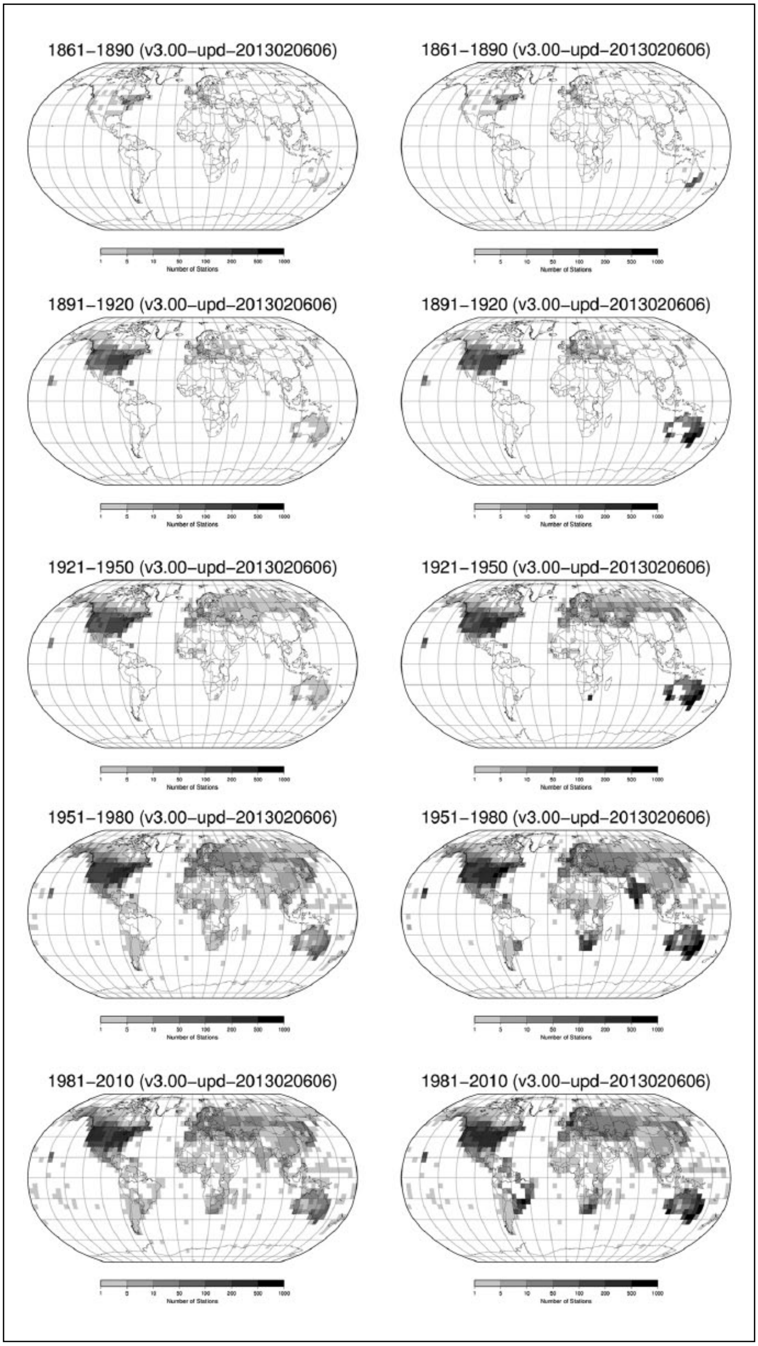

Figure 4. Maps showing temporal evolution (1861–2010) of the station network contributing data to the GHCN-Daily data set. Temperature stations: left column; precipitation stations: right column. Density has always been greater over North America and Eurasia than over Africa, Antarctica and South America. Note: The United States, Canada and Australia have made comprehensive contributions to the network.
Source: Maps created by Jon.Burroughs@noaa.gov were downloaded from NOAA's GHCN-Daily webpage, http://www.ncdc.noaa.gov/oa/climate/ghcn-daily/.

technological style, including various systems and standards for data collection and forecasting' (Edwards, 2010: 13). Thus, nation states provided an organizational structure; but they also created artificial borders in weather observation and forecasting techniques. In this way, the state of evolution in political self-organization of societies in the 19th and 20th centuries interfered heavily with meteorology and created serious noise in the realm of data, from which emerged the need for international cooperation to integrate national data into global weather models. Weather forecasters started out 'with regional models, they switched to hemispheric models by the early 1960s and global models by that decade's end. As scales grew, these models needed increasingly heroic quantities of data, demanding huge new efforts in standardization, communication systems, and automation' (Miller and Edwards, 2001: 14).

Another source of data inhomogeneity emerged from the diverging aims of meteorology and climatology:

> By the early twentieth century … Most national weather services, focused on providing short-term forecasts, paid scant attention to the observational needs of climatology. New observing stations often did not measure important climatological variables, such as precipitation. Meanwhile, existing stations changed location, replaced old instruments with new ones of a different type, disappeared, or saw their originally rural settings slowly transformed into (warmer) urban ones. These changes and many more affected the continuity, stability, and quality of their data records. (Miller and Edwards, 2001: 20–21)

Data management and administration also experienced considerable technological change with storage capacity growing exponentially in the age of electronic data processing. Looking backward, the technological shift from paper to digital record has created a kind of data bottleneck as one crosses the 1950 mark. Data exchange has been accelerated, and so has computing, increasing the demand for raw data to use these new capacities for improved meteorological forecasting and climate modelling.

In sum, since the establishment of national weather services, meteorological measurement experienced

(1) change in measurement technologies and noise from inhomogeneous national observation practices;
(2) changes in geographic location and density of station-based measurement;
(3) diversification of measured elements of climate;
(4) new practices of data handling and computing;
(5) a shift in data record and storage (from paper to digital).

These factors have created discontinuity and, consequently, various forms of inhomogeneity in the record of meteorological station data, which means that there is no homogenous 'instrumental period' with a clear beginning. The term 'instrumental period' might only, if at all, be preserved as a heuristic tool, as its meaning is entirely relative to time, geographic area, the type of measured information, measurement technology and practice. Vice versa, this implies that there is only a relative end to the potential for historical climate reconstruction; more to the point: there is no end to history in climatology. Even with standardized technologies in their hands, human observers remain the force of change that creates the threat of data loss and decay in meteorology and climatology and guarantees 'instrumental periods' a place *within* history.

Thus, current awareness about the necessity of data rescue (Brunet and Jones, 2011) and the findings of historians of meteorology and climate science question the distinction between a pre-instrumental and instrumental period and, with it, those between 'historical' and 'modern climatology' and between HistClim-PALEO and HistClim-METEO. This is not to deny that there is a qualitative difference between measured and non-measured data from human archives. Of course there is. The point is that the baseline for historical climate reconstruction is constantly shifting together with the state of the art in climate system observation. Consequently, even in Europe and in the USA, where national weather services were first created and rapidly achieved high station density, there is a lot of new territory for reconstruction to discover after 1850, as shall be illustrated by the case of hailstorms in Europe.

Hail appears in different forms, some of which are hard to distinguish from other forms of precipitation; it is often very local, which asks for a very high density of meteorological observation stations to achieve full geographic coverage. The invention of hail radars in the 1980s provided technical solutions to these problems, but also marked a caesura creating a new 'pre-instrumental' period for hail. In Switzerland, as in other parts of Europe (and probably elsewhere around the world) severely affected by the risk of hail (southern France, southern Germany, Austria, Hungary) the density of weather stations contained serious data gaps well into the 1950s. Already Bider (1954) demonstrated that indirect data of hail damage collected by crop insurance companies provided statistically much more reliable information for determining the severity, density, frequency and geographic distribution of hail events in Switzerland (Mauelshagen, 2011). These observations are still used today. However, the potential for historical reconstruction is far from fully exploited as meteorologists have hardly gone beyond the 1920 mark (OcCC, 2007). One of the consequences of the temporal limitations of hail data series is that they are far too short to model the influence of climate change on the changing frequency and severity of hailstorms in Alpine regions (OcCC, 2007; Schiesser, 1997). This sets obvious limits to proactive measures of mitigation and adaptation, which is particularly painful because hailstorms are among the most costly natural hazards in Europe (Munich Re Group, 2008). This situation may be significantly improved by a systematic evaluation of recorded evidence from hail insurance and reinsurance companies. The temporal extension of potential reconstructions is likely to vary with the scale of damaging effects of hailstorms. For Central Europe, it may well be possible to reconstruct large-scale events as far back as the Middle Ages using chronicles or official documents on disaster relief after hail storms for the time before insurance companies started business.

There are two consequences from the above discussion of the problem of periodization, both of which suggest that the definition of historical climatology requires revision:

(1) The idea of a distinct 'instrumental period' in meteorology and climatology has been invalidated by studies in the history of meteorology and climatology. Therefore, limiting research in historical climatology temporally, as has been done since 1978, such that in effect the most recent period of climate history (the Anthropocene) is being excluded by definition, no longer makes sense – particularly now that historical climatology is expanding globally. There is ample scope for historical climate reconstruction based on the record of human observation in the last two centuries. This new territory of historical climatology calls for exploration.

(2) Definitions of historical climatology require a more solid foundation with respect to the source of climate information they select to specify the territory of research. As the historical character of station data cannot be denied, particularly when they reach back more than a century, these data can no longer be kept away from the realm of historical climatology (that is: HistClim-PALEO). With regard to early meteorological measurements before the establishment of national weather services, exclusion has never been without exceptions anyway. It appears that it is time to reunite historical station data

> with reconstructed data from qualitative documentary evidence under the umbrella of historical climatology and, thus, reintegrate ClimHist-PALEO with ClimHist-METEO. However, this has other consequences, as 'documentary evidence' suddenly becomes an imprecise description of the source of information historical climatologists rely on. Many meteorological data today are digitized and will become the historical data of the future. 'Documentary evidence', written or pictorial (usually on paper), is only the most common form in which weather accounts or phenologic records have survived. However, the material quality of written records (e.g. on stone, on paper or digital) to which the term 'documentary evidence' alludes is of minor importance compared with what defines the specific quality of any type of information recorded in the archives of society, and that is: human observation. Thus, 'recorded human observation' would be a more appropriate term to use in definitions of historical climatology. Observations may be direct or indirect, measured or not measured, quantified or not. Generally, human observation is a specific form of selecting meteorological/climatological information through perception (the senses), which may or may not be equipped with technologies. It varies *culturally* in time and space. In contrast, natural proxies are a type of information selected through physical (geological), chemical or biological processes.

A cultural history of human meteorological/climatological observation would have the capacity to identify styles of observation in the past and in present and, thus, provide valuable information relevant for the content analysis of evidence recorded in the archives of society. This is one potential way in which historical climatology might better integrate two of its branches: reconstruction and the history of climate knowledge and science. However, there may also be an important dimension of the Anthropocene to be discovered here, worthy of further exploration: the expansion of technologically equipped scientific observation of the Earth System in the last two centuries parallels the explosion of human activities impacting the natural ecosystem of the Earth in the same period. It is worth noting that this is hardly accidental, because scientific observation systems are involved with economic efforts at resource exploitation as well as (more recently) with political efforts to guide human activities in the Earth towards pathways of sustainability. Knowledge and science play a key role in the expansion of modern societies and the dynamics they unfold in changing the natural environment.

Climate dynamics in the Anthropocene

Early alliance with descriptive climatology in its founding years produced the most effective path dependence for historical climatology. While the affinity of historical data with meteorological measurements of temperature, precipitation and air pressure has been one of the strengths of historical climatology (no other branch of palaeoclimatology could claim the same right to be termed 'palaeometeorology'), recent decades have seen a paradigm shift in climate science, to some extent pushed by climate modelling activities that were fostered by innovations in computer technology. The greatest push for innovation, however, came from the need to understand the causes of global warming – the key question of climate science ever since the UNFCC and the creation of the IPCC back in the late 1980s. This process has accelerated the previously discernible shift from a descriptive understanding of climatology towards causal models capable of explaining and projecting climate change (Claussen et al., 2002; Mauelshagen, 2010). *Climate dynamics* – 'the scientific study of how and why climate changes' (Cook, 2013: 1) – has become the key focus of climate science. The dynamics of the climate system results from a complex interplay of internal and

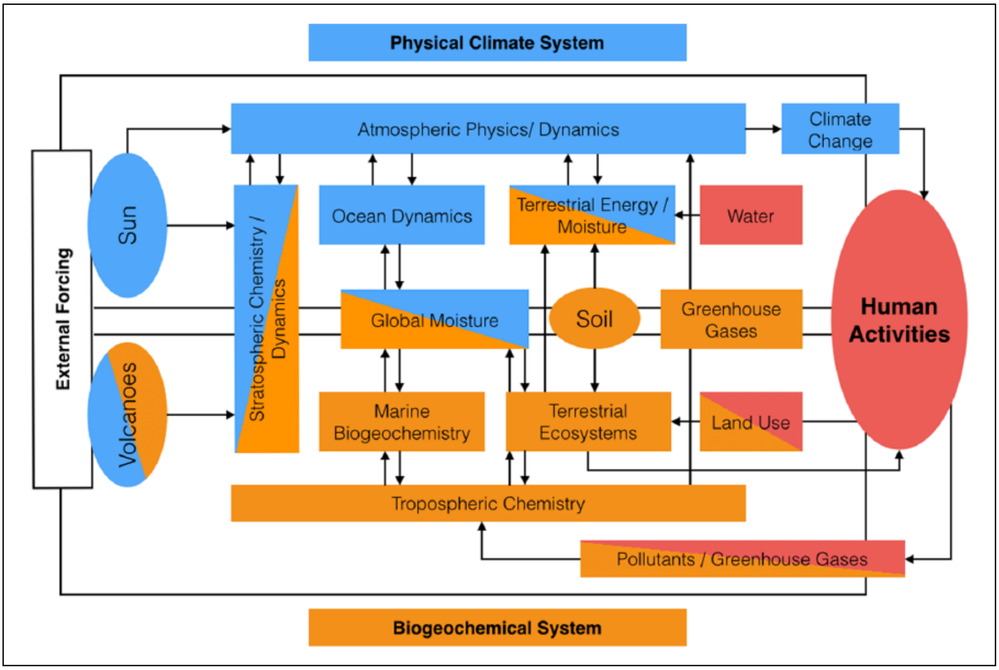

Figure 5. Modified version of the Bretherton diagram.

external forces (variables), schematically represented in a modified version of the famous Bretherton diagram (see Figure 5).

Historical climatology has contributed data to improve our knowledge of past climate dynamics (see Table 3). Most relevant are reconstructions of ENSO and NAO variability based on documentary sources. There is very likely more material to discover in the archives of society for improvements in ENSO and NAO time series, or for reconstructions of other local oscillations such as the Arctic Oscillation (AO). Information about Arctic sea ice cover can be drawn from English, Spanish, French, Dutch and Portuguese ship logbooks (Catchpole, 1992), which generally provide a valuable source of information on oceanic climates, to some extent exploited by the CLIWOC project (García-Herrera et al., 2005; Wheeler, 2009). Observations recorded in ship logbooks are pieces in the puzzle of proxy information from which past variability in the cryosphere (ice cover, which affects the radiative balance of the planet as it changes the albedo) can be detected.

In the area of external forces, the historical record of volcanic eruptions is of significance. Moreover, sunspot observations have long been accepted as reliable indirect information on the variability of solar irradiance, for which the period of direct measurement begins no earlier than 1978. The first 30-year period of measurement became available in 2008, forming the primordial basis for an overlap between group sunspot data and direct measurements (Bard and Frank, 2006). John A Eddy's reconstruction of solar activity from early, non-systematic observation of sunspots preserved in early scientific journals, astronomers' diaries and treatises (Eddy, 1976, 1978, 1980, 1983; Eddy et al., 1977, 1989; Hoyt and Schatten, 1995a, 1995b, 1996, 1998; Letfus, 2000; Schove, 1979, 1983).

However, clearly the greatest potential contribution of historical research is in the area of anthropogenic forcing. There is no better record of human activities in the Earth System than the

Table 3. Survey of historical studies in the area of climate dynamics. References in the 'Publications' column are selected. Evaluations in the rubric 'Research priority' were made with regard to the future, to how well researched the respective themes are, and to the relevance of historical observations compared with natural proxies. Evaluations reflect the author's opinion and are to some degree subjective.

Forcing/ feedback	Natural Earth System	Observation: What/record	Publications	Research priority*
Solar	External	Indirect: Sunspots (naked eye & telescope)/astronomers' accounts	Eddy (et al.) various (others: see main text)	very low
Volcanoes	External	Direct and indirect: volcanic eruptions and their effects (dimmed sun, red sky, etc.)/ diaries, official records	Lamb (1970)	low
Atmospheric circulation (ENSO, NAO, etc.)	Atmosphere	Indirect: drought, floods, rainfall, etc./administrative records, chronicles, weather diaries	Luterbacher et al. (2001); Gergis and Fowler (2009); García Herrera et al. (2008)	medium
Ice cover	Cryosphere	Direct: inland glaciers, arctic sea ice/ship logbooks, images of glaciers	Catchpole (1992)	high
Anthropogenic	External	Observation: pre-instrumental records	Publications	Research priority
Deforestation/ Reforestation	Biosphere	Direct: cultures of forest use, practices of forestry/official records, regulations, maps	Ramankutty (1999); Kaplan et al. (2009)	high
GHGs	Atmosphere (chemical composition)	Indirect: agricultural practice, livestock	Ruddiman (2013)	high
Land use	Biosphere	Direct: legal regulations, tracts on technological innovations in agriculture	Hurrt et al. (2006); Lionello et al. (2006, 2012)	very high
Internal dynamics of the social system	Sociosphere	Direct and indirect: documentary information on population growth, economic indicators, political management, etc., governmental records & others	Pfister (2010)	very high

*Assessments in this column are founded on evalutions of 1) the availability and quality of natural proxies, 2) how well the documentary evidence has been exploited in the past, and 3) the need of documentary evidence with regard to a specific aspect of climate dynamics.

written record. It is the only type of record capable of reintegrating direct or indirect (e.g. archaeological) information about use societies make of energy and (other) natural resources with concrete economic or political decisions. Archival documents related to land use, desertification, de- and reforestation (Kaplan et al., 2009) are pieces in the same puzzle of anthropogenic environmental changes that may affect local or global climate changes. Environmental historians use these sources of information regularly, while little has been done in historical climatology to exploit them and increase the amount of empirical data on past changes of land cover to feed climate models. In this respect, current models lack historical depth and often build their modelling of the planetary albedo on rough estimates calling for improvement (Brovkin et al., 1999; Deo et al., 2009; Lambin et al., 2001).

In the review section of this article it was assessed that historical research on anthropogenic forcing is still pending, because historical climatology is yet to adjust to the most recent developments in climate science and Earth System Analysis. Anthropogenic climate change in the Anthropocene challenges the idea that climate history can be written without considering human activities. As a consequence, (potential) human interference with the climate system requires consideration in any story of climate change since the appearance of biologically modern humans. This is particularly plausible for periods that follow the invention of agriculture, when new practices of deforestation and land use likely affected local or even global climates. More research is needed on periods prior to and after the onset of industrialization. However, it is precisely in the area of anthropogenic change where the complexity of scientific study reaches challenging new levels, which are far from easy to handle in theory and practice. The Anthropocene concept is in many ways the sum total of these challenges in the transdisciplinary research framework of Earth System science. It is, therefore, from this perspective that the demands of understanding climate dynamics today – one that involves human societies – shall be approached.

Anthropocene climate

The 'Anthropocene hypothesis', first announced by Nobel laureate Paul Crutzen (Crutzen, 2002a, 2002b, 2006; Crutzen and Stoermer, 2000), takes note of the traces of 'human activity' in all subsystems of the Earth System recognizing that cultural evolution has made *Homo sapiens sapiens* the 'dominant animal' (Ehrlich and Ehrlich, 2008). Some of the unfolding debate centred on the dating and temporal extension of the new epoch with William Ruddiman advocating an 'early anthropogenic hypothesis' (Ruddiman, 2003, 2005a, 2005b, 2005c, 2008, 2013). In response, Will Steffen, John McNeill and Paul Crutzen argued that Ruddiman's periodization focuses solely on atmospheric change in the early stages of the Holocene, while excluding other spheres of the Earth System; also, the anthropogenic origins of those atmospheric changes are rather uncertain and disputable (Crutzen and Steffen, 2003; Steffen et al., 2007, 2011).

Last but not least, the climate dynamics specific to the Anthropocene are best defined by domination of anthropogenic forcing over natural forcings. None of the climatic changes preceding recent global warming fulfils this criterion. Calculations of the relative weight of natural processes versus anthropogenic factors since the beginning of industrialization (c. 1750) are based on the concept of radiative forcing, nowadays explained in every textbook of, or introductory guide to, climate science (e.g. Archer and Rahmstorf, 2010: chapter 2). Calculations of radiative forcing are based on changes in the Earth's energy budget arising from natural and human causes. The latest IPCC Working Group 1 (physical science) summary report introduced the improved concept of effective radiative forcing (ERF) as a better indicator of temperature response and once more confirmed the dominance of greenhouse gas emissions as the driving force of global warming between 1750 and 2011 (Figure 6). Plotting historical effective radiative forcing in time shows the evolution of the relative influence of natural and anthropogenic forcing since 1750 (see Figure 7). This helps detecting the onset of the Anthropocene era from the perspective of recent climate history: total anthropogenic forcing increased steeply after 1850, which coincides with the most widely accepted dating of the end of the 'Little Ice Age'. Note that this total is the sum of anthropogenic factors that affect radiative forcing both ways, positively and negatively: atmospheric aerosols mitigate the

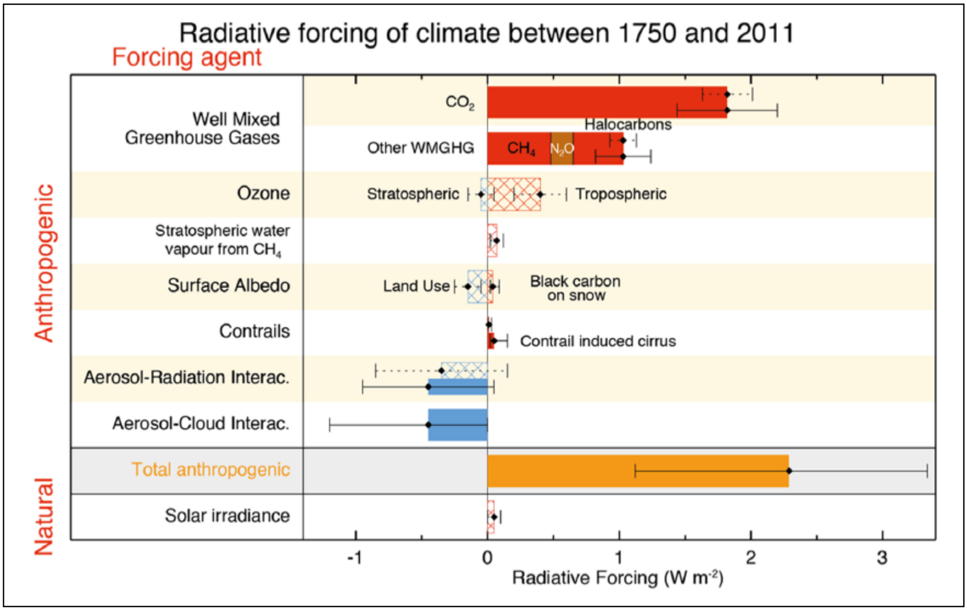

Figure 6. Radiative forcing of climate: bar chart showing totals for 1750–2011. RF (hatched) and ERF (solid) are shown with uncertainty ranges (5% to 95%) also for RF (dotted lines) and ERF (solid lines).
Source: Figure 8.15 from IPCC WG1-AR5.

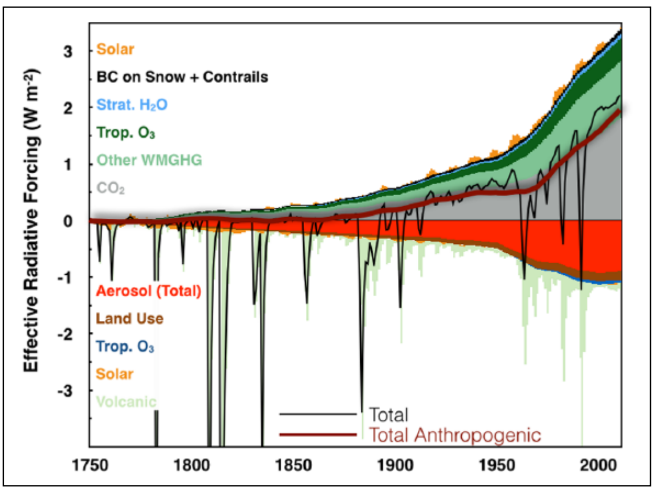

Figure 7. Temporal evolution of anthropogenic and natural radiative forcing, 1750–2011. Stack chart shows anomalies (W/m^2) given as deviation from 1750 (= 0). For the uncertainty ranges over the entire period (2011 versus 1750) see Figure 6.
Source: Figure 8.18 re-plotted from Annex II data in IPCC WG1-AR5 (modification: total aerosol is plotted here).

ERF effect of GHGs to some degree, as land surface changes counteract the effects of black carbon deposition in snow and ice. This scheme, which is characteristic of emissions produced by industrial fossil energy regimes, shows that the checks to anthropogenic increases in ERF are also largely

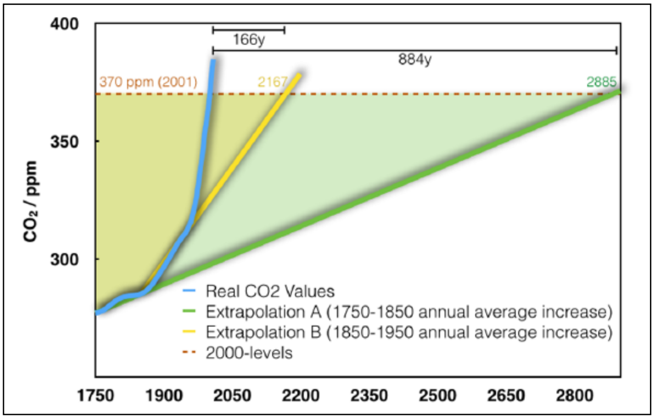

Figure 8. Extrapolation of three carbon regimes since the beginning of industrialization. Extrapolation A is based on an average increase of CO2 in the atmosphere between 1750 and 1850 by the margin of 0.082 ppm. These margins increased over the following period between 1850 and 1950 to 0.268 ppm annually, from which extrapolation B is drawn. Our data source for CO2-values in the atmosphere is Robertson et al. (2001). This graph visualized extrapolations first mentioned by Christian Pfister (2010).

anthropogenic. Placing this pattern into more long-term contexts also reaffirms Steffen's, McNeill's and Crutzen's chronology, which parallels the emergence of Anthropocene climate conditions with the history of industrial societies. Following this chronology here also makes sense, because it is more challenging from the point of view of historical climatology and its existing limitations in temporal range than any pre-industrial beginning of the Anthropocene would be. However, all this does not imply that anthropogenic forces of climate change (and more generally: environmental change) in pre-industrial ages of human history need not be considered. Quite on the contrary, more research in this area is desirable to improve our understanding of the interplay between natural and social forces of change, and historical climatology should get involved in it.

Steffen et al. (2007) subdivide the Anthropocene into three stages indicated by economic growth and traces of greenhouse gas emissions from fossil fuel burning in the atmosphere: they start with an early stage of slow growth before 1950, followed by a second stage of exponential growth since then, and finally they anticipate a third, and future, stage of human stewardship of the Earth System (cf. Steffen et al., 2011). Echoing Karl Polanyi's concept of the *Great Transformation* (Polanyi, 1944), the authors termed the second stage 'the Great Acceleration', which parallels what, some time ago, a group of economic historians termed 'the Syndrome of the 1950s' (Pfister, 1992, 1994, 1996, 1998, 2010). Steffen, McNeill and Crutzen refer to economic growth, rapid technological changes and population growth as indicators of the Great Acceleration. A comparison between the growth rates of CO_2 emissions before and after 1950 suggests, however, that the immediate roots of the greenhouse climate are to be found in the quarter of a century after approximately 1950 (see Figure 8). An extrapolation of the average growing rates of these concentrations for different stages of industrialization reveals the downside of accelerated economic growth, i.e. the acceleration of fossil fuel burning, exponential growth of carbon emissions and the time lost for a return to sustainable energy production and consumption.

Industrial patterns of global change have gained their ever-accelerating pace from the social dynamics that unfolded with the availability of fossil energy resources. Yet, conceptualizing – not even to speak of modelling – the role of society in the Earth System still continues to cause quite a headache.

Conceptualizing societal dynamics

Earth System Analysis (ESA) nowadays is very well capable of modelling geophysical and geochemical processes, equilibriums and feedbacks in the Earth System. Global Change Analysis (GCA) describes ecosystem changes based on a general theory of complex open systems with the Earth System as the all-encompassing system of subsystems, which include the cryosphere, the hydrosphere, the pedosphere, the biosphere and the atmosphere. Somewhat ironically, ESA reveals weaknesses exactly in modelling that force which is considered the most important driver of global change:

> Current observations focus strongly on non-human systems. With the notable exception of global economic and related national statistics, the all-important human dimension is subject merely to weak, largely unsystematic or under-evaluated observation. A more comprehensive observation of the whole, particularly of the exchange processes between human societies and their environment, is urgently required if a crude look at the whole is to be achieved. (Lucht, 2010: 28)

However, the underlying problem is much more elementary than a mere gap in the existing observation systems and statistics would suggest. There is more to address than an information and quantification problem here: GCA still suffers from an elementary deficit in understanding human collective agency and the social dynamics underlying it. In this regard, relatively little has changed since the Bretherton Report leveraged ESA back in 1988 stating that attention was restricted 'to the physical, chemical, and biological processes that interact to determine the evolution of the Earth System and to produce global change'. Discussion of 'economic, social, or political factors' were explicitly excluded, 'since these issues lie outside the mandate and professional expertise of the Earth System Science Committee'. Consequentially, 'human influences' on the Earth System were considered 'simply as additional system inputs in the form of activity scenarios, such as conjectured time sequences for the burning of fossil fuels or patterns of land use' (NASA Advisory Council, 1988). This continues to be the example that IPCC Working Group 1 follows in developing emission scenarios (AR1–AR5). While this pragmatic decision is fully understandable considering the uncertainty of future GHG emission controls of world society, it is nevertheless unsatisfactory that climate models 'reach the limits of their predictive power when they need to bring people into the equation' (Cornell et al., 2012: 2). To leave blank what is considered to be the dominating force of global change, i.e. human societies in general and industrial forms of society in particular, is a limit of knowledge hard to accept from the perspective of Anthropocene research.

Several conceptual 'solutions' to determine the place of human activities in the Earth (or: eco-) System have been proposed in the past, either in the framework of ESA, or in the longer traditions of the earth sciences and General Systems Theory. In the following, three terms and the conceptual ideas underlying them shall be assessed with regard to their theoretical power to seize the ecological dynamics (or: ecodynamics) of societies (Boulding, 1978). These terms are: the biosphere, the anthroposphere and the sociosphere.[7]

(1) Biosphere. In the early days of earth sciences, humans and their activities were assigned a place in the 'biosphere', a term introduced by Eduard Suess to denote a sphere of 'life on this planet and all the conditions in regard to temperature, chemical composition and so forth necessary for its existence' (Suess, 1885, 1875: 159; see also Samson and Pitt, 1999). According to Vaclav Smil 'it took a long time before it entered the scientific vocabulary', but was finally pushed 'to the

center stage of scientific attention during the last generation of the twentieth century' because of satellite monitoring systems and concerns about anthropogenic environmental change (Smil, 2002: 2). As a biological species human beings belong to the biosphere; but at the same time they are 'social animals' that build and transform societies. This capacity and its implications will hardly be grasped with a species concept of humanity, because the biological construction of *Homo sapiens sapiens* contains little, if any, explanatory force for elucidating recent anthropogenic climate change. Sociality, the ability to socialize, may have biological preconditions and, thus, may be considered a genetic feature of our species that helps to bridge the gap between a biological and a social science approach to the ecological role of humankind (Ehlers, 2008; Ehlers and Krafft, 2006a, 2006b). However, it fails to explain specific forms of human society and their impact on the environment.

(2) Anthroposphere. Some researchers proposed the inclusion of an anthroposphere in the Earth System. Yet, most of them hold on to regarding the anthroposphere as subordinate to the biosphere (Baccini and Brunner, 1991; Brunner and Rechberger, 2001; Cornell et al., 2012), which in the end raises the same questions as above (sub 1). Hans Joachim Schellnhuber, however, deviated from these examples in his Earth System formula:

$$E = \left(N, H\right), \text{ where } N = (a, b, c, ...); H = (A, S) \quad (1)$$

Here, E is the Earth System, N the ecosphere, H the human factor; N is subdivided into interconnected subspheres a (atmosphere), b (biosphere), c (cryosphere) etc.; H, on the other hand, 'embraces the "physical" sub-component A ("anthroposphere" as the aggregate of all human lives, actions and products) and the "metaphysical" sub-component S reflecting the emergence of a "global subject"' (Schellnhuber, 1999: C20). Schellnhuber explains his somewhat unusual idea of a 'global subject' by pointing to international climate politics and climate protection treatises as expressions of it. Yet, while recognizing that there is more to the 'human factor' than physical populations, Schellnhuber's concept of the anthroposphere still seems to rest on aggregate ideas of society. Building on Schellnhuber's 'symbolic formalism of Earth system analysis', Martin Claussen proposed a slightly modified concept of the anthroposphere, which 'includes all cultural and socio-economic activities of humankind which can be subdivided into subcomponents' (Claussen, 2001: 147). His version of the anthroposphere is probably more easily accessible for the social sciences and the humanities than Schellnhuber's. However, it is more meaningful that both Schellnhuber and Claussen give the anthroposphere a place within the Earth System, but outside the ecosphere or 'natural' (part of the) Earth System. As Claussen pointed out, this means that the anthroposphere and its dynamics cannot be modelled by conventional means of thermodynamics.

(3) Sociosphere. The Scottish naturalist John Arthur Thomson (1861–1933) first termed the sociosphere and, yet again, regarded it as a subsphere of the biosphere in the all-encompassing cosmosphere. Using an expression by Francis Bacon he circumscribed the sociosphere as 'The Kingdom of Man', which not only includes society and its produce but also that part of nature 'which man subdues to his service or transforms for his purpose' (Thomson, 1921: 248). In the first decades of the 20th century the term 'sociosphere' occurred sporadically in sociological publications such as Eubank's *Concepts of Sociology* (1932: 65) which added a geosphere to Thomson's classification.

Independent of these earlier uses of the term, the nowadays forgotten sociologist Joyce O Hertzler (1895–1975) defined: ‘The sociosphere is the sum total of environments as modified and created by man’ (Hertzler, 1954: 131). However, it was the economist Kenneth E Boulding (1910–1993), who substantialized the idea of a sociosphere based on his profound understanding of the social sciences (Boulding, 1966, 1980). Boulding emancipated the sociosphere from the biosphere, treating it as synonymous with what he called the social system:

> The social system consists of all human beings on the planet and all their interrelationships, such as kinship, friendship, hostility, status, exchange, money flows, conversation, information outputs and inputs, and so on. It includes likewise the contents of every person’s mind and the physical surroundings, both natural and artificial, to which he relates. This social system clings to the surface of the earth, so that it may appropriately be called the sociosphere, even though small fragments of it are now going out into space. The sociosphere thus takes its place with the lithosphere, the hydrosphere, the atmosphere, the biosphere, and so on as one of the systems which enwrap this little globe. It has strong interrelations with the other spheres with which it is mingled and without which it could not survive. Nevertheless, it has a dynamic and an integrity of its own. (Boulding, 1966: 5–6)

The task of conceptualizing the dynamics of society in the climate system looks different from the perspective of different disciplines. Biology, behavioural ecology, human and social ecology, anthropology, human geography, environmental history, environmental sociology are just some of the disciplines currently taking part in an ongoing debate. The above discussion of conceptual alternatives has revealed some fundamental problems in current approaches to societal ecodynamics:

(1) It is an open question how concepts of humanity as a species and concepts of (human) society in sociology and in the humanities relate to, or connect with, each other. In the context of the Anthropocene debate, Malm and Hornborg (2014) have questioned the use of the species category, because it covers up inequalities in the ecological footprint between industrialized and developing countries and, thus, blurs unequal responsibilities for global (climate) change. The same argument has been made before with regard to the word ‘anthropogenic’ in ‘anthropogenic climate change’. However, there are also advantages to the species category, one of them being that it places humans among a community of life on Earth and makes the unequal share of ecological resources visible, which threatens life – human and non-human – around the world today. Another advantage is that it recognizes the ‘body physique’ of society, i.e. population. Yet, this is turned into a weakness if human societies are reduced to mere aggregates of individuals.

(2) Diverse as theories of society may be in the social sciences of today, there is agreement that society is not just the sum of its parts; it is held together by communication, which is the nucleus of cooperation and organization of individuals through assemblies and groups (political parties, companies, ethnic groups, states, nations, etc.). Therefore, to understand and describe the ecological dynamics (or: ecodynamics) of globalizing societies, which accelerated in the process of industrialization, these dynamics need to be recognized as specifically societal. However, that leaves the question for the role of material and energy flows play ‘in’ or for society. Though a broad generalization, it is not unjust to say about sociological theories of modern society that they ignore the energy costs of complex social structures. ‘Humans and the complex social systems we create are clearly constrained by the energy fluxes at all scales of social organization’ (Sibly et al., 2012). Not least, this is

also indicated by strong correlations between variables reflecting standard of living and per capita energy use (Brown et al., 2011).

(3) Another unsolved problem is the relationship between society and the Earth System. Is the social system separate from or part of the Earth System? Or is it a subsystem of the Earth System that needs to be separated from the natural ecosystem? What seems clear enough is that thermodynamics is not the key to societal ecodynamics. Approaches in human energetics and sociometabolism help bridging the gap between the social system and the natural ecosystem; but they are one-sided in that they describe society only as an open, resource-depending system. This is exactly what leaves the 'inside' behind as a *terra incognita*, which simply produces contingency and unpredictability in the Earth System, making climate scenarios inevitable to handle this uncertainty. Such difficulties of determining the inside and outside of systems, their borders, and their relation call for basic research on the level of systems theory.

This is not the place to solve these problems deeply involved with anthropogenic global change and, therefore, with the Anthropocene. For future debate the most appropriate terminological starting seems to be the 'sociosphere'. It has the potential to become a basic concept of global systems ecology. It is in this sphere in which the social system develops its own specific ecodynamics, the character of which changed dramatically in the course of human history. A working definition of the sociosphere would be:

> The Sociosphere is that part of the Earth System (or the global sphere) inhabited, worked, and changed by human societies. It is a direct subsystem of the Earth System, not of any other of the Earth System's subsystems. Amplification or diminution of the sociosphere depends on the ecodynamics developed by human social systems and the limits of the surrounding ecosystem which is relative to specific modes of societal growth, i.e. the way in which human societies make use of energy and material resources.

In this working definition, the ecodynamics of social systems is key to understand processes of global change. *Social ecodynamics* may be defined as the sum of all the driving forces of (global) ecological change emerging with social systems. *Climate dynamics* is a specific form of ecodynamics with regard to sociogenic changes in the climate system. With regard to these definitions, the task of historical climatology in contributing to the climate history of the Anthropocene can now be determined more clearly: it is to identify those sociogenic forces and their emergence within the history of social systems that have become the drivers of global climate change. Obviously, this task opens a completely new field of inquiry – a new branch for future research in historical climatology.

Conclusion: Redefining historical climatology

When historical climatology took shape as a field of study many decades ago, anthropogenic climate change had not yet been on the agenda of mainstream climatology, which explains why historians of climate did not consider anthropogenic forces. However, this continued to be so for another reason, i.e. because historical climatology by definition excluded the most recent period of climate history, global warming, from its agenda. However, the idea of climate history as independent of human history has been invalidated in our age, now termed 'the Anthropocene'. Climate is influenced by human societies. Social systems have (for the most part unintentionally) developed a climatic dynamics of their own that, in our age, has become the driving force of global warming.

The purpose of this review article was to spell out the implications of those developments for historical climatology and its potential for the study of the Anthropocene. As a result, certain adjustments in the definition of historical climatology and its territory seem necessary. They can be summarized as follows:

(1) The idea of a distinct period of instrumental record beginning with national weather services in the 19th century – a period to which the methods of historical climatology do not apply – needs to be abandoned. There is great potential for historical climate reconstructions in the most recent centuries of history, because the baseline for instrumental data is shifting due to changes in the infrastructure of, and rapid (technological and conceptual) innovation in, meteorology and climatology. That potential should be explored as a matter of urgency, as it will allow historical climatologists to make a direct contribution to the study of the Anthropocene era in the future.
(2) Definitions of historical climatology require a more solid foundation with respect to the source of climate information that specifies its territory. If this territory is to be expanded into the 20th and, eventually, the 21st centuries it is more precise to speak of 'recorded human observation' rather than 'documentary evidence' when it comes to define the specific source of information that distinguishes historical climatology from the branches of paleoclimatology that rely on natural proxies.
(3) Although historical climatologists have helped to confirm that recent global warming is in many ways a unique occurrence in the climate history of the last 1000 years, definitions of historical climatology are yet to adjust to the standards of climate change science and its main task: the understanding of climate dynamics, particularly in the Anthropocene. More concretely, this means that historical climatology needs to step forward from the present focus on atmospheric variability (surface temperature, precipitation and air pressure) to a wider range of relevant elements of the climate system on which human observation has been recorded and preserved. This includes external climate forcing and feedbacks in the climate system. Reconstructions and rescue of historical station data will help extending existing time series as far back into the past as possible.
(4) In the Anthropocene, anthropogenic forcing through land clearance, changes in agricultural land-use patterns, and greenhouse gas emissions, etc. is centre stage. However, most attempts in Earth System Analysis fail to grasp the societal nature of the dynamics underlying global warming. Any attempt at adequately describing the emergence of the Anthropocene without including the ecodynamics and evolution of modern societies is likely to fail. Following from this is the need to rewrite the history of industrialization from the perspective of the ecodynamics of the social system. In acknowledgement of this, I have suggested introducing a new sphere into ESA: the sociosphere.

Thus, I suggest the following redefinition (short version): Historical climatology is the study of climate history based on recorded human observation (direct or indirect; measured or not measured); it reconstructs previous states of the climate system on a subannual to millennial scale ($<10^{-1}$ to $N \times 10^3$ years, with $N < 5$, i.e. roughly the maximum period for which written record exists) and explores the interrelationship between human cultural evolution and the evolution of the climate system. (A more explicative version of this definition is given in the box.) The modified definition of historical climatology, its purposes and future perspectives will extend the scope of study in, and is designed to strengthen the relevance of, historical climatology in future research on global warming, its causes and its socio-cultural implications.

Modified definition of Historical Climatology

Historical Climatology is a trans-discipline working at the intersection between history and climate science. Recorded human observation is its specific source of information about previous states of the climate system and its interactions with human societies. Consequentially, the temporal and spatial extension of research varies with the availability and preservation of recorded direct or indirect observations at a certain time and place. Historical Climatology has two major domains of study:

(1) It contributes historical data to the *reconstruction of previous states of the climate system* (temperature, precipitation, air pressure, wind, storms, solar activity, volcanic activity, land and ice cover, human activity: e.g. changes in land-use patterns) with regard to its internal variability, particularly extremes, external forcing factors of climate change and their feedbacks.
(2) It investigates the history of climate–society interactions. This includes the following – in many ways interwoven – aspects:

   (a) The *history of cultural adaptation to climatic variability and extremes* (e.g. long-term effects of changes in global glaciation on human health and habitats, impacts of short-term variability and extremes on agricultural practice, impacts on other economic branches and the built environment, etc.).
   (b) The *history of climate perceptions and knowledge* (including the *history of climate science*) as a key element of human cultural adaptability.
   (c) The *history of the sociosphere*, i.e. the history of social systems and their ecodynamics which, in the 20th century, has made society the dominating force of global environmental change in general and climate change in particular (*the history and pre-history of the Anthropocene*).

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Notes

1. An easy way to solve the problem of historians' discomfort with the term 'climatology' would be to avoid it and speak of the 'historical study of climate' or 'historical climate research'. However, for a review article it would not be advisable to invent a new term for a field of study known as 'historical climatology'.
2. See the 'Overview' on GHNC-Monthly Version 3 at https://www.ncdc.noaa.gov/ghcnm/v3.php (accessed 3 April 2014).
3. For example: radiocarbon dating, potassium-argon dating, or amino acid dating; see chapters 3–4 in Bradley (2014).
4. See the webpage http://climatehistory.com.au (accessed 8 April 2014).
5. The webpage of 'Historical Canadian Climate Data' is https://sites.google.com/site/historicalclimatedata/Home (accessed 8 April 2014).
6. For more detail see the members list on the ACRE website, http://www.met-acre.org/wg5-non-instrumental-and-documentary-data (accessed 11 April 2014).
7. Much has been written about the noosphere – a term invented by Vladimir I Vernadsky (1863–1945) and popularized through the work of the French Jesuit Teilhard de Chardin (1881–1955) (Fuchs-Kittowski and Krüger, 1997; Oldfield and Shaw, 2006). While deserving a treatise of its own, not least because of its recent popularity among researchers working in the earth sciences, the term has always had a speculative content that fundamentally questions its capacity to grasp social reality and, therefore, has too little connectivity with existing theories of society in the social sciences and humanities.

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