Geo-cultural Time: Advancing Human Societal Complexity Within Worldwide Constraint Bottlenecks—A Chronological/Helical Approach to Understanding Human–Planetary Interactions

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Abstract:

The integration of feedbacks between Holocene planetary history and human development benefits from a change in perspective that focusses on socio-historical periods of stability separated by global-scale events, which we call foundational transitions or bottlenecks. Transitions are caused by social and/or astronomical and biogeophysical events such as volcanoes, changes in solar emissions, climate change such as sea-level/ice volume conditions, biogeochemical and ecological changes, and major social and technical innovations. We present a global-scale cultural chronology that accounts for major changes generated by such events in the late Pleistocene and Holocene. These changes are governed by transitions that make energy more or less available to human groups. The chronology is followed by methodologies to incorporate the innate, Malthusian–Darwinian human tendency to grow systems over time into a helical-feedback equation that provides for testing the hypothesis. A proof of concept test of these ideas using information system-based data from the Maya lowlands in conjunction with other civilizations suggests a troubled transition for the current worldwide economic system because of potentially catastrophic climate impacts and resource constraints on biogeophysical-social resilience in the face of obvious needs of the system to change to a more sustainable mode of acquiring energy. The Maya case implies that change is more likely to transpire because of planetary-scale disturbances/constraints in the Earth (human and planetary) system and will likely lead to strong social disruptions. There may be as many as 200 such case studies to test this idea worldwide. Our analysis suggests that a transition toward sustainability for the current energy dense globalized industrial society will be very difficult.

Keywords: Holocene | Complex societies | Worldwide cultural stages | Terminology platform | Maya lowlands | Fossil fuel | Empires | Sea-level stabilization

Article:

Introduction

As with the consensus that humans are impacting and compounding global climate change (IPCC 2014, 2018; USGCRP 2018), it is increasingly clear that a theory of human engagement with the planetary system has become a matter of integration rather than segregation of the human subsystem out of the planetary system. In other words, humans are a part of the biogeosphere rather than apart from it. This is especially the case given that the Earth is at the same time the home planet of human beings and coming to be dominated in matters of status change in at least some of its aspects (atmosphere, oceans, soils) by humans (e.g., Day et al. 2018)—the idea of the Anthropocene (Steffen et al. 2015).

In this article, we present a mode of human and planetary integration that relies on some newly recognized characteristics of the human species to provide a basis of understanding of human societal dynamics. This is followed by concepts from archaeological cultural chronologies, and complex systems thinking (self-organization and attractors), to understand the peculiar path that humans have taken in the late Pleistocene and Holocene to make a departure from the Pleistocene tendency for humans to be interactive with the planetary system and take a position more at the scope of domination of the Earth system that we believe must be short-lived. We develop an Earth-scale chronology that relies on associating major disturbances in the biogeosphere that precipitated transitions in many human societies worldwide. We call these "foundational transitions" or "bottlenecks" because they commonly offer important subsidizing and constraining incentives to change and innovation. In essence, each of these transitions reflected a change in energy flow caused by natural and/or human-caused forcings that enhanced or diminished energy availability to some human populations while disadvantaging those in other areas or populations, or sometimes the Earth as a whole. What we are suggesting is that society, from hunter-gatherers to the modern industrial age, repeatedly adjusted to shifting baselines within which human populations were resilient and quasi-sustainable. However, when variability became too great due to factors such as planetary cycles, volcanism, or resource scarcity, foundational transitions or bottlenecks occurred, resulting in state changes in society. For example, Colten and Day (2018) showed that climate change, human impact, and resource scarcity in the Mississippi Delta are shifting the environmental baseline beyond historical limits for both the delta and its human inhabitants that is leading toward growing non-sustainability.

The objective is to provide a platform for social action that might correct the course of society toward a more sustainable future, if indeed such can be identified. The platform provides common ground for cultures past and present and the planet by recognizing worldwide events that repeatedly formed the initial conditions of human social and physical evolution in the Holocene. These initial conditions came to equifinality in the agrarian empires of the first millennia BCE and CE. From there arose the world economic system of the second millennium CE through transitions to maritime transportation. The transformational foundation of the Fossil Fuel Age in the last few centuries poses both the current end-point of human evolution and the devolution of the planetary habitat. Recovery from this tendency is the goal of this perspective through understanding of the human past.

We should mention to regional and period specialists whose works we draw on for our inferences that in the half dozen or so regional cultures we gather information from (most notably China, Peru, Mesopotamia, Mesoamerica, Egypt, Mediterranean Rome), we are attempting to select a set of features that reflect human/planetary interactions at the global scale. This is the simplification process of modeling that everyone does for their particular studies. For this reason, regional specialists will observe missing features in our work from their local models that are important for their thinking about their regional specialty. This is the way modeling is done at all scales including regional and global and the combination of the two. From the modeler's point of view, we are constructing a theoretical phase or measurement space in which the two different scales can inter-act. For an example of such a phase space, see the Maya example at the end of the article. The features on which entities in the two scales interact may be relatively limited in number, probably fewer than the many features the more holistic models that local specialists have constructed for their understanding. The basis of our thinking for example is that early in the Holocene, regional cultures reacted to climate change, especially global sea levels and the changes in productivity, and the populations and settlement patterns that imply. Late in the Holocene other features became salient such as the size of empires (i.e., information exchange distances) and are added cumulatively to the earlier features. This process of accumulation culminates in the modern, world economic system of the last 500 years and the last two to three centuries for the industrial revolution. From the local modeler's point of view, this is admittedly a limited point of view, but one that for the global modeler accounts for a great deal of the behavior of social groups in the Holocene relative to the planet.

The Scope of the Environment

Looking back into the history of human intellectual traditions, generally a unitary or monistic perspective was held of all Earth phenomena. At times dualist perspectives such as appeared during the Enlightenment and have formed the basis of most experimental science have been periodically re-examined and applied for at least 3000 years (Lamberg-Karlovsky and Sabloff 1979; Robinson 2017). Descartes' philosophy is frequently cited as the source of modern dual-ism embedded in his separation of the mind and body. Geo-physically the tradition was carried on to planetary processes by James Hutton (1785) suggesting that it was geological processes that dictated the direction of planetary evolution rather than god(s). Now over 200 years later we have come once again to need a unitary perspective that allows for clear understanding of where humans came from and where they are going in the future and how they fit into the total system of agent networks (Pickering 1995; Crutzen 2002; Barad 2007; Costanza et al. 2007; Cornell et al. 2010, 2012; Steffen et al. 2015; Day et al. 2018).

Humans are in fact of an environment that extends well beyond the planet due to the gravitational and magnetic fields of the sun and planets. While plate tectonics generally control the long-term direction and movement of continental scale plates, in the short term, at the scale of human lifetimes, other forces intervene. As an example, Fig. 1 shows that most of the eruptions with volcanic explosive indexes of 5 or more since 1950 follow periods of major solar activity. The sun not only emits electromagnetic radiation that makes the planet habitable to biological life, but it also explodes great masses of matter, known as coronal mass ejections, that tamper with the rate of planetary rotation causing tec-tonic plates to sway and friction from that aggravates volcanoes (Landscheidt 1987; Windelius and Carlborg 1995; Sharp 2013). Of course, as everyone was recently reminded by dozens of dash cams in northern Russia in 2013, the planet also partakes of disturbances from the outer edges of the solar system as far as meteors from the Asteroid and Oort belts (Brumfiel 2013).

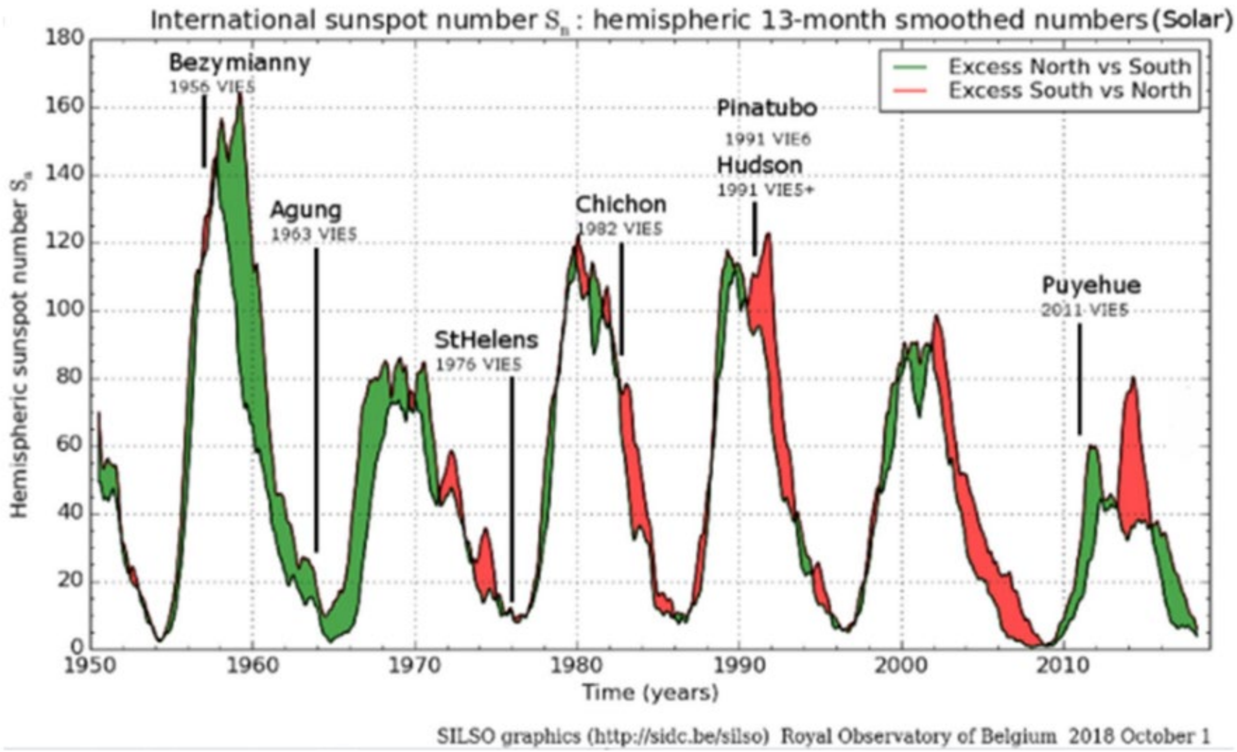

Fig. 1. Major volcanic eruptions tend to follow periods of high solar emissions. Sunspot numbers and volcanic eruptions of Volcanic Explosive Index, ⟹ VEI 5 since 1950 (Source: WDC-SILSO, Royal Observatory of Belgium, Brussels" http://www.sidc.be/silso/ssngraphics)

The Scope of Human Endeavors

At the same time that science born of the Enlightenment perspective was developing a greater understanding of the solar and planetary environment by rigorous studies piece-by-piece, understanding of human origins was similarly explored. Perhaps most germane to this discussion is that humans are a species of "growth" in the broadest Malthusian–Darwinian sense—a characteristic shared with most species. Almost all species have the ability to grow exponentially if resources are available. But there are many limits to them. In recent centuries, humans have for a brief period been able to overcome these limits by exploiting fossil fuels but this, as we will explain, will soon pass. The specific processual roots of the human tendency to growth have yet to be worked out in detail but it seems that it has something to do with the human–chimpanzee split about 6 million years ago when the populations of the two species were presumably similar. The support of this argument lies in the often-cited differences in present-day human and chimpanzee populations with chimpanzees having declined to less than a million and humans proceeding toward ten billion. Most of this human growth has occurred in the last 14,000 years since the Pleistocene with six of the current seven plus billion occurring since 1800 CE. However, the initial momentum of human growth must have begun well back in the ice ages and is probably attributable to the highly varied and therefore challenging environments imposed on diverse human populations at all latitudes resulting in the evolution of our species to be highly adaptable using tools, clothing, language, and most recently proposed to be the human ability to design and execute new habitats for themselves. This argument has been explored in a range of contexts from leaving Africa (Roberts and Stewart 2018) to leaving the planet (Smith and Davies 2012) and includes thinking directly related to our focus on empires as a form of niche construction (Morrison 2018) to which we will return later. While this is not our chief concern, human econiche inclusion and construction are important to our design as will become apparent.

Table 1. Bottlenecks and drivers in Holocene geo-cultural evolution

Stage	Bottlenecks	Drivers	Beginning	Disruption source(s)	Archaeological terms
1	Worldwide adaptation	Volcanism advantages *Homo sapiens*	72 ky	Planet Driven	Paleolithic
2	Food production	Milankovitch orbital, global climate warming	14 ky	Global cooling commonly produces droughts, warming moister conditions	Neolithic
3	Towns (pop. 500–10 k)	Sea-level stabilization, enhanced coastal margin productivity	6–7 ky	Sea level ceases rapid rise	Towns
4	City states (<10 k)	Social stratification and bureaucracies, enhanced ability of humans to take advantage of energy surplus due to better organization	5 ky	Planet/human balance	Cities
5	Multi-ethnic (axial) empires	Transportation technology (ships), imports of energy from colonies, focus on cooperation (the golden rule)	4.5 ky	Impoverishment of colonies	Empires
6	Human world system	Information technology (e.g., printing), information resulting in more efficient use of energies—much imported from colonies, Columbian exchange	0.5 ky	Human driven	World system
7	Industrial urbanism	Fossil energy technology	0.2-near future	Climate change, environmental degradation	Fossil system
8	Sustainable urbanism	Renewable non-fossil energy, depopulation of cities, extreme localism	2100 and beyond	Extreme climate change, environmental degradation, population growth, energy limitation	Fossil system collapse, green, sustainability, Anthropocene

To make sense of the Holocene component of human growth, we propose that human societies worldwide have passed through a number of bottlenecks or foundational transitions (Table 1) that at the same time restricted human populations and provided them with the sociological and psychological tools to navigate the social phase space well beyond the boundaries of families and tribal societies characteristic of the ice ages. Major changes in the status of the planetary–solar environment, some of which induced cli-mate change, were responsible for some part of these bottlenecks, while human changes were important for others. We suggest that foundational transitions (bottlenecks) can be defined as worldwide phenomena that impose changes on local bio-social structures. These changes provide humans advantages, and sometimes disadvantages, in obtaining energy to support enhanced activity. In most circumstances, the phenomena will contain both “constraint” and “subsidy” (push/pull) components. For example, in the case of sea-level stabilization discussed below, the subsidy component was increased food resources, especially in coastal mar-gins (Day et al. 2007, 2012). The constraint component for societies outside the coastal margin was the need to compete successfully with the larger, more stratified societies that developed in the coastal margin contexts. From archaeological records, we estimate that the size of the initial, stratified societal structures would have been about four times the size of the standard Neolithic social unit (Day et al. 2012). This is implied by the increase in size of societies surrounding delta/estuarine coastal margin complexes that included lower river valleys subsequent to sea-level stabilization. It applies both in the eastern (Euphrates, Indus and Chinese) and west-ern (Peru and Mesoamerica) hemispheres.

The basic stages that human systems go through in the course of history appear to parallel those through which the British energy system has traversed in the last millennium (Fig. 2, Fizaine and Court 2016). Before about 1600 CE Britain was an agrarian state much as the rest of the world had been since 6000 years ago. Following a pattern long since set by China, Britain developed a colonial empire that imported potential energy from its colonies. The use of coal began in the fifteenth century and accelerated in the sixteenth and following centuries. As the environmental burden of coal became evident and the flexibility of oil products became apparent in the 20th century, displayed blatantly in the surprising Japanese victory over the Russian Navy in 1905, oil was favored, though supply is now in decline or anticipated to be so, an environmental burden problem (Day and Hall 2016). Through these transitions, the percent of GDP used to obtain basic resources (food, fodder, fuel) decreased from greater than 50% to less than 10%. For most of the energy history of human complex societies discussed next exhibited a food–fodder–fuel profile like Britain. After 1600, the transition to colonial exploitation and fossil fuel builds to the present day.

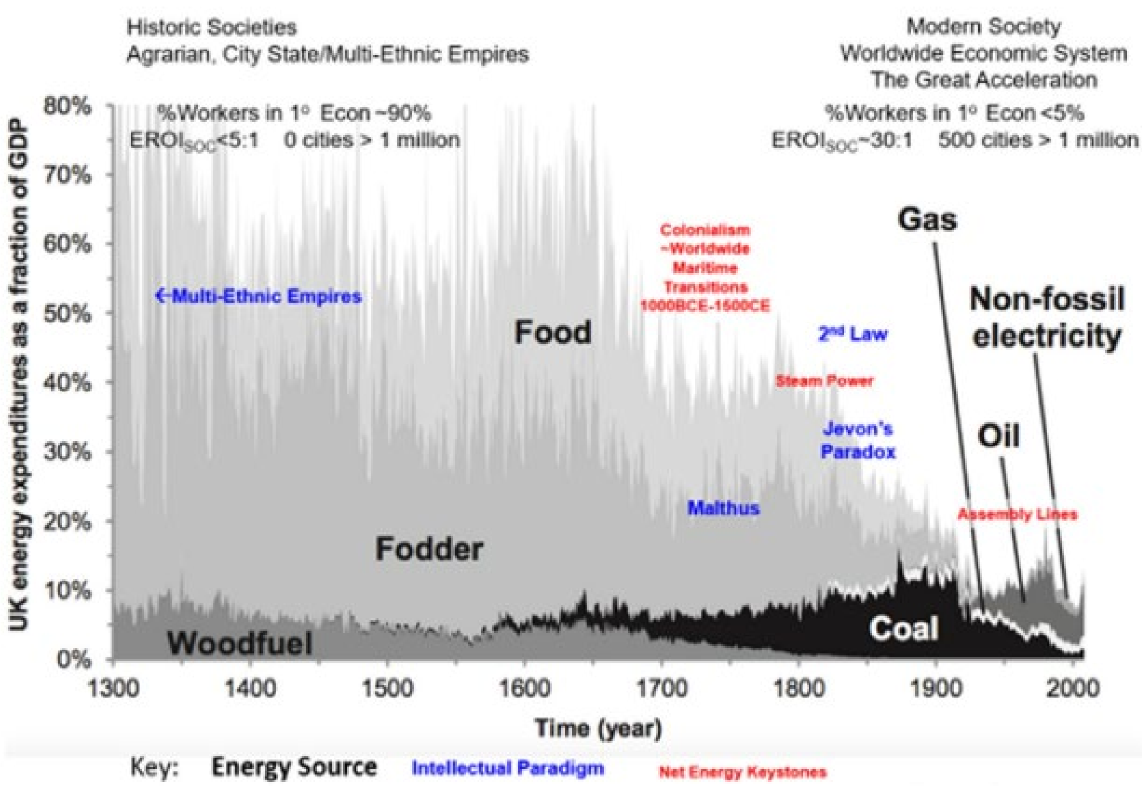

Fig. 2. Percent energy consumption by GNP for fuel, fodder, and food in Britain in the last millennium Modified from Day et al. 2018 as modified from Fizaine and Court 2016)

An example of a geophysical event that generated world-wide interruptions of energy systems is the so-called AD 536 Event (Stothers 1984; Baillie 1994; Keys 1999; Gunn 2000). It was once thought to be the product of a single volcano but more recent work with polar ice cores indicates three closely spaced, major volcanoes in 536, 540, and 547 CE in Iceland and tropical regions such as Central America (Toohey et al. 2016; Büntgen et al. 2016; Gibbons 2018). The atmospheric dust resulted in global cooling and reduction in primary production worldwide. In European history, the cataclysm associated with AD 536 was blamed by early historians on Justinian, emperor of the eastern Roman Empire, who at that time attempted by military measures to reunite the east-ern and western Roman Empires (Young 2000). Because of coincident famines and plagues, the population of Europe was reduced to about 50 percent from the Roman Empire maximum (Crumley 1987; Keys 1999). However, there were parallel famine-and-plague events in China that killed millions of people (Houston 2000). The cause of the famines was lowered agricultural productivity as amply documented by Procopius (Young 2000).

Important for our worldwide-effects argument is what happened in the western hemisphere. One of the eruptions happened to be a Honduran neighbor of the Maya lowlands (Dull et al. 2001) so there is little doubt that there were local as well as global impacts; we see a contraction in the urban footprint of Calakmul at that time (Gunn et al. 2009). It was followed by Calakmul's "Golden Age" under Yuknoom the Great's dynasty from the late 500s to 695 CE (Martin and Grube 2008). Yuknoom's reign was probably the clos-est that the Maya lowlands came to a multi-ethnic empire with the philosophical component being supplied by the Cult of Quetzalcoatl (Ringle et al. 1998; Folan et al. 2016) and Teotihuacan military intervention (Freidel et al. 2007). Following AD 536, in the Mexico highlands a transition was made from Teotihuacan to Tula. Teotihuacan appears to have been abandoned following the AD 536 event (Robichaux 2000) with the center of power moving 90 km northwest to Tula. Tula implemented marine interactions between the Mexican Highlands and the Maya lowlands by means of the Chontal Maya as well as the Pacific coast of Mexico, and ultimately northern Mexico and southwestern United States.

In parallel fashion, polities in Peru experienced droughts in the 500s. In the 400s, the Huarpa polity formed in south-ern Peru as a stratified society (Leoni 2008, p. 301) followed by Balkanization into several small polities in the 500s. Around 600 CE, the Huarpa reformed as the Wari Empire (Nash 2018, 2019) and is thought to be the first of the multi-ethnic empires in South America. These developments in Mesoamerica and Peru paralleled the Carolingian Renaissance in Europe and the Sui/Tang dynasties in China. So, the ad 536 Event(s) facilitated ongoing transformations to multiethnic empires in both hemispheres, which we consider to be the *condicio sine qua non* of planetary-scale disturbances, followed by relative global-scale stability.

The 600s-700s quasi-stability episode is bookended by global cooling due to a downturn in solar emission in the 800s recently labeled the Late Antique Little Ice Age (LALIA) (Büntgen et al. 2016). In the Maya lowlands that would encompass the ninth century droughts and the collapse of the Yuknoon Empire. The Mexican highlands experienced a parallel transition from the "early village" phase of the Tula empire, otherwise known as Tula Chico, into the following Tula Grande phase after the LILIA. In any case, the AD 536/late first millennium climates are a good example that supports the idea that disturbances/stabilities sequences overlapp with the human developmental sequences.

The AD 536 Event has been argued by some to be a transitional moment to the modern era (Keys 1999). In our terms, the huge population losses during the Late Antique Little Ice Age (earlier discussed as the Vandal Minimum by Reid Bryson, 1977) created a bottleneck. It bolstered the already-underway foundational transition to multi-ethnic empires, the Axial Age in philosophical terms (Armstrong 2006) (see Table 1, Stage 5) and fit with the worldwide scale of technology. The next major transformation was to the Age of the global-scale economic system beginning some time before Columbus with incipient European empires and culminating in the Columbian Exchange beginning in the 1500s CE and followed by the age of European worldwide empires. So the AD 536 Event encouraged adherence to and conversion to the ongoing multi-ethnic empire paradigm. It did not result in a transition to another paradigm. Transformation to multi-ethnic empires was a more important change already underway that encompassed the AD 536 Event which helped to displace the older city state empire-based paradigm in some regions as in the Maya lowlands and Peru. The multi-ethnic empires or "Axial Age" is a philosophical concept that encourages empires based on the principles of economic cooperation rather than ethnic domination, which is basically an exploitive, mercantilist principle. Well-known examples are the Neo-Assyrian Empire (ethnic domination, early 1st millennium BCE) and the Persian Empire (economic cooperation late 1st millennium BCE). The Neo-Assyrian empire is well documented by Jewish history and the Persian Empire by Jewish and Greek history (Armstrong 2006). As described above, there were also candidate transitions in Mesoamerica and South America, the first multi-ethnic empires in the western hemisphere.

Fig. 3. Time Lines of the major events in Holocene Geo-Cultural Evolution. Bottlenecks appear in purple, causes appear in green, planetary disruption sources appear in red, global population in blue, and geological-archaeological-economics terminologies for the seven different stages appear in black on the far right, ky = thousand years. The major events and locations in the development of civilizations populate the timelines

An interesting question is why there should be a multiethnic transition in both hemispheres. We suggest that complex urban societies had a common beginning point, initial condition, starting with sea-level stabilization beginning 7000 years ago as discussed below, and that the decision paths to civilization are constrained enough by basic human tendencies in growing populations to expect they would all tend to escape the liabilities of city state-based polities to establish economic cooperation eventually, a case of equifinality. Worldwide this transition required about 2500 years.

So, using the Earth-scale disturbance principle, let us look at the possibilities as posed in Table 1 and Fig. 3. Figure 3 shows that we are using virtually all of the long-term scales important to human societies: decades, centuries, millennia, and tens of millennia (Lane 2019).

1. The *first* bottleneck of immediate interest may have been caused by the Mount Toba eruption of about 75,000 years ago. It is thought to be the largest volcanic eruption in the Pleistocene. Although the scope of the effect has been a source of controversy, it obviously did not depopulate the world of humans but it appears to have advantaged small, populations of *Homo sapiens* (Anatomically Modern Humans) in Africa and the southern hemisphere by weakening the positions of northern, high latitude, near-humans such as Neanderthals and *Homo erectus*. Bottlenecks of this sort can be tested by analyzing human genomes. Human genomes support the idea that there was no bottleneck in Africa but there was outside of Africa, and there were repeated blows to higher latitude genomes from about 70 to 30,000 years ago (Reich 2018, pp. 15–16). The cooling likely lowered ecosystem productivity in higher northern latitudes, while moister conditions continued in east Africa (Lane et al. 2013) and other circum-Indian ocean areas (Petraglia et al. 2007). While it has become clearer that the southern hemisphere was little affected, climate modeling and ice core observation suggest a millennium of cooling and drying in higher northern latitudes such as China (Robock et al. 2009). Parallel evidence of genetic bottlenecks in other species and human world expansion after Toba point to a change of status of some sort. We suggest that the south-ern refugium of nearer-constant productivity was an energy subsidy for *Homo sapiens*. It pointed toward a basic geo-graphical scope of anatomically modern humans, the opportunities and constraints of worldwide ecological occupations (Roberts and Stewart 2018). Of special interest is Robock's thought that humans may have been driven toward shore ecosystems, a habitat of great potential previously largely unoccupied by humans. As a potential alternative hypothesis, it should be kept in mind that a more diffuse event such as the onset of the last stadial of the Pleistocene might have produced similar consequences.

2. A *second* foundational transformation transpired less dramatically and controversially at the end of the ice ages. About 14,000 years ago, the glaciers began to retreat due to a warmth-inducing re-configuration of the planet's orbital and rotational characteristics (the Milankovitch cycles). This configuration maximized global temperatures about 9000 years ago (Davis and Sellers 1994). It brought with it increased precipitation over most of the planetary land-masses including the then-green Sahara. It provided an energy subsidy for humans to begin settling down, and for high agricultural productivity and domestication of plants and animals. This was a worldwide phenomenon. It had its origins in the subtropics and tropics in regions such as north Africa, Mesopotamia, south Asia, China, Peru, and Mesoamerica but soon spread to the temperate zone in north-ern Europe, China, and North America. During periods of exceptional

global warming, it spread into latitudes now characterized as boreal zone (Bryson 1977). This energy subsidy began a Holocene series of developmental cycles worldwide driven by the Malthusian–Darwinian dynamic (Nekola et al. 2013) that has lasted to the present day.

3. The *third* important bottleneck comes at the end of deglaciation about 6000–7000 years ago when sea level rose nearly 150 m and reached near its modern elevations. Since then sea level has varied minimally in the range of a few meters compared to the hundred or more meters characteristic of the ice ages. Also, being high on the continental margins, sea-level stabilization provided broad, shallow estuaries, broad lower river valley floodplains, and increases in primary productivity and fishable resources in shore zones by about a factor of 10 (Day et al. 2007, 2012). Under these conditions, the higher productivity of deltas, estuaries, and lower river floodplains in the coastal margin zones could support several times, possibly about four times (Day et al. 2012), the population of the surrounding Neolithic country side by providing protein and critical nutrients such as DHA (docosahexaenoic acid, Day et al. 2012), an essential component of nervous systems and brains in complex animals. These rich resource areas were occupied within about 500 years of sea-level stabilization (Stanley and Warne 1997) and some of these environments gave rise to multi-strata societies such as those that appeared in Mesopotamia, coastal Peru, and elsewhere. Stanley and Chen (1996) and Stanley and Warne (1997) have identified 34 such environments around the world that might have supported substantial coastal human populations some of which may remain to be identified.

It seems likely that the process by which multi-strata societies were created was through inter-tribal warfare, also apparently a stubborn legacy of pre-human/chimpanzee-split cultural and possibly genetic/epigenetic inheritance (de Waal 2007). This process of state building by warfare (Fukuyama 2011), a fundamental principle in history and political science, eventually resulted in class-based socie-ties that became the foundations of urbanization (Day et al. 2012). Archaeologically, the evolution of these societies can be traced through more efficient energy use first for higher status grave goods, and later by labor mobilization to con-struct monumental architecture (Day et al. 2007) and water control actor networks (Ertsen 2016). Reich (2018) believes the next step in the use of full human genomes is to test local populations in detail. We suggest that analyzing local population in the areas of deltas for genetic bottlenecks caused by classist societies would be an interesting test of this model that goes beyond grave goods to determine if these delta societies evolved as casts or more generalized stratified societies. Large public works projects followed based on com-plex urban–rural relations and urban social units larger than about 10,000 persons to run complex information systems (Cowgill 2004) and construct large public works projects such as irrigation networks. The centers of classist societies eventually found their ways into lower river valleys, Uruk being the classic example but similar developments were underway in other areas such as the Supe River valley at the sites of Aspero and Caral in coastal Peru (Moseley 1975; Solis et al. 2001; Day et al. 2007, 2012). This was because the increasingly rich valley floodplains could be agriculturally intensified by irrigating Neolithic domesticates. From this intensification came the food surpluses from both coastal marine resources and agricultural surpluses necessary to support large, class-based societies with engineering, literacy, and productivity specialists. Thus, the emergence of these more complex social organizations resulted in more efficient use of energy resources enhanced by sea-level stabilization and coastal margin enrichment. Mesopotamia may have had a slight temporal edge on other delta/lower river valleys because it was not deeply incised during the Pleistocene

(Pournelle and Algaze 2014; Pournelle 2018). This was because the Persian Gulf itself is not as deep as Pleistocene sea levels, so there was no change in river base level after 14,000 years ago.

4a/b. The *fourth transitional* bottleneck is a filling in of the world's exploitable agricultural spaces with city state-based class systems spreading out from the coastal margins. This second wave of civilization (Gunn et al. 2014a) was highly varied, urban-dense societies in the tropics, subtropics, and temperate zones. They were based at least in part on the inherent needs of lower river valley complex societies to trade in resources such as salt and stone that are inherently scarce or absent in lower river floodplains (Algaze et al. 1989). In many cases, the archaeological evidence points toward incessant squabbling among urban societies of limited dimensions over access to resources, trade routes, and land. They nevertheless maintained connections to their ancestral coastal margin ecosystems to support basic nutritional requirements (Trigger 2003; Day et al. 2012). The central Maya lowlands are a relevant case where essential nutrients have to be supplied by fish from the sea, lower rivers, or fish farming, without which porotic anemia results (Scherer et al. 2007). Fish farming undoubtedly supplied part of this nutrition in all such societies such as Mesopotamia (Pournelle and Algaze 2014; Pournelle 2018).

Ethnographic and ethnohistorical studies suggest there were about 200 such regional societies, or humanities, world-wide (Murdock and White 1969). At this time, the scope of the world's harvestable lands became the bottleneck. Many of these societies took on the form of low-density, agrarian-based societies (Fletcher 2009) with the lowland Maya and Angkor being significant examples. They probably included the Amazon (Heckenberger et al. 2008) and Congo basins and many other somewhat forgotten venues waiting to be recovered from ethnohistorical and archaeological reports. These populous societies were not limited to architectural or even agricultural societies, some being nomadic and based on domesticated animals or on very rich ecosystems that did not need agriculture as an energy base for society. Examples are the northwest coast societies of North America based on salmon and Poverty Point in the lower Mississippi Valley that was at the juncture of rich riverine, wetland, and upland ecosystems. This stage of human Holocene development is generally discussed as "city states" and can be thought of as something of a tribalized urbanism and lasted in most parts of the world until the coming of the Axial Age (see sidebar, Armstrong 2006; Jaspers 2011) (link) in the first millenniums BCE–CE from 1000 to 3000 years ago. Nevertheless, tribalized urbanism has not entirely gone away as is evidenced in the present-day Near East.

A third substage (4c) of city states followed dense settlement of lower river valleys. Villages in passes between river systems were populated with representatives of lower river cities. Uruk, for example, established colonies near Carchemish (2400–975 BCE) and Tell Qannas in the passes between the Euphrates and Mediterranean coast (Algaze et al. 1989, pp. 577–578, 590). In a parallel case, in the Peruvian Andes the city of Chavin de Huantar (golden age 1800–500 BCE) rose in a pass between the Santa River valley in the Pacific slope and the Marañon River toward the Amazon basin (Rick 2004).

Substage 4c of urbanization is separated out because it is to some extent dependent on the needs of the city states in the lower river valleys for salt, stone, timber, ores, and other commodities. Since transportation of produce would have been difficult, these trade-route cities would have been dependent on local food production to support their populations. Brak on a tributary of the upper Euphrates is an early and large city on the crossroads between east–west and north–south routes, some going to the Asian steppe. Wilkinson (2003) identified this area of low rainfall in norther Syria as an area into which irrigation agriculture spread about 6000 BCE at a time contemporary with the Sumerian cites of the lower Euphrates. The 2009 drought that precipitated the Syria Civil War (Ahmed 2017) had the worst effect in Hasakah province where Brak is located so it may be that the confluence of several rivers allowing irrigation may be key to understanding Brak's location and role. It appears that as Wilkinson says, it is another model for making urbanism apart from the city state model prevalent in the lower Euphrates. However, the early onset of Holocene scale human populations in the lower Euphrates probably prompted some of its development.

It was during the fourth stage (see Table 1) that humans began to leave their mark on the Earth's geochemistry. By about 9000 years ago during the Neolithic Period, atmospheric carbon dioxide diverged from expected values that previously followed the planet's changing orbital configuration (Ruddiman 2005a, b). At that stage, carbon dioxide does not appear to have had much of an impact on the temperature of the atmosphere or the volume of oceans. However, around 3000 years ago methane, a greenhouse gas over 20 times more potent than carbon dioxide, began to be produced by wet rice agriculture and animal husbandry. From that time onward, the temperature and related variables such as global ice volume, sea level, and rainfall began to follow changes in human world population and agricultural practices rather than purely the orbital-rotational configurations. An important example is the global cooling that followed triple volcanic eruptions of the AD 537 event discussed above that lowered agricultural productivity. As noted above, worldwide famines and plagues resulted contributing to a 300-year decline in global temperatures and ultimately in the extended droughts in the Maya lowlands and elsewhere that precipitated economic transformation for the Maya from an interior, trans-peninsular focus to a maritime trade focus (Gunn et al. 2017).

5. The *fifth* foundational transformation leads to the multi-ethnic empires of the Axial Age. During the Axial Age (see side bar) from about 1000 BCE to 1500 CE, quarreling city states were aggregated into "empires" of various descriptions. The basic characteristic is that they attempted to override tribal feuding and local resourcing with multiethnic cooperation resulting in more efficient use of agricultural and other energy resources and thus provided a net energy increase to society. This cooperation was framed in power hierarchies (Crumley 2003; Morrison 2018) that are intolerant of intolerance. An example is the Roman Empire that persecuted the Christians because they were intolerant of other religions officially sanctioned by the Roman government (Downey 1977). Official empire outlooks were supported by philosophical expositions of cooperation such as the "golden rule" first and most expansively elaborated in China and later in the Near East and Mediterranean (Armstrong 2006). Ultimately it was characteristic of most such empire's social organizations worldwide. Also, benevolent bureaucracies became a part of this social package providing for stable and sustainable governments (Fukuyama 2011, 2015). There, however, appears to be a limit to sustainability in these agrarian economies imposed by loss of soil fertility and forest health (Chew 2007).

Axial Age: a stage in human social evolution characterized by cooperation among regional states. Cooperative attitudes are generally presented as individual but also apply to religious and ethnic groups as evident in pantheons, laws of tolerance,…. The idea was first introduced by Jaspers (2011[1949]) who suggested an important philosophical transition between about 800 and 200 BCE across Eurasia. Other authors such as Karen

Armstrong (2006) have expanded the concept greatly. Axial principles were advocated by Confucius, Buddha, Jesus, Mohammed, Plato, and other Greek philosophers. These principles were incorporated into policy in the Zhou/Han dynasties of China, Alexander of Macedon's empire, Roman Empire, Ashoka's (Maurya 320–185 BCE) Empire in India, and probably the Teotihuacan (Cult of Quetzalcoatl) and Wari empires in the western Hemisphere.

As will be briefly tested below, we are experimenting with the thought that multi-ethnic empires should be inherently larger than their local, city state-based predecessors and are therefore detectable in the archaeological as well as literary records. Empire area represents the size of the information system under local conditions. This is especially so because, as Morrison (2018) points out, empires are prone to vastly engineering landscapes in empire-sized econiches. Because of this, Morrison sees an overlap between human and other engineering-prone species and thus a monistic point of view that heals dualistic, disciplinary divisions. We add that it reflects the evolution of information systems.

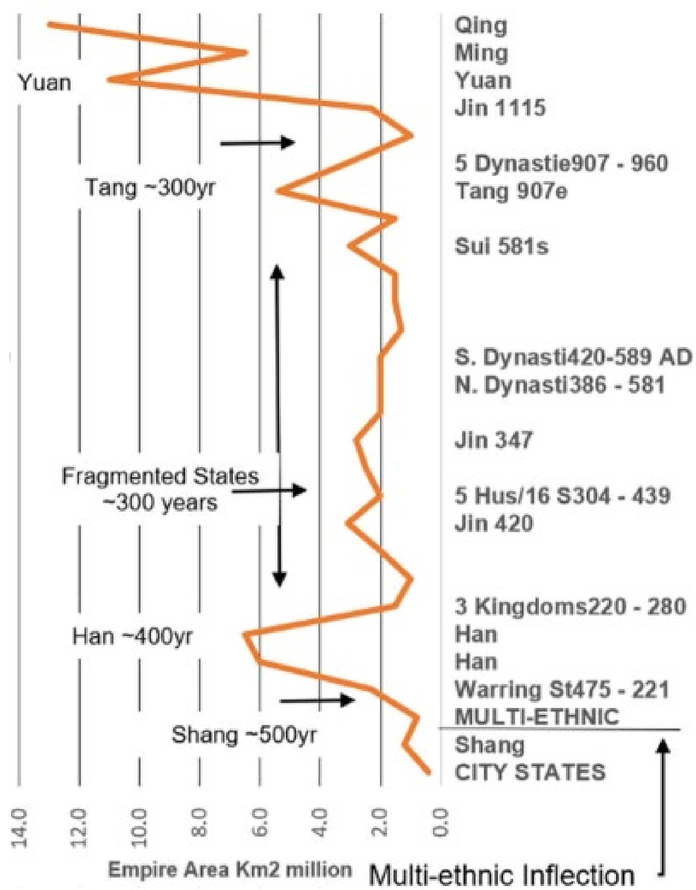

Fig. 4. Chinese dynasties/empires from the last 3000 years and their areas of rule in millions of km^2 (data from Taagepera 1979 list link accessed January 2, 2019. Mapping can be seen in Online Resource 1)

China is a good region to examine the hypothesis that multi-ethnic empires represented new ruling principles and information organization because of census data and historical records kept more or less continuously for more than 2000 years (Hammond 2004). Taking as an experimental data set, a list of empires compiled according to Taagepera's criteria (1979), we looked at 27 dynasties/empires from 3000 years of Chinese history (Fig. 4). As anticipated, the size of area influenced by states expanded by a factor of 5.2× with the advent of Axial principles during the Zhou and Han periods. This was followed by 300 years of smaller state sizes, some of the fragmentation undoubtedly arose from the precipitous global climates of the first millennium CE discussed above. Following the Siu/Tang dynasties after the seventh century, territorial controls once again trended upward with re-establishment of Axial principles.

The post-Han fragmentation of the Chinese empire addresses a current topic of discussion that early states are quite fragile and may be so for some time (Crumley 1987; Yoffee 2016; Scott 2017). The best studied examples appear in the Mesopotamian floodplains as brief experiments with multi-ethnic-like empires earlier than those in China. The Ur III Dynasty (2112–2004 BCE—Middle Chronology) bore many of the basic characteristics of multi-ethnic empires such as a code, the Code of Ur-Nammu, a standing army, centralized and standardized administration, archival documentation, a tax system, and a national calendar all of which would have contributed to maintaining a multi-ethnic empire. Furthermore, it was the last of the Sumerian dynasties in lower Mesopotamia, the people with the greatest amount of experience at designing governments. However, as usual before Cyrus II the Great (559–530 BCE) these multi-ethnic experiments were soon terminated by invasions of uncivilized groups from the peripheries. We also suggest that multi-ethnic empires exhibit two-way exchanges of information and customs. Uruk (> 3200 BCE), for example, influenced other societies as far away as the central Asian steppe, but was not influenced itself other than receiving raw materials from distant places. This pattern is reflected in the genomic sphere as well (Reich 2018). Cyrus' empire was very much an empire of shared customs and information as well as materials.

6. The sixth transformation is into the dimensions of the planet itself. It is probably best envisioned in terms of the Columbian Exchange beginning in the 1500s CE, the ongoing worldwide homogenization of biota and human social organization in the context of the worldwide economic system. This stage of human development appears to have been driven by the evolution of marine navigation and trans-port of goods in large quantities. The deep roots lie in the Mediterranean Bronze Age and in the transition to the Iron Age around 1000 BCE (Cline 2014). Similar transitions were unfolding in southeast China/Taiwan resulting in the colonization of the Indo-Pacific shores and islands by Austronesian-speaking sailors (Damon 2017). The Roman Empire again provides an interesting case as around 100 BCE to 500 CE its grain was transported from at least six breadbaskets (Egypt, Syria, Anatolia, North Africa, Spain, Burgundy) to support a city of a million people in Rome. The Maya made a similar transition at the time of the so-called "Maya collapse," which was more a repurposing of the interior cities into the newly dominant maritime economy of the "Postclassic" (Sabloff 2007; Gunn et al. 2017). After about 1500 CE, the period of the great European colonial empires began. Some Mesoamerican states were conquered by the Spanish, the Austro-Hungarian Empire, but the western lowland Maya actually joined the Hapsburg world reorganization viewing them as a similar maritime culture (Scholes and Roys 1968; Faust 1998; Gunn et al. 2014b; Gunn 2019). In these cases, empires from the Roman to the great age of European colonization funneled huge amounts of resources that were energy subsidies to the central parts of empires.

7. The third bottleneck (sea-level stabilization) is bookended by a *seventh* formational transition whose constraint is carrying capacity, or ecological footprint, of the planet. By the 1500s CE, human demands for food fodder and fuel on woodlands was so great that a turn to fossil fuel was

inevitable. Although humans have used coal on occasion for many millennia, it seems to have been used by Chinese at least since the Bronze Age 3500 years ago. However, a highly indicative moment in the use of coal in west Eurasia occurred in 1527 when Henry VIII of Britain facilitated the undoing of monasteries on which most coal reserved were located and giving permission to mine it for industrial purposes.

Since then the number of Fossil Fuel Age humans has grown well past the planet's carrying capacity by a factor of at least 1.5 times and the current trajectory of industrialization, population growth, climate change, and environmental degradation is clearly unsustainable (Rees and Wackernagel 2013; Steffen et al. 2015; Day and Hall 2016; Day et al. 2018; Crownshaw et al. 2018; Burger et al. 2019). The modern industrial city has taken on a new significance on the worldwide sustainability stage after the recent urban transition to greater than 50% of global population living in cities and more than 500 cities with more than a mil-lion people (e.g., Glaeser 2011, p. 338). This transition is the industrial revolution underwritten by the massive use of fossil fuels. The fossil resource bases for modern cities are fundamentally non-sustainable in the face of growing biophysical constraints on resources, ecosystem degradation, population growth, climate change impacts, and a profoundly dysfunctional economic system based on continued growth (Graeber 2012; Hall and Klitgaard 2012; Day et al. 2018; Crownshaw et al. 2018; Burger et al. 2019). Components of this dismal picture lie ahead. They include human impacts that have caused global-scale degradation of natural ecosystems (Roberts 2009) and decreasing ability to provision ecosystem goods and services to vulnerable areas like coastal zones and arid regions. Any effort to transition to renewable energy will compete with resources needed to mitigate climate change and environmental degradation and to support a growing population (Day et al. 2018). How these needs are balanced is the primary decision-making challenge of the immediate future. At the end of the article, we will return to the details of this stage.

What drives the Humanities' Change Engine in the Holocene?

Probably what the present can learn from the past (see IHO-PEnet.org, Integrated History and future of People on Earth) is that not only are modern economies prone to growth, but growth seems to be an inherent characteristic of the Earth's humanities. Amplification of this tendency expresses itself in extremes when they are engaged in competitive and cooperative feedback loops with other planetary system variables. Unfortunately, past periods of growth have almost always ceased due to depletion of resources and competition (e.g., an effective reduction in available energy). Changes often come with extreme economic and social disruption. An interesting example has emerged in the Maya lowlands. The Classic Period (200–900 CE) of the Maya lowlands came to be organized for the most part around water-managing cities such as Calakmul, Caracol, and Tikal (Scarborough 1993; Martin and Grube 2008; Lucero et al. 2011; Chase and Scarborough 2014; Gunn et al. 2014b; Scarborough 2017). They were in large part city states although since scholars have learned to read Maya writing it has become clear that there was an alliance between Calakmul and Cara-col that approached the scope and form of an empire during the Calakmul Golden Age in the 500 s and 600 s CE. This would have been an empire in the hegemonic sense much like the tenuous distant reaches of the Aztecs at Tenochtitlan or the Sumerians at Uruk. Mesoamerican cities would have had very limited military reach because of the tropical environment (Chase and Chase 1998). Also, during the approximately 2000-year history of the Maya interior urban system (about 1000 BCE–1000 CE), it was buffeted by regional volcanoes (Tankersley et al. 2011), global cooling (Gunn et al. 1995; Brenner et al. 2003) that caused local droughts, and external conquests (Freidel et al. 2007) that injected regional politics into local Maya lowlands economies. These and other events repeatedly fragmented polities and resulted in a 200-year struggle for dominance between the Calakmul–Caracol alliance and the Teotihuacan–Tikal alliance (Martin and Grube 2008; Gunn et al. 2014b).

An information-based study of this system has shown that through a half-dozen archaeological periods from the Late Preclassic to the Terminal Classic (400 BCE–900 CE) (Table 2) the system was repeatedly buffeted and struggled back to social coherence (Adams 1991; Gill 2000; Gunn et al. 2002, p. 292, 2017; Dunning et al. 2012). Coherence was measured among seven southern lowland cities by expert opinions on the amount of upper status ceramics exchanged among socio-economic elites. Especially during the Late Classic these so-called codex vessels with writing and pictures were exchanged among elites of the interior cities at feasts. Thanks to thousands of neutron activation determinations by the Smithsonian Institution, these arti-facts can be traced from their point of manufacture to their final resting places in royal palace rooms and tombs (Reents-Budet et al. 2011; Gunn et al. 2017). Observations on the frequency of these exchanges were analyzed to show the times of coherence/cooperation and disintegrations of city state elites through time. When factored with pollen indica-tors of soils and forest health and general climate models, three patterns (factor scores, Fig. 5) emerged: Pat_1) the rise and fall of the interior cities with soil and forest depletion, Pat_2) the rise of the coastal cities with the development of maritime technology and sustainable food production, and Pat_3) a shift of the economic and political center of coherence from the east coast of the peninsula in the earlier Classic periods to the west coast in the later periods.

Table 2. Integrated History and Future of People on Earth (IHOPE)—Maya area-wide BCE–CE chronology Adapted from Chase et al. (2014)

Beginning	**Period name**	**Major events**	**Symbol**
1958 CE	Post-IGY	International Geophysical Year Earth System Observations	IGY
19th/20th centuries	Instrumental observation	Carnegie Institution of Washington research	Inst
1550	Historic Maya	Maya integrated into modern world economic system	Hist
1250	Late Postclassic	Northern lowlands heavily occupied	Lpo
1000	Early Postclassic	Florescence of eastern Yucatec coastal sites and Itzamkanac and Champoton on the west coast	Epo
900	Terminal Classic 2	Florescence of Chichen Itza in northern lowlands	T2
800	Terminal Classic 1	Political collapse in the southern lowlands, worst droughts in 9000 years (Brenner et al. 2003; Douglas et al. 2015)	T1
700	Late Classic 2	Regional polities dominates the lowlands, 695 CE pivotal wars between Calakmul/Caracol and Tikal	L2
550	Late Classic 1	Florescence of regional centers in southern lowlands, AD 536 Event	L1
450	Early Classic 3	Transition to stratified regional polities	E3
350	Early Classic 2	Vaulted buildings and Teotihuacan-like elite pottery	E2
250	Early Classic 1	Widespread appearance of polychrome ceramics	E1
1 BCE/CE	Late Preclassic b	Changes potentially reflective of a collapse because of drought	Plb
–300	Late Preclassic a	Large vertical monument constructions	Pla
–800	Middle Preclassic	Large horizontal monumental constructions	Pm
–2000	Early Preclassic	First recognizable Maya peoples, drought toward the end of the period	Pe
–3500 BCE	Archaic	Paleoindian lithic points	Ar

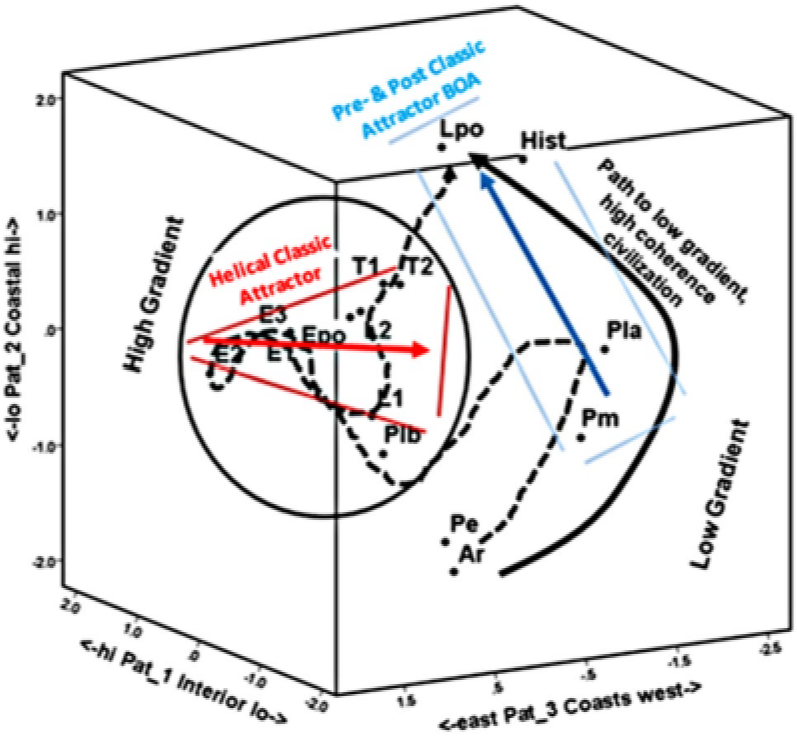

Fig. 5. During the Early Classic (Ex), Late Classic (Lx), and Terminal Classic (Tx), the Maya cultural trajectory seems to be caught up in a Classic Attractor, the red arrow. Otherwise, the Maya system followed the Pre/Postclassic trajectory, the blue arrow. The shift from one attractor basin to the other appears to be contingent on trade external to the peninsula

Pat_1 Since the interior cities required huge amounts of effort to construct and maintain water management facilities, administrative and religious structures, etc., we have associated pattern 1 (Pat_1) with high-energy expenditures or gradients (see Tainter et al. 2003).

Pat_2 The second pattern is very efficient with energy (low-energy gradients) thanks to the increasing use of marine transportation. It also appears to have stressed its soils and forest environments much less than interior pattern 1; the health of the environment improved with high-information coherence.

Pat_3 We interpret the third pattern as related to political and military changes over the Classic periods. We assume that greater information coherence on this pattern means greater economic and military cooperation between cities on the west coast with the increasingly dominant Mexican highlands polities from ancient Teotihuacan (~ 400 CE) to the historic Tenochtitlan of the Aztecs (~ 1400 CE). The relationship was so cozy at the time of Spanish contact that the Aztecs regarded the Maya Lowlands to be off limits to military conquest lest the highly valuable trading center at Xicalanco on the Laguna de Terminos be disrupted (Coe and Coe 1996, p. 75; Folan et al. 2016).

In essence, these patterns reflect the utilization of energy resources as influenced by ecosystem productivity levels (e.g., coast vs inland) and technological and social developments to utilize energy sources (development of maritime trade).

There is a certain cyclicity of the system that appears to be driven by interaction with an approximately 300-year cycle in global climate variables, the local rise and fall of polities, and changes in the general context of Mesoamerican trade and political relations. The progress of this system of planetary climate change and internal and external politics is plotted in three dimensions (Fig. 5) across the 5000-year trajectory of the lowland Maya system. It shows two apparent patterns of interaction. One, the blue arrow, begins in the far prehistoric Archaic (Ar), which was a low-energy demanding, low-information coherence society beginning about 5500 years ago, a hunter-gatherer society. Over time it proceeded through various stages to become a low-energy and high-information coherence society, in this case a maritime, coastal trading network (Folan et al. 2016). However, during the 200–1000 CE era of the interior Classic periods (Plb to T2), the system was sidetracked into a high coherence, and unfortunately unsustainable high-energy demanding society (the need for complicated, high-maintenance water management systems), the red arrow. This was the social stage that produced beautiful cities and arts, and it eventually succumbed to competition from more efficient coastal societies such as those of the Chontal Maya (Scholes and Roys 1968; Trigger 2003) and climate change (Gunn et al. 2017).

The Classic Period sidetrack has "rotational" characteristics that suggest that it may be in some sense an attractor. In complex systems terminology, an attractor is the confluence of a number of variables that combine to cause a spiraling path through the plot or phase space of the combined variables (see Gleick 1987 for examples). In the more usual sense of a physical attractor such as the Lorenz atmospheric attractor, time (seasonal) issues are ignored to bring out the spiraling of the system through its phase space (Finnigan 2017, personal communication). However, with archaeological/historical data, time is clearly a key variable along which growth transpires. To accommodate time-based trajectories we have experimented with modeling the Maya historical sequence using the helical equation (screws, DNA double helix) with the archaeological period sequence (t) serving as the temporal core of the changing, growing system (Gunn and Folan in press). Average duration of archaeological periods defines the angle of pitch (theta) change through the helix time dimension, and the radius of the helix (r) is the average deviation of time periods from a regression line through the core of the attractor. The direction of the Classic attractor through the phase space may represent the increasing energy investment in marine technology and the inversely correlated decline of interior forest and soil resources. The shape of the attractor trajectory can be gauged by subtracting it from templates, funnel for growing, tunnel (cylinder) for steady state, and cone for decline. The interior trajectory is clearly a cone of decline.

Helical equation
$x(t) = \cos(t)$
$y(t) = \sin(t)$
$z(t) = t$
Cylindrical coordinates
$r(t) = 1$
theta $(t) = t$
$h(t) = t$

Early results indicate that there is a rotation or oscillation through time involved (Fig. 6). It hardly scribes Vico's perfect spiral of history (see Lamberg-Karlovsky and Sabloff 1979, p. 14) but it at least carries the suggestion of a spiraling or oscillating set of relationships (the blue and light tan lines are equivalent to the sin and cos of t). We are ready to suppose that for a geo-cultural attractor to rotate it requires at least three super variables or factors as discussed above, the more usual quantities of global–local climate, the local ecosystem resources, and a human decision-making com-ponent loaded with a tendency to grow. This seems to characterize many of the social systems discussed above. Such a configuration integrates the planetary and the humanities into a single equation. As Pickering (1995) points out, in such a matrix humans and combinations of limiting entities have in effect agency, so this analysis treats humans and planetary components as decision making, complimentary forcings in the progress of local systems and "the Earth."

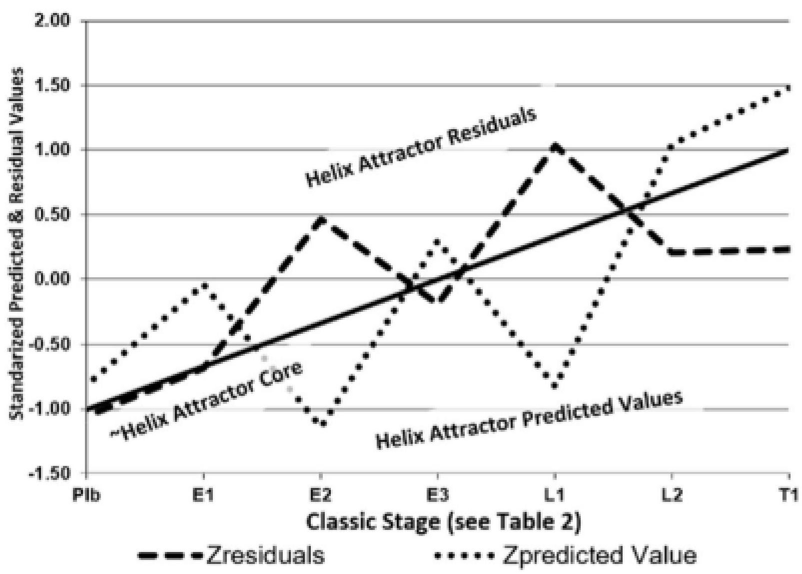

Fig. 6. Regression through Maya Classic Attractor. Dashed and dotted lines are roughly the sin and cos waves of the helix

In the case of the Maya Late Classic, when the planetary climate is included, which declines toward global cooling over the duration of the trajectory (see Kilimanjaro sequence in Online Resource 2, Thompson et al. 2002), environmental disturbances such as droughts (see Table 2) appear to drive the transitions from one stage/period to another. There is a clear tendency for social periods to hang on, even if moribund, till they are disturbed by planetary-scale upsets, especially evident in the second period of the Late Classic (L2). This may be because there is enough redundancy in the greater Mesoamerican economic and biophysical system as a whole to carry on until the entire system is upset. Following such upsets, there are otherwise inexplicable period changes across the several regions of Mesoamerica, and in many cases across continents and hemispheric landmasses as discussed above. On a worldwide scale, this helical attractor defines one of the 200 regional (Murdock and White 1969) geo-cultures roughly approximated now by the ~190 countries in the United Nations that compose the total human adaptation to the planet's surface. China is an interesting case where about 22 ancient cities have churned up into modern megacities (Kaplan 2018).

In addition to the apparent political, technological and environmental forces at work in the Maya Lowlands, there are other possible reasons and/or co-reasons for the declining trajectory of the interior Maya cities. As van der Leeuw (2019) points out, complex systems may have inherent tendencies to decline because of accumulating, unintended consequences of decisions made through their time frames. Another built in tendency is suggested by Bardi et al. (2019), which is that empire-scale systems (Roman in their study) appear to spiral into attractors in the presence of declining resources. This is a condition that Chew (2007) suggests all such empires/civilizations hold in common.

Time-to-Transition Outcomes

Steffen et al. (2015) point out that there are a number of critical variables in the Earth system and from all appearances some remain within the safe living space of human existence and some do not. Clearly one of the great concerns on a short fuse is greenhouse gas accumulation and climate change (IPCC 2018). Looking forward into the future based on the Classic Maya experience will bear some merit because, like the present-day world system, the Maya were a loosely held concept of unity based on common cultural background something like the United Nations or perhaps the current United States. If the information exchange capabilities of the two civilizations are held constant, the com-parison might be instructive (van der Leeuw 2007 and 2019 for discussion of this comparison; see Gunn et al. 2017). The Maya extreme limitation was annual rainfall for agricultural surpluses required to maintain the information cities through the dry seasons. In a similar manner, the modern world system requires fossil fuels to maintain its subsistence and information links (Fig. 7) (Day and Hall 2016; Day et al. 2018). A considerable consensus has accumulated that there are distinct limits on the amount of greenhouse gas emissions that can be tolerated by industrial civilization (NYT, Rich 2018; IPCC 2018) and also that the fundamental energy base of that civilization is in decline (Day and Hall 2016; IPCC 2018; Crownshaw et al. 2018; Burger et al. 2019).

Sgouridis et al. (2016) developed a simulation reflecting these constraints and the growth in renewable energy required to offset fossil fuels and maintain typical energy levels in the world system. The amount of renewable replacement achieved during the twenty-first century can be set against the emerging social systems by speculating on the quantities of renewables achieved at a given date assuming that is all that is achieved. A general comparison is made in Fig. 8 using the archaeological terms for past and pre-sent periods of comparable economic and social complexity from Table 1 last column. Burger et al. (2019) reported that currently near-subsidence countries have per-capita energy consumption of about 500 watts or only a few times more than the human metabolic rate of about 100 watts, while inhabitants of modern first world cities have energy consumption of 10,000 watts or more. Pre-industrial towns had per-capita values around 1000 watts. This scheme suggests that if the required renewables are installed by 2020 or shortly thereafter, cities as they are currently understood can be maintained without overstepping the greenhouse gas threshold, at least for some first world countries. However, there is little evidence that this is possible (e.g., Day et al. 2018). If the effort to install renewables fails at 2040 levels, towns similar to early agrarian-based civilizations will be possible. If the effort achieves most of the replacement by 2060, communities more like Neolithic villages will be the most likely social structures to be maintained. It is important to consider that the peak renewable production shown in Fig. 8 is about 40% higher than total current fossil fuel production—an enormous and perhaps unachievable goal (Day et al. 2018).

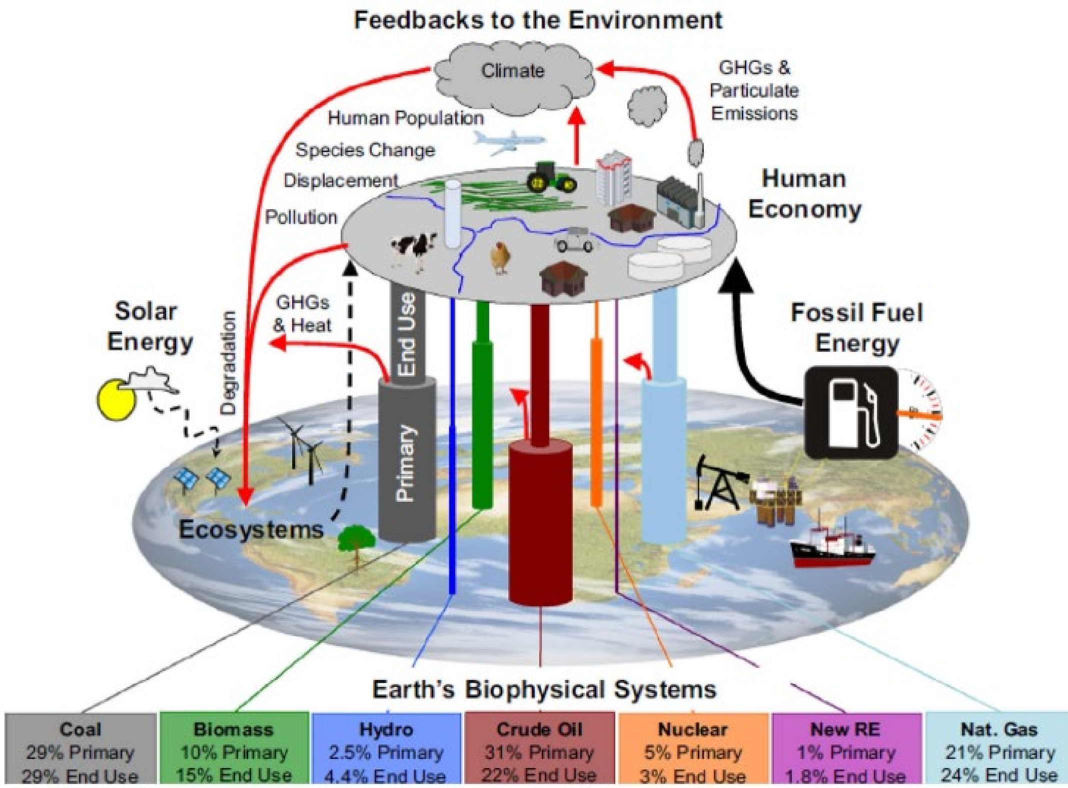

Fig. 7. The energy pillars diagram. Society is supported by a number of sources, primarily fossil fuels. Ultimately, the global society rests on the biosphere, which is currently being degraded (from Day et al. 2018)

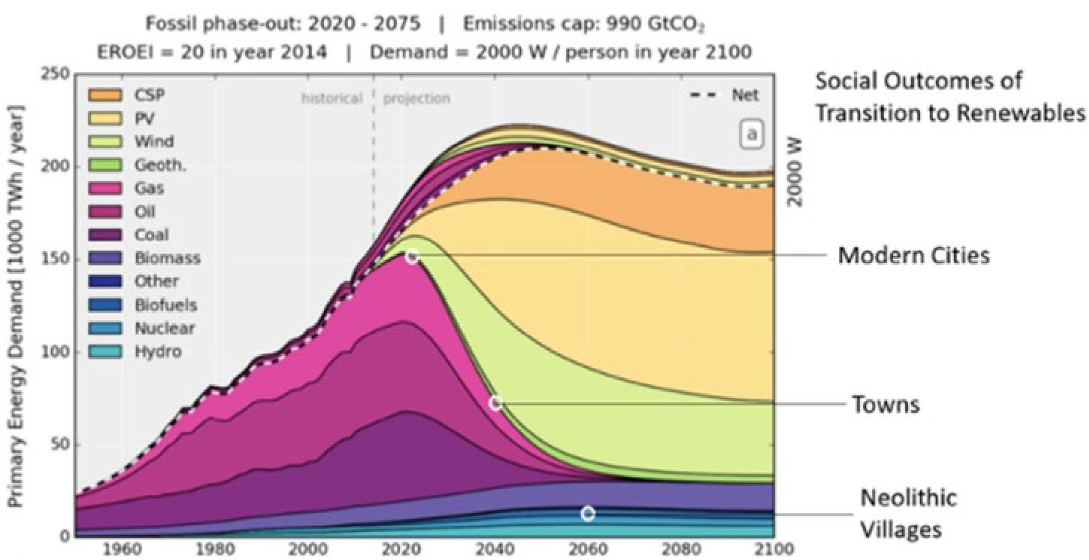

Fig. 8. Reduction in fossil fuel consumption and growth of renewable energy required to offset fossil fuels to meet climate goals and maintain typical energy levels in the world system (from Sgouridis et al. 2016). The estimated per-capita energy consumption needed to sup-port modern first world cities, pre-industrial towns, and Neolithic villages based on information from Burger et al. (2019). Note that these are presented to give a general idea of energy use by modern cities, pre-industrial towns, and Neolithic villages and do not relate to the axes of the Sgouridis et al. graph

If the graph of renewables replacement from Sgouridis et al. (Fig. 8) is compared to the energy pillars diagram (Fig. 7), the enormity of the problem becomes clear. The current energy system needed to sustain modern society is overwhelmingly dominated by fossil fuels and it will require an enormous effort to substitute new renewables, which currently account for a few percent of total energy use, for old fossil fuels. Climate change, population growth, and other human-caused activities are seriously degrading the environmental biophysical resource base that supports society. Implementing climate mitigation will have to compete for increasingly scarce resources to address both climate impacts and environmental degradation. This will be made all the more difficult due to a growing population and a dysfunctional economic system. There is also the potential for increasing violence and reactionary political states (Ahmed 2017; Heinberg and Crownshaw 2018; Crownshaw et al. 2018).

While these outcomes may seem preposterous to some-one sitting in early-2019, they do open important questions about the urgency of the issues at hand and the feasibility of solutions (Crownshaw et al. 2018; Burger et al. 2019). Crownshaw et al. argue that an economic paradigm change will be predicated on an involuntary and unplanned cessation of growth.

The recent IPCC report on Global Warming of 1.5 degrees C, however, makes these suggestions seem less implausible (IPCC 2018) as does Nathaniel Rich's editorial "Losing Earth" published by the New York Times August 1, 2018.

Conclusions

In this brief exploration of seeing the history of the humanities as an integrated aspect of the Earth System by redefining its time scales to geo-cultural dimensions and suggesting how period-to-period changes can be analyzed in the context of evolving resource (energy) constraints within an ongoing set of cultural attractors, it provides a platform from which to view the future. Very important among the implications of this perspective is that local system components may be resilient enough to continue until interrupted by a global-scale disturbance. Such disturbances could be either of planetary or human origin, likely both, as we have seen in our Holocene view of human–planet interactions. The curious aspect of a disturbance in the current situation is that it might be a product of human decision making relative to energy consumption and other resource utilization, perhaps a self-organized, geo-cultural transition. Current evaluations of the energy dependency at the worldwide scope of human societies are the transition to a new energy regime. Such a regime is no doubt a far reach given the conflicts that can be anticipated between investments necessary to underwrite the transition and at the same time maintain the old regime while the new regime is composed. The most likely outcome is an entirely new regime of unpredictable description, but likely much more local, less energy intensive, a cessation of economic growth, and with a significant potential for violence and repression. A successful transition is not entirely out of reach but is approaching impossibility. Previous transitions to maritime trading systems may provide guidelines for such a change.

One of the immediate benefits of placing historic and modern Earth-system change on a common conceptual plat-form is a clearer understanding of scales of change. From the discussions above, it is possible that, in the context of the current and growing understanding of global climate change, it is approaching not on a scale of centuries as once thought but in decades or even years; thus the scope of appropriate analogies change. Looking at the various cultural experiences with changes, especially in the first millennium CE, this suggests to us that the change records of the 200 or so eco-cultural regions around the world can be stratified on the scales of events that cause them. The AD 536 volcanic event, for example, was causing crop failures within a year according to Procopius and in 5 years was generating full-blown famine and pestilence in the higher latitudes. The duration of the event seems to be a couple of decades. By way of contrast, the Late Antique Little Ice Age of the ninth century was caused by reduced solar emissions and took 300 years to develop. (See the Kilimanjaro O18 record in Online Resource 3, Thompson et al. 2002). The impacts were at the duration of a century as in China, or permanent in the case of the Maya transition to maritime transportation. Viewed in this way, it is clear that timing (years to decades) and spatial scale (global) are probably unprecedented for humans over the past 10,000 years.

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