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EXPLORING THE EARLY ANTHROPOCENE: IMPLICATIONS FROM THE LONG-TERM HUMAN–CLIMATE INTERACTIONS IN EARLY CHINA

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ABSTRACT

Because human modification has been significant enough to alter the atmospheric chemistry, some scholars argue that our planet Earth is going beyond the Holocene and coming into a new geological epoch, the Anthropocene. While the Anthropocene concept is widely acknowledged, some key issues, such as the starting point of this epoch and how humans influenced climate, are unclear. This paper provides an overview of the long-term, broad-scale interactions between climate evolution and increasingly intensive human activities (mainly farming) in Early China. It firstly reviews both the traditional "climate in charge" hypothesis and Ruddiman's "anthropogenic greenhouse gases" hypothesis. Then pollen and isotope data on paleo-climate is summarized to shed light on the climatic history in China from ~3500 BCE to ~220 CE. It is followed by an overview of the cultural history within the same time span. Finally, by integrating these two lines of evidence, the dynamic process of the interplay of human activity (particularly farming) and climate is synthetically discussed. Based on the evidence, I argue that the onset of the Anthropocene is a prolonged process with a notable mark in the early centuries CE.

KEYWORDS: Anthropocene, Paleoclimate, Early China, Ruddiman's hypothesis, Mediterranean, Bronze Age, Atmosphere, Culture, Greenhouse

1. INTRODUCTION

Most people today understand the human effects on the atmosphere that surrounds us, particularly in countries that are experiencing rapid industrialization. The problem of gaseous emissions, from inhalable particulate matter such as PM 2.5 to greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4), has become a focus of public concern, because it is bound up with the fate of humans and the planet. Likewise, more and more scholars have turned their attentions to issues of the interactions between human and atmosphere/climate. How do climate fluctuations drive social changes? Do human activities have effects on earth's climate? If so, when did these effects start and by what means did humans influence climate change? These questions have attracted but also puzzled scholars, including historians and archaeologists.

Traditionally, historic and archaeological research emphasizes the importance of climate change as a driving force of social dynamics (Weiss, 1997; Weiss and Bradley, 2001; Catto and Catto, 2004; Issar and Zohar, 2007; Kennett et al., 2012). Recently, scholars began to consider if humans affected the atmosphere and climate in the past. They argue that since beginning of the Industrial Revolution anthropogenic factors have become an important cause of increasing greenhouse gases and rising global temperatures (Crutzen, 2002). This argument has been reinforced by scientific research. Analysis of air bubbles trapped in ice cores from Greenland and Antarctica indicates that the absolute levels and the rates of change of two important greenhouse gases (CO_2 and CH_4) in the last 200 years have increased significantly (Blunier et al., 1993; Etheridge et al., 1996). Because human modification has been significant enough to alter the atmospheric chemistry, they claim that our planet Earth is going beyond the Holocene and coming into a new geological epoch, the Anthropocene (Crutzen and Stoermer, 2000; Crutzen, 2002).

In the recent two decades, the Anthropocene concept is increasingly acknowledged. It is now being used by multiple cultures and in a number of ways to understand the changing human-environment relationship as a conceptual framework. However, further and deeper understanding of Anthropocene still suffers from two issues. Firstly, human (or "Anthropo-") is usually taken as a global, united power, while local/regional contexts and diversity of this power are ignored to a large extent (Biermann 2016). Secondly, the starting point of this epoch has long been in heated debated: although Anthropocene is generally regard as a post Industrial Revolution concept (Zalasiewicz et al., 2010; Steffen et al., 2011), a number of scholars suggest that human impact on environment has a much longer history (Ruddiman 2003; Doughty et al., 2010; Fuller et al., 2011; Certini and Scalenghe, 2011; Smith and Zeder, 2013; Edgeworth et al., 2019).

Among these "early Anthropocene" arguments, Ruddiman's "anthropogenic greenhouse gases" hypothesis is particularly intriguing and influential. After re-examining the CO_2 and CH_4 content in ice cores, Ruddiman and his colleagues suggest that humans started to take control of climate as early as 8000-5000 years ago, correlating the onset of the Anthropocene with the origins of increasingly intensive agriculture in the Near East and especially in China (Ruddiman and Thomson, 2001; Ruddiman, 2003; 2005; Ruddiman et al., 2008).

This controversial but plausible argument has tremendous implications. Is it possible that a small number of early farmers with primitive technologies altered the atmospheric chemistry long ago? Is this the case in East Asia where rice was first domesticated? To answer these questions, I review both the traditional "climate in charge" hypothesis and Ruddiman's "anthropogenic greenhouse gases" hypothesis. Published pollen and isotope data on paleo-climate are summarized to shed light on the climatic history in Early China, from the beginning of early state-level society to the end of the Han dynasty (ca.3500 BCE – 220 CE)[1], followed by an overview of the cultural history within the same time span. By integrating these two lines of evidence, the dynamic interplay of human activity (particularly farming) and climate are synthesized, and new understandings on early Anthropocene is gained from this regional-scale observation.

2. THEORETICAL DEBATE

2.1 Climate in charge

Changing climates are frequently related to great transformations or to crucial events in human history, and traditionally are seen as their cause since the early Holocene. In the debate on agricultural origins, some archaeologists suggest that climate played a significant role in forcing inhabitants in the Fertile Crescent to abandon their hunting and gathering life and to turn to farming (Rosen, 2007). After the Holocene Optimum (roughly from 7000 BCE to 3000 BCE), a climatic shift to globally drier conditions during the late

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[1] This time range covers the Neolithic, the Bronze Age, the Iron Age and the early Imperial period of China, from the beginning of the early-state society to the formation of a huge empire of Han. It roughly corresponds to the time range from the beginning of the Bronze Age to the collapse of the Roman Empire in the Mediterranean region.

4th millennium BCE may have pushed farmers originally living in the hilly flanks or foothills into fertile alluvial plains such as are found in Mesopotamia and the North China Plain; in turn, this process drove the emergence of the earliest cities and states (Brooks, 2006; White, 2012). At the end of 3rd millennium BCE, a hypothesized worldwide environmental deterioration may have led to political crisis and even social collapse in Mesopotamia (deMenocal, 2001; Weiss and Bradley, 2001), Egypt (Stanley et al., 2003) and Indus valley (Staubwasse et al., 2003) (Fig. 1).

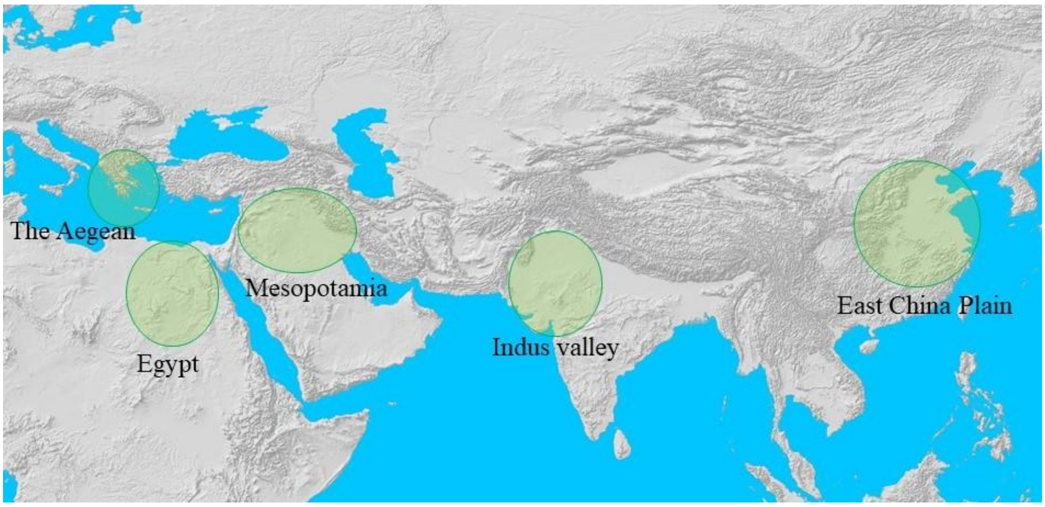

Figure 1. Location of major civilizations in Old continent. They all experienced social reorganization at the end of 3rd millennium BCE, which is thought to be related to the abrupt climatic change around 4200 BP.

Case studies in the eastern Mediterranean illustrate how human civilizations have been affected by climate change (Rick et al., 2020). The moderate climate conditions during the middle Holocene favored the Aegean civilization in the Bronze Age, known for the palatial urban centers, intensified agricultural production, and developed trade system (Broodbank, 2013; Knapp and Van Dommelen, 2015). However, data from oxygen-isotope speleothems, stable carbon isotopes, and alkenone unsaturation ratio suggest climatic shifts that followed (Bar-Matthews et al., 2003; Jahns, 2005; Emeis et al., 2000). During the late Bronze Age, the surface temperature of the Mediterranean Sea declined sharply, resulting in lower evaporation rates, less freshwater flux into the atmosphere, and thereby a remarkable decrease in land precipitation (Drake, 2012). This climatic anomaly led to social collapses in the Aegean: reduced agricultural production could not support the palatial centers in the Greek Bronze Age once with high population density, and most of them were ruined and/or abandoned between 13th and 11th century BCE (Knapp and Manning, 2016; Finné et al., 2017). The 'Greek Dark Ages'(ca.1000-800 BC) occurred afterwards during prolonged aridity that lasted until the Roman Warm Period, which witnessed the expansion of Rome across the whole Mediterranean basin (Post, 2017).

Climatic change also played a significant role in the origin and development of Chinese civilization. Relatively warm and wet conditions in the mid-Holocene favored social advances and hierarchy in the Yangshao period. Collapses of a variety of late Neolithic cultures in China were attributed to an abrupt climatic deterioration around 4000 BCE (Dalfes et al., 1997; An et al., 2005). After relatively mild but fluctuant period of 2000 years in the Bronze Age, another major environmental shift emerged and a period of cold and dry climate may have directly or indirectly resulted in the collapse of the Han dynasty (206 BCE – 220 CE), followed by a "Period of Disunion" that lasts for nearly four centuries (Yang et al., 2002). Besides, some scholars of Chinese history associate changes in climatic conditions (notably shifts towards cold and dry conditions) with the chaos of late Tang dynasty (618 CE – 907 CE) (Fei et al., 2006), the retreat of Mongolians in the end of Yuan dynasty (1271 CE – 1368 CE) (Brook, 2010), and the fall of the Ming dynasty (1368 CE – 1644 CE) (Zhang et al., 2006; Brook, 2010).

2.2 Another voice: Ruddiman's hypothesis and early Anthropocene

At the beginning of 21st century, scholars began to reconsider the traditional paradigm of "climatic determinism", and to review the human-climate relationships from an opposite perspective that suggests humans altered or influenced the climate. It was against this backdrop that the term "Anthropocene" was proposed. The concept of the Anthropocene was introduced in 2000 by Paul Crutzen and Eugene Stoermer (2000) to highlight the remarkable effects of human activity on the global atmosphere. The term was coined to indicate that the Earth was going out of the previous nature-dominated Holocene and coming into a new geological epoch dominated by human activities.

While Crutzen and Stoermer identify significant increases in greenhouse gases resulting from the Industrial Revolution in mid-18th century as the start of the Anthropocene, Ruddiman suggests a much earlier onset for the Anthropocene (Ruddiman and Thomson, 2001; Ruddiman, 2003; 2005; 2013). His argument is reasonable: the tilt, eccentricity and precession of the Earth's orbit around the Sun largely determine the amount of solar radiation reaching to Earth surface, which in turn has an effect on the global climate and greenhouse gases in the atmosphere. Therefore, global climate changes at regular cycles with the periodic variation of these natural factors, making it predicable (Ruddiman, 2010). If an abnormal trend that does not fit with the natural rules occurs, the human effects may be responsible for the divergence from natural trends.

Ruddiman argues that changes in greenhouse gases do not fit the expected pattern associated with natural, orbitally-controlled processes (see also, Shackleton and Pisias 1985).

By re-examining methane records in Greenland ice cores (Blunier et al., 1995), he noticed that methane concentrations have risen since 5000 years ago, contrary to the expected natural trend (Fig. 2(a)). Agricultural activities (rice irrigation, livestock emissions, biomass burning, and human waste) in the Old World, the eastern Mediterranean and East Asia, seem to be plausible explanations for this abnormality. Among all these potential forms of methane inputs, wet rice agriculture may play the most significant role in contributing to its increase (Ruddiman, 2010; Fuller et al., 2011). This hypothesis is supported by a recent archaeological research in China, in which Ruddiman and his colleagues (2008) presented a compilation of 311 archeological sites in rice-growing regions of China and found that the number of new sites between 6000 and 4000 years ago increased almost tenfold compared with those during previous millennia.

Similar to methane, according to the high-resolution data from ice cores, the CO_2 concentrations goes against the predicted decreasing trend and starts to rise after 8000 years ago (Fig. 2(b)). After eliminating several suggested natural explanations, Ruddiman (2010) concluded that humans must have been the cause of the anomalous CO_2 reversal. He also pointed out the primary way that human would have released CO_2 was by forest clearance resulting from agriculture.

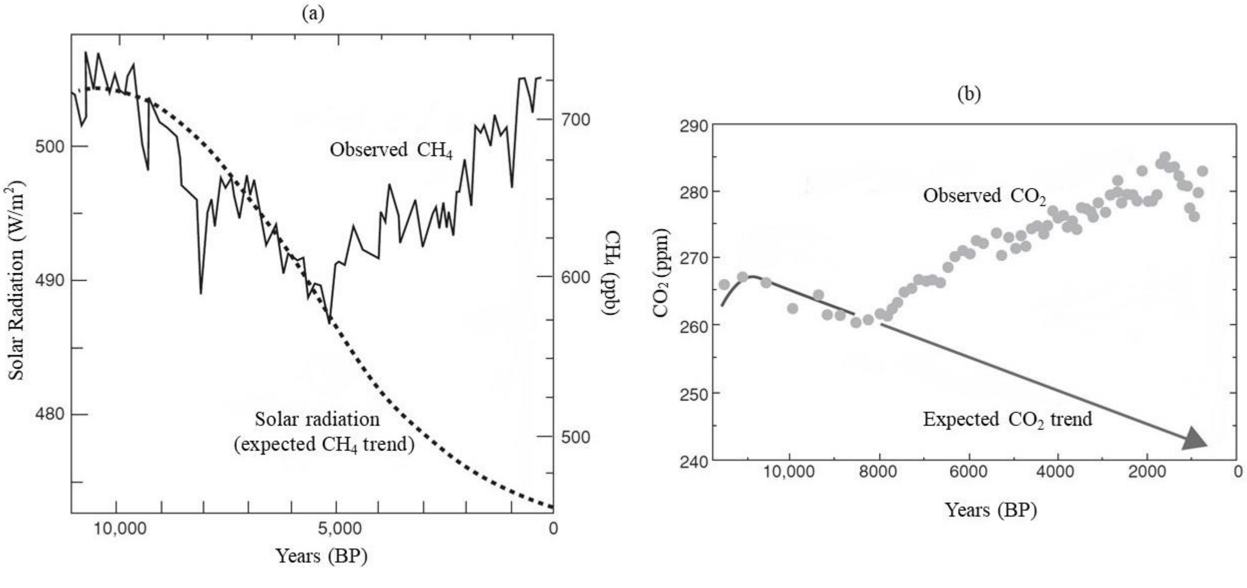

Figure 2. (a) Observed CH_4 and expected CH_4 trend since early Holocene; note the divergence since 5000 BP (adapted from Ruddiman, 2010, p.77, fig. 8.1). (b) Observed CO_2 and expected CO_2 trend since early Holocene; note the divergence since 8000 BP (adapted from Ruddiman, 2010, p.87, fig. 9.2).

In sum, from Ruddiman's perspective, natural factors fail to explain the changes in the concentrations of methane since 3000 BCE and carbon dioxide since 6000 BCE. Therefore, the only reasonable cause of the anomalous trends of the two greenhouse gases is various human activities. Ruddiman's argumentation sparks controversies on the onset of the Anthropocene.

A number of scholars, following Ruddiman, believe that the post Industrial Revolution Anthropocene underestimates the human impacts on the Earth system far earlier than 1750 CE. Various potential start dates for the Anthropocene have been proposed, ranging from the late Pleistocene around 13800 years ago to the arrival of Europeans in America in 15th century CE; markers include megafaunal extinctions, human niche constructions, anthropogenic soils, crop exchanges between Old and New World, and so on (see table 1; also see summaries by Smith and Zeder, 2013; Braje et al., 2014; Lewis and Maslin, 2015; Edgeworth et al., 2019).

Table 1. Dates and markers of the onset of Anthropocene

Dates	Markers	References
~13800 BP	Megafauna extinction	Doughty et al. 2010
11000-9000 BP	Domestication and niche construction	Smith and Zeder, 2013
8000-5000 BP	Anthropogenic green gases	Ruddiman, 2003; 2010
~3000 BP	Metal mining and smelting	Krachler et al., 2009
~2000 BP	Anthropogenic soil	Certini and Scalenghe, 2011
~1500 CE	Columbian exchange	Lewis and Maslin, 2015
~1750 CE	Industrial Revolution	Crutzen, 2002
1945-1964 CE	Great acceleration	Zalasiewicz et al., 2010; Steffen et al., 2011

3. PALEOCLIMATE AND SOCIAL CHANGES IN EARLY CHINA

Both types of explanation take China as a case study to reinforce their arguments. What, though, are human-climate relationships like in Early China? What new thoughts and enlightenments concerning the theoretical debate on Anthropocene can be gained through the case in China, where was and still is one of the most populated areas in the world? To answer this question, an accurate reconstruction of the paoleoclimate and a thorough overview of social and economic dynamics are essential.

3.1 Paleoclimate in Early China

Development of increasingly sophisticated techniques of paleoclimatic reconstruction enables scientists to gain a deeper insight into climatic conditions in the past. In China, a variety of projects on paleoenvironmental reconstruction have been conducted using lacustrine sediments from lakes mainly in the North and speleothems from caves mainly in the South (Fig. 3).

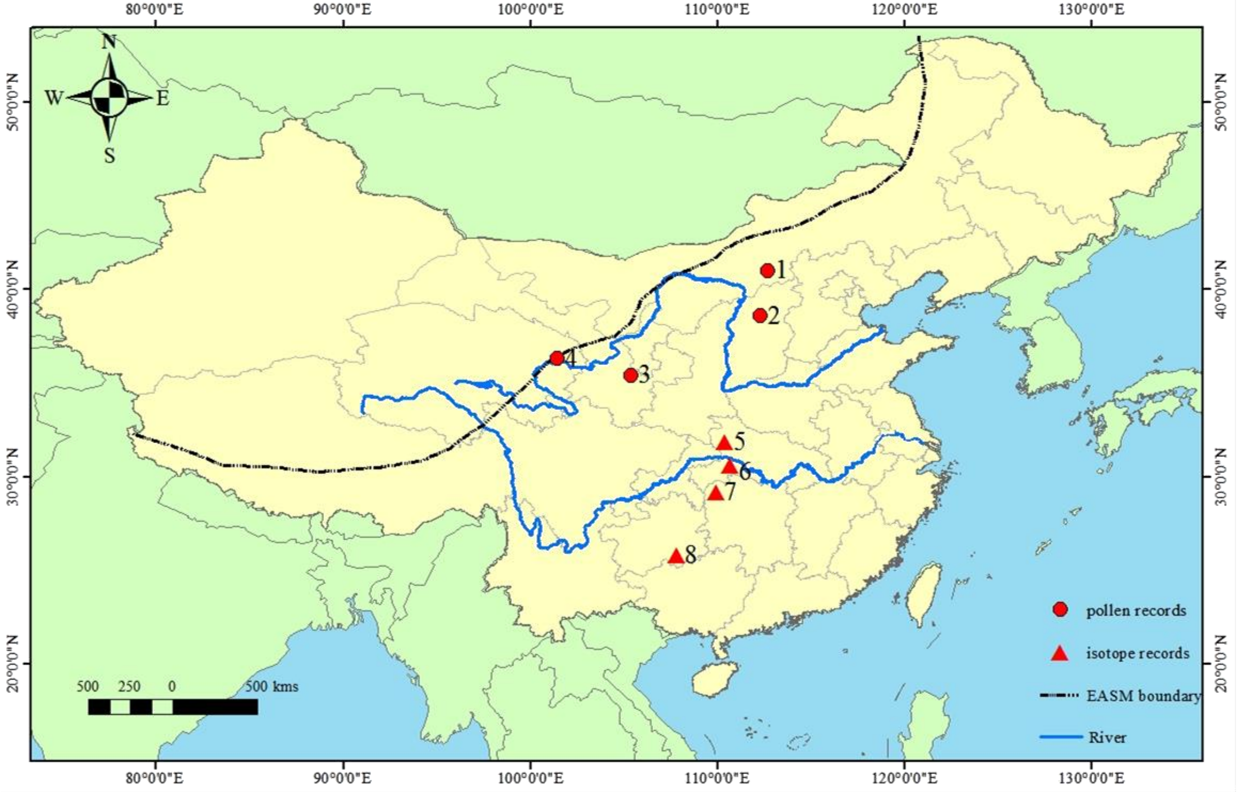

Figure 3. Sites with pollen records and isotope records in the monsoon region of China. The pollen records are from lakes: 1 Daihai, Inner Mogolia; 2 Gonghai, Shanxi Province; 3 Tianchi, Gansu Province; 4 Qinghai, Qinghai Province. Oxygen istolpe records are from caves: 5 Heshang, Hubei Province; 6 Shanbao, Hubei Pronvince; 7 Lianhua, Hunan Province; 8 Dongge, Guizhou Province.

At Daihai Lake in Inner Mongolia (Xiao et al., 2004; Xu et al., 2010) a pollen analysis of a lake sediment core reveals that during the time period from 3500 BCE to 2500 BCE, mixed coniferous and broadleaved forests dominated, indicating a mild and humid climate. This period could be viewed as the late phase of the Holocene Optimum in terms of warm temperature and ample precipitation. From 2500 BCE to 900 BCE, the climate became cooler and drier as indicated by the decrease in pollen concentrations of woody plants. This period is followed by an increasingly colder and drier period because vegetation density sharply decreased and forests almost disappeared. This episode lasted for about 1200 years and the climatic conditions didn't get better until 300 CE. After that, the reoccurrence of woody plants suggests milder climatic conditions.

Pollen analysis of sediments from Tianchi Lake in Gansu (Zhao et al., 2010) suggests that the deciduous and coniferous forests dominated the lake catchment between 3500 BCE and 900 BCE. From 900 BCE to the end of the 200 CE (and even later), both deciduous and conifer trees declined sharply and herbs replaced trees. In general, the regional landscape degraded from a canopy forest to an open landscape, suggesting a gradual trend of becoming colder and drier. This result, although with a relatively lower resolution, fits quite well with the Daihai case.

Another paleoclimatic reconstruction based on pollen comes from Qinghai Lake in Qinghai Province, which is located at the margin of the East Asian monsoon (EAM) (Shen et al., 2005). Between 3500 BCE and 2500 BCE, although climate was still mild, forest vegetation started to shrink and the landscape changed to forest steppe, implying that the warmest and wettest period of Holocene Optimum came to an end. From 2500 BCE to 500 BCE, particularly after 1900 BCE, *Pinus* gradually declined with little *Picea-Abies* and *Betula* remaining, showing a shift of regional climate from cool and humid to cold and arid. After 500 BCE, pollen concentration rose slightly; however, large quantities of *Gramineae*, *Cyperaceae* and *Thalictrum* indicate that cold and arid conditions still dominated.

Recently, new insights have been gained from a well-dated, multi-proxy based research project at Gonghai Lake in Shanxi Province (Chen et al., 2015). Using a comprehensive analysis of pollen and magnetic susceptibility, scientists reconstructed quantitatively quantitative regional climate record. From these analyses they argue that 3500 BCE – 3300 BCE overlaps with the maximum monsoon intensity interval with an average annual precipitation of 574 mm, 30 percent higher than the present value. This episode is followed by a two-step gradual decrease in monsoon intensity at 3300 BCE and 1300 BCE respectively. Although some proxies suggest that the decline continued until the end of Little Ice Age, it is noteworthy that the carbonate content indicates a recovery occurred around 1st century CE.

In addition to pollen, oxygen-isotope ($\delta^{18}O$) records from cave speleothems provide another proxy with very precise age control for paleoclimate reconstruction. Different from pollen, which reflects both temperature and precipitation, speleothems $\delta^{18}O$ is mainly an indicator of regional rainfall, and in turn, the strength of EAM (Wang et al., 2005). In recent years, a series of oxygen-isotope analysis have been done based on cave speleothems in Southwest China.

Information on changes in precipitation brought by EAM over the last 16000 years is provided by over 900 $\delta^{18}O$ measurements of a speleothem at Dongge Cave, Guizhou Province (Wang et al. 2005; Dykoski et al. 2005). According to this research, during the interval between 3650 BCE and 3220 BCE the monsoon experienced a gradually weakening and precipitation slightly decreased. From 2700 BCE to 1500 BCE, $\delta^{18}O$ values fluctuate, but the general trend goes neither up nor down, showing a relatively stable period. Then an abrupt shift of $\delta^{18}O$ occurs at around 1500 BCE and the climate during this period was extremely dry. After that, a period of high amplitude variations in moisture takes place and lasts for 1500 years. Since the very beginning of CE, $\delta^{18}O$ values indicate a slight increase in precipitation.

At Heshang Cave, Hubei Province, a similar analysis generally fits the conclusions drawn by the $\delta^{18}O$ records at Dongge Cave (Hu et al., 2008). Furthermore, by making a comparison between the two datasets, secondary controls (temperature, moisture source, and non-local rainfall) on $\delta^{18}O$ are diminished and we can obtain a quantitative history of regional precipitation. According to the reconstruction, rainfall was 8 percent higher than present between 3500 BCE and 3000 BCE, and 4 percent higher from 3000 BCE to 1000 BCE. During the wetter intervals, significant variability also occurs, with notable dry periods at 2800 BCE–2100 BCE and 1700 BCE –1100 BCE. These two dry periods, particularly the first one, are also captured by stalagmite $\delta^{18}O$ records from Lianhua Cave in Hunan Province (Cosford et al., 2008) and Sanbao Cave in Hubei Province (Shao et al., 2006; Dong et al., 2010).

Although there are slight temporal and spatial variations in these different records, these research findings enable a reliable reconstruction of climatic history in Early China. In general, the climate follows an increasingly drier and perhaps colder trend. The second half of the 4th millennium BCE (3500 BCE – 3000 BCE) coincides with the end of the Holocene Optimum with the warmest and wettest condition. Between 3000 BCE to 2500 BCE, both temperature and precipitation start to decline gradually. An abrupt drop in rainfall occurs at the transition between 3rd millennium BCE and 2nd millennium BCE, indicating an extremely dry period. This anomalous event is followed by a relatively stable stage with slight fluctuations: a warm and humid first half and a mild and dry second half of 2nd millennium BCE. After that, a gradual decrease in both temperature and precipitation lasts for nearly 1000 years and this trend doesn't change until some point in the early centuries of 1st millennium CE (see Fig. 4).

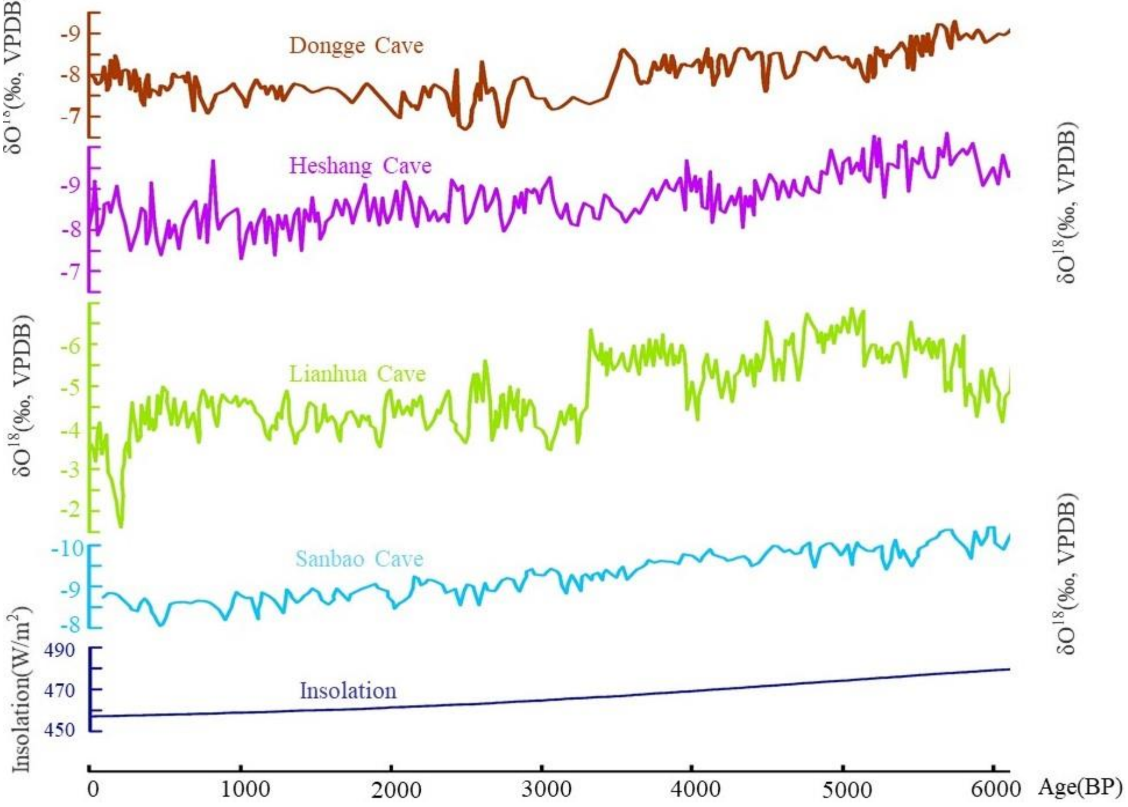

Figure 4. δ18O data from caves (Dongge (Dykoski et al., 2005), Heshang (Hu et al., 2008), Lianhua (Cosford et al., 2008), and Sanbao (Dong et al., 2010)) in Southern China. Note that although insolation shows continued decline over time, δ18O values reversed downward trend at some point between 2000 BP and 1000 BP, which may indicate human influences.

3.2 Social changes in Early China

Late phase of Mid Neolithic Age: 3500 BCE – 3000 BCE

This period witnessed a variety of substantial social changes. Firstly, in terms of scale, all regional cultures became more widely distributed and for most cultures both the number and size of settlements increased (Chang, 1986; Wagner et al., 2013), suggesting a population expansion; secondly, in terms of complexity, several lines of archaeological evidences, such as hierarchically organized settlement patterns, large public buildings, differentiation in burial practices, and elite control over prestige goods, indicate a hierarchical and unequal social structural had emerged (Liu and Chen, 2012).

Agriculture during this period was well developed. In the north, broomcorn millet and foxtail millet played a significant role in human diet (Lu and Zhang, 2008; Liu et al., 2012). The quantity of stone sickles for harvesting increased and the number of hunting and fishing tools, represented by arrowheads and stone harpoons, decreased significantly (CASS, 2010), indicating a drastic transformation of subsistence patterns from hunting/gathering to farming. In the South, large quantities of rice grain/chaff remains, and paddy fields found at several waterlogged sites in Zhejiang Province, demonstrate the wide distribution of rice cultivation (Zheng et al., 2007). However, although rice was consumed as a staple food, wild plants, such as acorn, water caltrop, wild jujube, gorgon fruit, and Job's tears still played a significant role in the human diet in the South (Sun and Huang, 2007; Wang et al., 2016).

Late Neolithic Age: 3000 BCE – 2000 BCE

The 3rd millennium BCE coincides with the Late Neolithic Age in China. During this period, several major social changes took place. Among the most important changes, social stratification became increasingly common. Political power and material wealth were increasingly concentrated in small elite groups (Liu and Chen, 2012; Shelach and Jaffe, 2014). Secondly, large settlement centers were frequently surrounded by rammed-earth walls, indicating an intensification of conflicts and warfare between different social entities. Thirdly, the Central Plain was no longer the most culturally-advanced area. Taosi in the Loess Plateau and Liangzhu in the Lower Yangzi River represent the most developed and complex societies during this interval. However, both Taosi and Liangzhu, as well as several other Neolithic cultures, declined suddenly at the transition between 3rd millennium BCE and 2nd millennium BCE.

During the Late Neolithic, agricultural advances are indicated by several archaeological findings. In North China, both the absolute quantity and the kinds of agricultural tools increased in Longshan phase sites. Particularly the emergence of the wooden plow was especially profound in the dry and semi-arid land farming in the North (CASS, 2010). Carbon isotope analyses of human bones (Pechenkina et al., 2005) indicate that C4 plants (probably foxtail millet and broomcorn millet) were increasingly used as staple food source. Another agricultural innovation during this period in the North is the introduction of wheat. Unlike rain-fed crops such as millets, wheat is more water intensive, which eventually led to the beginning of large-scale irrigation (Zhuang and Kidder, 2014). Archaeobotanical research in the ecology of farming fields provides new insights into the relationship between agricultural land use and water management (see, e.g. Shqiarat, 2019)[2]. In the South, the percentage of rice in the human diet rises sharply to 70 percent, indicating a further intensification of rice domestication in contrast to the diverse pattern of food resources in the middle Neolithic (Fuller et al., 2009).

The Bronze Age and early Iron Age: 2000 BCE – 221 BCE

This period coincides with the Xia (2070 BCE – 1600 BCE), Shang (1600 BCE – 1046 BCE) and Zhou (1046 BCE – 221 BCE) dynasties recorded in historical written texts. It also largely overlaps with the Bronze Age and early Iron Age in China. During this period, the Central Plain took over the leading position again in terms of social complexity after the collapse of once well-developed Neolithic cultures in the Loess Plateau and lower Yangzi River valley. The earliest cities, e.g., Erlitou, Yanshi Shang City and Zhengzhou Shang City, emerged in this area at the first several centuries of 2nd millennium BCE. The presence of these urban centers with political, economic and ceremonial functions, along with the intensification of social differentiation, an increasingly mature writing system, concentration of material wealth, and professionalization of craft, mark the establishment of state-level societies in China (Chang, 1986; Von Falkenhausen, 2008; Liu and Chen, 2012).

Several agricultural innovations took place during this interval. First, food resources were increasingly diversified. Rice, foxtail millet, broomcorn millet and wheat were found within a large geographic range (CASS, 2003). Large quantities of domesticated animal bones, including cattle, buffalo, sheep, pig, dog, chicken and horse are found (CASS, 1994). By late Shang, cattle, sheep and pigs were commonly used for sacrificial occasions and indicate a surplus of meat available at least to the elite. Second, various and plentiful implements, made of stone, wood, bone and shell have been unearthed, and suggest the prosperity of agriculture. Common implements included pickaxes, spades, wooden plows and shovels for tillage, and blades and sickles for harvesting (Hebei Provincial Institute of Archaeology, 1985). Thirdly, a series of new field management practices, represented by rotating cultivation and the "nine square" (sometimes called "well field") system, were established and promoted.

This period witnessed the widespread production and use of bronze vessels and the initial invention of iron weapons. These revolutionary technological developments have far-reaching effects on both human and environmental history. However, during this period, copper and iron, as precious resources related to power, were firmly controlled by elites and were not been widely used by commoners. Therefore, the effects of metal production on environment do not yet emerge yet.

Imperial Age: 221 BCE – 220 CE

In 221 BCE, the Qin state defeated other six rival states and unified much of China. In contrast to Zhou Dynasties' system of enfeoffment, Qin centralized administrative power and adopted a system of prefectures and counties as the basic political structure. These events launched China into the Imperial Age. The Han Dynasty (206 BCE – 220 CE), retained most of Qin's social and political institutions, and on this

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[2] In Jordan, Near East, the water management problem can be characterized by water shortages, environmental quality issues, and supply distribution concerns. Two major factors influence water availability: the semi-arid climate and the high population growth. Shqiarat (2019) gives a chronological overview of water management from the prehistoric to the Islamic periods.

basis, Han achieved great advances in politics, economy, science, and culture (Hsu, 1980; Loewe, 2006). The identity of China and the underpinnings of the modern Chinese nation developed during this historical period. This golden age ended with the collapse of the Han Empire in 220 CE and was followed by a dark age of chaos and conflicts. This "Period of Disunion" in China lasted for more than three centuries.

The foundation of the societal progress during Qin and Han dynasties was agriculture. The central role of agriculture can be understood by the fact that it was often referred to as the "fundamental". After several thousand years of development, agricultural crops, tools and practices matured during this timeframe and the profound influences of Qin-Han agrarian innovation last for the entire historical period. The subsistence pattern of "five corns", which refers to broomcorn millet, foxtail millet, rice, wheat and soybean, emerged and remained fundamentally stable until the introduction of maize from the New World. At the same time, a great number of newly developed cultivation measures were invented and are especially associated with the widespread use of iron implements (Bray, 1978; 1984; Bai, 2005; Wagner, 2001; 2008). Furthermore, the central government promoted a series of measures to institutionalize agricultural practices. All these lines of evidence confirm the status of intensive agriculture in the Han dynasty (Fig. 5).

Figure 5. Archaeological features at Sanyangzhuang, Henan Province: (a) agricultural fields; (b) Stone roller and millstones; (c) hoof prints on the ground. All these features suggest an intensive agricultural system in Han dynasty.

A cornerstone of prosperity during the Qin and Han dynasties is iron. Industrial-scale development of iron production during this period is reflected by the large quantity of iron-made products and their sophisticated technology. Iron implements and weapons are found not only in the Central Plain but also in the frontier areas such as Yunnan (Li, 1962), Liaoning (Li and Gao, 1996), and even the Korean peninsula (Bai, 2005). Large production facilities that include furnaces up to 50m^3 also indicate the remarkable output of iron (Zhengzhou Museum, 1978). Cast iron smelting technology was perfected and a series of cast-iron based technological innovations were employed (Wagner, 2001; Bai, 2005). These highly efficient technologies allowed the mass production of iron and fulfilled the substantial demand for both agricultural production and military during the Han dynasty (see Fig. 6).

Figure 6. Furnace and iron pieces at Guxing iron smelting site, Henan Province, suggesting high quantity of iron production in Han dynasty.

4. DISCUSSION: TRAJECTORY OF HUMAN-CLIMATE INTERACTIONS

Evidence from climatic and human history provides new insights on the relationship between changes in atmosphere/climate and human activities in Early China. During most of this interval, climatic fluctuations have had a quite prominent impact on social development. From 3500 BCE to 3000 BCE, most parts of China that is affected by EAM, although with regional variation, reached the peak of temperature and precipitation. In these favorable climatic conditions, population increased and settlement number and size increased. With the termination of the Holocene Optimum at the transition of the 3rd and the 2nd millennium BCE, climatic deterioration might have resulted in the scarcity of natural resources and limited agricultural production. Diminished food resources and increasingly uncertain agricultural returns probably aggravated conflicts and warfare between communities. In particularly, the end of the 2nd millennium BCE witnessed rapid collapses of several well-developed societies in China and these collapses are frequently attributed to the contemporary abrupt drop in wetness (and perhaps in temperature) (Xia and Yang, 2003; Wu and Liu, 2004; Wu and Ge, 2005; An et al., 2006; Liu and Feng, 2012). From the beginning of the 1st millennium BCE, while influences on human societies from climate are less obvious, some scholars still correlate climate changes with the rise and fall of Bronze Age societies in ecotones as well as with the collapse of the Han Empire (Yang et al., 2002; An et al., 2006).

In sum, climate changes often paralleled and may have played a significant role in social prosperity and decline in Early China. Nevertheless, it is worth noting that this is not an argument for climatic determinism. In fact, in many circumstances, it is how humans respond to climate changes rather than climate changes *per se* that defines the social changes.

What, though, do we understand about human effects on the atmosphere and climate during Early China? Ruddiman's "anthropogenic greenhouse gases hypothesis" inspires us to rethink the timing of the onset of the Anthropocene, and summaries of Chinese climatic and human history in the previous paragraphs enable us to look at early human effects on climate from a diachronic perspective. Evidence suggests that before 3000 BCE, humans were modifying several aspects of their environments (Zhuang and Kidder, 2014). Nevertheless, in terms of atmosphere and climate, human effects cannot be discerned. Farming, particularly rice farming that is associated with increasing CH_4 emissions, is viewed by Ruddiman as the primary way human affected the atmosphere. However, recent archaeological findings show that although the cultivation of rice started as early as 11000 years ago in the lower Yangzi river valley (Zheng et al., 2007; Zheng and Jiang, 2007), the scale was probably quite limited and its proportion in the human diet was relatively low for several thousand years. Rice didn't become a major food source until

Liangzhu culture in the second half of the 3rd millennium BCE (Fuller et al., 2009). In the North, millets played a more significant role in human diet than rice in the South. However, 1) millets are dryland crops so they generate very little methane; and 2) fallow and rotational cultivation allowed a recovery of forest and thus limited the influence of land clearance on CO_2. Therefore, we should be cautious about estimating the contribution of early farming to atmospheric greenhouse gases before the start of 3rd millennium BCE.

The time span from 3000 BCE to the end of the 1st millennium BCE witnessed an acceleration of human effects on the environment and particularly on changes to land surface vegetation that is associated with greenhouse gas emissions. First of all, rice paddies expanded rapidly. According to Fuller's estimation, irrigated rice land (mainly in China, but also in India and Southeast Asia) dramatically increased from around 0.1 million hectares to over 2 million hectares, and this growth should produce a logarithmic growth in methane emissions (Fuller et al., 2011). Secondly, bronze vessels and iron weapons, although highly controlled by elites, were produced in large quantity (Bagley, 1999; Linduff and Mei, 2009). Forest clearance might have been exacerbated because of the demand for fuels in the smelting and casting process for metal production. Thirdly, with urbanization and social differentiation during this period, exploitation of timber resources became intensive for the construction of large building structures for either housing or ritual purpose, as well as wooden coffins and chambers (Wang et al., 2011; Zhuang and Kidder, 2014; Kidder and Zhuang, 2015).

After lengthy accumulation, human influences on climate may have become detectable in the late phase of Early China, probably during the Han dynasty (206 BCE – 220 CE). The direct evidence is the climatic pattern. From 3500 BCE to the end of the 1st millennium BCE, there was a persistent decrease in average temperature and precipitation, and this general trend was congruent with the declining solar insolation. Therefore, the general climatic pattern in this interval actually fits the predicted natural model quite well. However, paleoclimate reconstructions demonstrate that average temperature and rainfall have gradually risen since the beginning of the 1st millennium CE. This is the first time that climatic pattern goes against the decreasing trend of solar insolation (Fig. 4).

Because there is no consensus on exactly how humans influence climate change, we should be cautious about completely attributing the divergence between the climate and solar insolation to human activity. Nevertheless, several lines of indirect evidence suggest that during the Han dynasty human activity might have been intense enough to change atmospheric chemistry and even the climate. As inferred by Ruddiman, human may influence atmospheric greenhouse gases in various ways, including forest cutting, biomass burning, and increasing amounts of human and animal waste. During the Han dynasty, intensive agriculture, iron production, and sharp demographic growth constituted three major contributing factors of human effects on climate. In terms of agriculture, an intensive agriculture system was established. Most arable land was given over to agricultural fields rather than forest, and reforestation was rare. As for iron production, its potential influence on greenhouse gas concentration is embodied in two ways. First of all, widespread cast-iron smelting technology is energy intensive and would have required large amounts of wood to sustain production; thus, this technology contributed to CO_2 emission increases. Secondly, much of the smelted iron was used to make highly efficient tools for tree cutting and field clearing, amplifying CO_2 and CH_4 emissions. In terms of demography, the population in the Western Han reached as high as about 60 million (Ge, 2002), which is four-time larger than that in the Late Bronze Age (Jiao, 2007). With sharp population growth, the large quantity of human and animal waste played a noticeable role in CH_4 emissions.

5. CONCLUSION

Evidence from climatic and human history indicates a changing scenario of climate-human interaction in Early China. On one hand, for most of this timeframe, natural climate changes parallel social changes. In some circumstances, extreme climate fluctuations may have triggered important historical events such as societal or dynastic changes or even collapse. On the other hand, human effects on the atmosphere and climate gradually accumulated and accelerated during the Middle and Late Neolithic and the Bronze Age. Roughly at the transition between BCE and CE in the Han dynasty, several potential contributing factors to greenhouse gases, i.e., agriculture, iron industry, population, reached a zenith within Early China and even long after that; the climatic trend began to go beyond the natural insolation circle and human impacts on climate became somehow discernible. This fact makes us realize that the onset of the Anthropocene is a prolonged process with a notable mark in the early centuries CE.

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