THE ANTHROPOGENIC GREENHOUSE ERA BEGAN THOUSANDS OF YEARS AGO

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Abstract. The anthropogenic era is generally thought to have begun 150 to 200 years ago, when the industrial revolution began producing CO_2 and CH_4 at rates sufficient to alter their compositions in the atmosphere. A different hypothesis is posed here: anthropogenic emissions of these gases first altered atmospheric concentrations thousands of years ago. This hypothesis is based on three arguments. (1) Cyclic variations in CO_2 and CH_4 driven by Earth-orbital changes during the last 350,000 years predict decreases throughout the Holocene, but the CO_2 trend began an anomalous increase 8000 years ago, and the CH_4 trend did so 5000 years ago. (2) Published explanations for these mid- to late-Holocene gas increases based on natural forcing can be rejected based on paleoclimatic evidence. (3) A wide array of archeological, cultural, historical and geologic evidence points to viable explanations tied to anthropogenic changes resulting from early agriculture in Eurasia, including the start of forest clearance by 8000 years ago and of rice irrigation by 5000 years ago. In recent millennia, the estimated warming caused by these early gas emissions reached a global-mean value of $\sim$0.8 °C and roughly 2 °C at high latitudes, large enough to have stopped a glaciation of northeastern Canada predicted by two kinds of climatic models. CO_2 oscillations of $\sim$10 ppm in the last 1000 years are too large to be explained by external (solar-volcanic) forcing, but they can be explained by outbreaks of bubonic plague that caused historically documented farm abandonment in western Eurasia. Forest regrowth on abandoned farms sequestered enough carbon to account for the observed CO_2 decreases. Plague-driven CO_2 changes were also a significant causal factor in temperature changes during the Little Ice Age (1300–1900 AD).

1. Introduction

Crutzen and Stoermer (2000) called the time during which industrial-era human activities have altered greenhouse gas concentrations in the atmosphere (and thereby affected Earth's climate) the 'Anthropocene'. They placed its start at 1800 A.D., the time of the first slow increases of atmospheric CO_2 and CH_4 concentrations above previous longer-term values. Implicit in this view is a negligible human influence on gas concentrations and Earth's climate before 1800 AD.

The hypothesis advanced here is that the Anthropocene actually began thousands of years ago as a result of the discovery of agriculture and subsequent technological innovations in the practice of farming. This alternate view draws on two lines of evidence. First, the orbitally controlled variations in CO_2 and CH_4 concentrations that had previously prevailed for several hundred thousand years fail to explain the anomalous gas trends that developed in the middle and late Holocene.

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Second, evidence from palynology, archeology, geology, history, and cultural anthropology shows that human alterations of Eurasian landscapes began at a small scale during the late stone age 8000 to 6000 years ago and then grew much larger during the subsequent bronze and iron ages. The initiation and intensification of these human impacts coincide with, and provide a plausible explanation for, the divergence of the ice-core CO_2 and CH_4 concentrations from the natural trends predicted by Earth-orbital changes.

2. Early Anthropogenic Methane Emissions

Several studies have inferred anthropogenic methane emissions in pre-industrial centuries (for example, Etheridge et al., 1996), but Ruddiman and Thomson (2001) proposed that large-scale generation of methane by humans actually began back in the middle Holocene, when natural processes lost control of methane trends. For hundreds of thousands of years, CH_4 concentrations in Vostok ice had followed the 23,000-year orbital insolation cycle (Figure 1a). The highly coherent match between methane and insolation reveals this natural orbital control. Age offsets between the time scale shown (from Ruddiman and Raymo, 2003) and earlier time scales based on ice-flow models (Jouzel et al., 1993; Petit et al., 1999) lie within the estimated errors of the latter.

This coherent relationship supports the view that orbital-scale methane variations primarily reflect changes in the strength of tropical monsoons (Chappelaz et al., 1990; Blunier et al., 1995; Brook et al., 1996). The orbital monsoon theory of Kutzbach (1981) posits that increases in summer insolation heat land masses and cause air to rise, and the rising air lowers surface pressures and draws in moist air from the ocean. As the incoming ocean air rises over high topography and cools, it drops moisture in heavy monsoon rains. The monsoon rains flood wetlands, which release methane. The methane signal follows a 23,000-year tempo because orbital precession dominates summer insolation changes at low latitudes where monsoons occur.

Differences in CH_4 concentrations in Greenland versus Antarctic ice indicate that ~2/3 of the CH_4 flux on orbital time scales comes from tropical monsoon sources, and the remaining third from high northern latitudes (Chappellaz et al., 1997; Brook et al., 2000). Both of these sources follow the same 23,000-year tempo, because the insolation peaks that heat low-latitude landmasses and create monsoons also warm higher latitude wetlands that release additional CH_4.

Annually layered GRIP ice in Greenland provides a more stringent test of these proposed controls (Figure 1b). The most recent CH_4 maximum is centered between 11,000 and 10,500 years ago (Blunier et al., 1995), coincident with the last maximum in July (mid-summer) insolation. This timing agrees both with the orbital monsoon theory and with simultaneous precession control of boreal (mainly Siberian) CH_4 sources. Although brief CH_4 minima interrupted this trend during