Introduction

Lively 'Frost Fairs' were held on the frozen River Thames in London, during what glacial geologist Francois Matthes (1874-1948), termed 'The Little Ice Age,' spanning the 14th-20th centuries. Equally lively are the debates surrounding the question this paper asks; 'To what extent did anthropogenic (human) activities contribute to the Little Ice Age?'

Figure 1 Frost Fair on the Thames at Temple Stairs, c.1684 Hondius

Figure 2 The Thames during the Great Frost of 1739-40 Griffier

A full proxy record, providing temperature variance from 1005–1960, showed 60% of the variance is due to external forcing; "solar, volcanic, greenhouse gas, and sulphate aerosol in the 20th century". These records and simulations help to understand past climate, origins of changes, test methods of reconstructions and enable detection of specifics such as volcanic activity, solar forcing (in some periods) and anthropogenic signals (IDAG, 2005). Furthermore Earth's changing angle of tilt is considered; solar radiation can vary around the average value by more than 10%, larger than the difference experienced between London and Lisbon. Ruddiman talks of climate related cycles and their predictability and resolves departures from the norm are not natural (Ruddiman, 2005). If the Little Ice Age is considered a 'departure from the norm' this paper evaluates evidence towards understanding to what extent anthropogenic activities contributed to it?

The Little Ice Age

During the early medieval period population growth saw London swell from 10,000 in 1086 to 50,000 in 1300, increasing demands on agricultural resources. By the 13th & 14th centuries the brackish Thames Estuary, lying in one of the most economically developed and busiest trading areas was a mosquito breeding ground rapidly spreading malaria. At the same time, the Little Ice Age is believed to have begun with increased storms, flooding of coastal areas and Thames breaches (Galloway & Potts, 2007). Further a field, in New Zealand, parts of North & South America, Asia and the Swiss Alps the Little Ice Age was also underway (Grove, 2004).

By the late 14thC and early 15thC, the climate in Greenland became very cold, cooled by the North Atlantic, shortening the already brief hay-growing season, reducing supplies of the main Norse sustenance (Diamond, 2003).

In the middle of the 16thC a dramatic and global downturn in temperature occurred. The first bitter cold winter of 1564-5 grasped Europe bringing great hardship upon it, as captured by Pieter Brugegel (c.1525-1569), Fig. 3. Glaciers and artic ice pack extended enabling Eskimos to land their kayaks in Scotland. Agricultural practices had to adapt to the climate and loss of land (claimed by flooding due to violent storms), to alleviate famine (Reiter, 2000). Further south, between 1547-1648, the Greek Island of Crete experienced eight very severe winters. Long lasting excessive snow fell causing great suffering in 1595, with many deaths in 1601/2 and snowfall reached the coast falling for two months in 1659. Elsewhere in Eastern Europe severe cold was reported in 1709 and one of the coldest winters on record experienced in Southern France. In 1713/4 Switzerland, France and England experienced the driest winter for 500 years (Grove, 2004).

Figure 3 Brugegel's 16thC Bitter cold landscape

Glaciers told similar stories of deep time, providing temperature records and historical climate information. In 1939, amidst an upsurge of interest in historical climate records, Matthes founded the term 'the Little Ice Age'. Glaciers were, however not the only means through which post-glacial change could be recorded. Quaternary geologists, pollen analysts, and geoscientists measuring time-layers of clay accompanied dendrochronologists in their quest to establish a better understanding of the past (Sorlin, 2008).

Anthropogenic activities

The start of the 'Anthropocene' has been placed at 1800 A.D, based on slow increases in CO_2 and CH_4 concentrations over long-term values, whereas Ruddiman suggests it started thousands of years ago (Ruddiman, 2003). These debates need to be mindful of the deep relationship between climate change controversy and field research precision-culture growth, but cannot ignore modern computer based modelling revealing human induced climate change. Even in 1901, meteorologist Nils Ekholm (1848–1923), "speculated over a future where humans would regulate the global climate, using burning of fossil fuels as a gas pedal and the planting of CO_2-eating plants as the brake." (Sorlin, 2008). A century later, CO_2-capturing algae-technology (Skjånes et al 2007), is applying that brake.

Arctic researcher Hans Ahlmann (1889-1974), considered the climate was changing at an unprecedented rate, illustrated in 1953 by Virgil Partch, showing the irony and noticeable regional difference of it Fig. 4 (Fleming, 1998). Guy Callendar (1898-1964), a British Mechanical Engineer, inspired scientists to look at climate change closer and Canadian-born physicist Gilbert Plass (1921-2004), warned anthropogenic carbon dioxide in the atmosphere could become “a serious problem in the near future”. By the 1950’s people were certain Earth’s weather was changing, were aware of rising sea levels, habitats and agricultural zones changing and that climate change was occurring. Despite the fluctuating public awareness of climate issues, they only became a firm agenda item in the 1970s (Fleming, 1998).

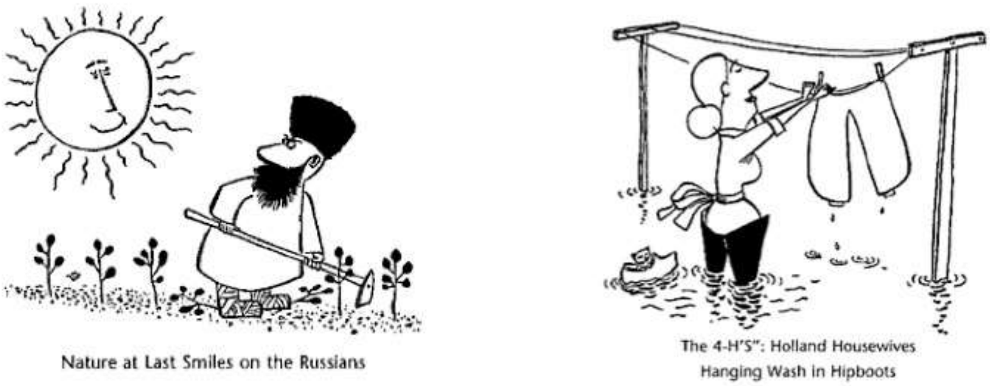

Figure 4 Partch illustrates regional climate changes (Fleming, 1998).

Figure 4 Partch illustrates regional climate changes (Fleming, 1998).

According to Ruddiman (2003), atmospheric concentrations were first altered thousands of years ago, by anthropogenic emissions of CO_2 and CH_4 gases. 8000 years ago an anomalous increase in the CO_2 trend began and 5000 years ago in the CH_4 trend. Ruddiman rejects explanations for these mid-to late-Holocene gas increases being due to natural forcing, based on paleoclimatic evidence. He suggests the gases arose from early anthropogenic changes through agriculture in Eurasia; 8000 years ago with the onset of forest clearance and 5000 years ago with irrigation of rice. These viable explanations come from evidence in the geological, historical, archeological and cultural records (Ruddiman, 2003). Ruddiman’s hypothesis has welcomed and provoked deeper debate and consideration of the evidence, that cannot all be considered here and is still on-going. However, Crowley thought Ruddiman’s hypothesis was ‘outrageous’, but acknowledged that forest re-growth *after* plague outbreaks could have been a significant cause of the Little Ice Age and concedes that Ruddiman is a careful researcher, with no agenda (Crowley 2003).

Anthropogenic evidence

Understanding the *'history of understanding'* is essential to unpack the evidence, as the history of climate science isn't cumulative. Sorlin identifies the "procedures and rituals" of the narratives of climate change being told and through time, as "institutional and practice-based" (Sorlin, 2008). Mindful of this and as described earlier, this paper will look at the sources of the evidence and the reasoning for evaluating the impact of anthropogenic activity on the climate to cause the Little Ice Age. Farming, plague, reforestation, temperature drops and depopulation are all common Little Ice Age themes, but how they are placed in time differs, (Fig. 5).

Ruddiman found depopulation was caused by plague, causing reforestation, which contributed to a cooler climate. Whereas Lamb (1977) earlier conceived the cooler climate of the Little Ice Age caused the famine and depopulation and increasing incidences of disease (Ruddiman, 2003).

Figure 5 Two Peasants Binding Faggots Brueghel, Pieter the Younger (c.1564-1638)

Farming Activity

Ruddiman hypothesizes that South East Asians changing water courses to irrigate rice fields thus creating unnatural wetlands and cutting up virgin carbon filled land for farming, triggered a change in earth systems, due to the sudden rise in methane these activities caused and their consequences. Farming is responsible for the largest alteration of Earths surface (Pongratz, et al 2009), and has caused atmospheric CO_2 values to depart from their natural trend. These effects can be considered with the knowledge that 6400 years ago the wheel was invented, 6000 years ago farming was present in Europe as it is today and 5000 years ago China, Burma & Thailand were using controlled irrigation (Ruddiman, 2005). 5000 years ago, cyclic trends would suggest methane should have decreased, but instead it increased, evidence from Greenland show a methane peak at this time. During summer, radiation reached a maximum and the 'expected' relationship broke down. The methane increase was as Ruddiman describes, a 'direct violation of the rules'. Even suspected Boreal sources did not produce the methane, as evidence has indicated, or Siberian wetlands, as they were stable and decreasing and tropical wetlands were drying out (Ruddiman, 2005).

For this period, humans must have been the new source of methane generation. A rapidly growing population in South East Asia, through diversion of river water, irrigating rice, keeping livestock, biomass burning, weeds, 'slash & burn' forest clearing techniques and the burning of peat created methane. Departure from the methane trend was abrupt which again does not comply with natural variations that are controlled by growth and shrinkage of wetlands. Past forest footprints strongly position Ruddiman's theory as in 1089 they were 9ha, whereas 6000 years ago it was 3ha. Ruddiman believes glaciation is overdue because of this, yet others believe it's an exceptionally long inter-glacial or that changes were caused by stronger solar radiation that drove stronger monsoons (Ruddiman, 2005).

With this scale of activity impacting on the climate, this essay asks did human activity and similar exchanges of CH_4 & CO_2 further influence the climate prior to and causing the Little Ice Age?

Between 1100-1700 Chinese rice-growing regions per capita land-use also dropped 78.57%. By then with 90% of land cultivated, past larger per-capita emissions had contributed to a decoupling (Ruddiman et al *in press*, 2010), alongside other factors (Mischler et al, 2009).

Plague

Ruddiman's hypothesis finds a significant causal factor for the Little Ice Age (1300–1900 AD) temperature changes, they were plague-driven changes in CO_2 (Ruddiman, 2003), caused by dramatic population fluctuations, (Figs 6-9).

Figure 6 11thC Plague-The Plague of Tournai in 1095, Gallait

Figure 7 13/4thC Plague-Dante, Virgil and the Plague-stricken, Alighieri

Figure 8 14th C-Plague The Black Death, 1348.

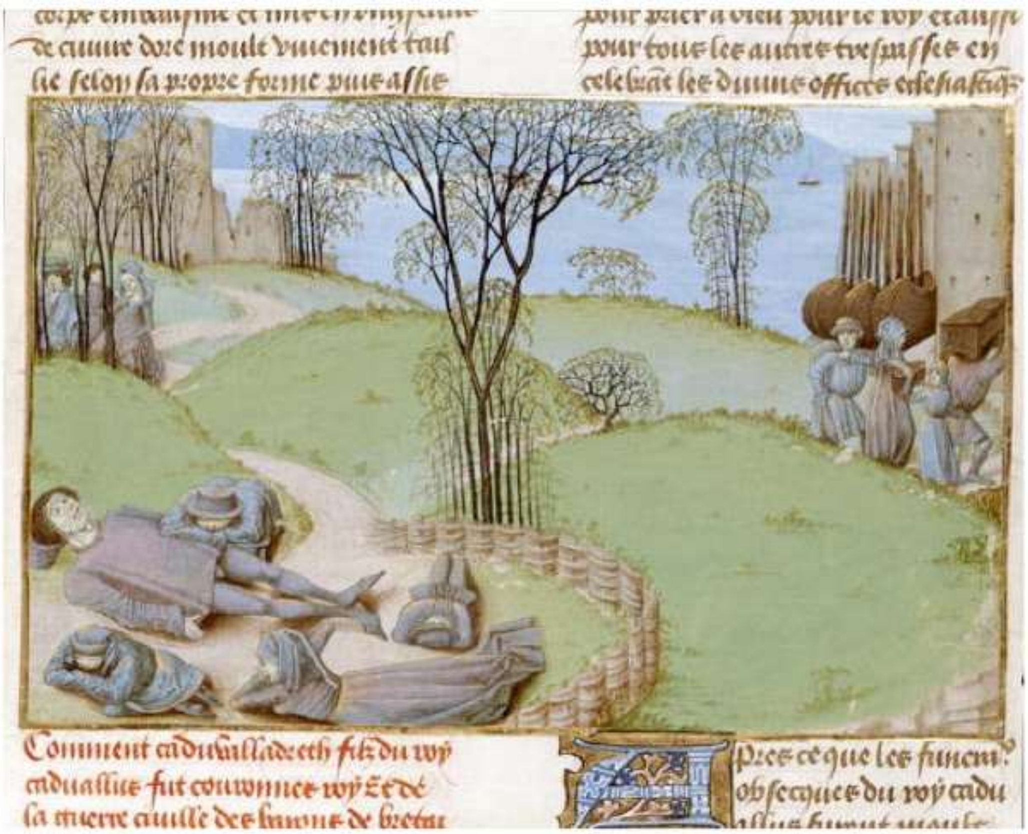

Figure 9 15th C-Plague Deaths from famine, de Wavrin

Plague-induced reforestation events can be seen in the CO_2 records in Antarctic ice cores. The amplitude of the 10ppm CO_2 drops must have led to cooler temperatures causing the Little Ice Age. These drops probably occurred just after 1350 AD and during the period 1500 and 1750 AD (Ruddiman, 2003), (Fig.10). These concentrations can be compared with the historical records of diseases, (Fig. 11). The extensive history of plague and the fluctuating population sets scenes of animals on farms where masters lay dead on the land, many not even buried. As some began to recover, another plague would strike (Bray, 1996). The forest having been burnt before disease decimated the population (Ruddiman et al *in press*, 2010), grew back on the cleared land and sequestered the carbon sufficiently to account for the CO_2 drops, providing a reasonable mechanism to reverse the slow CO_2 emissions rise within the short time spans indicated (Ruddiman, 2003).

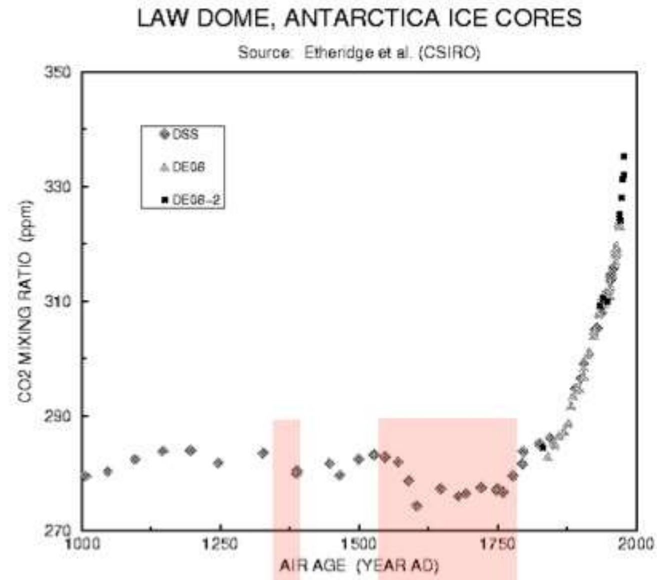

Figure 10 Historical CO_2 Records from the Law Dome DE08, DE08-2, and DSS Ice Cores (Etheridge et al, 1998).

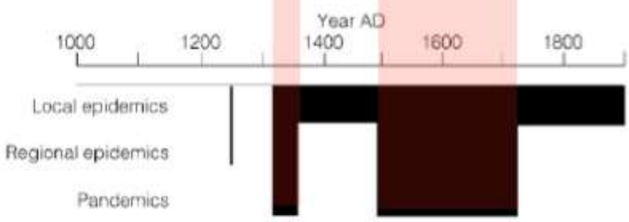

Figure 11 Epidemics and Pandemics 1000-1900 (Ruddiman, 2003)

While this paper focuses on what caused the Little Ice Age, its after-effects can also portray the strength of anthropogenic activity on the climate. Climatologist Hubert Lamb (1913-1997), found its effect on the ocean accounts for some of the decreases in 17th & 18th century CO_2 concentration (IDAG, 2005), further explored later (Kutzbach et al, 2010).

Farming, plague, deforestation- the evidence

The evidence for Eurasian landscapes being altered by humans since the late Stone Age at a small scale, growing to a larger scale by the Bronze and Iron Age, lies within geology, palynology, archeology, cultural anthropology and history. In particular, Earth-orbital changes related to CO_2 and CH_4 concentrations are predictable and are recorded in ice core records that show divergence from natural trends. This coincides with the beginning and intensification of anthropogenic activity, providing a plausible explanation (Ruddiman, 2003) for land-use changes (Pongratz, et al 2008), (Goosse et al, 2006) and varying stocks of carbon (Houghton, 2000).

Ruddiman's hypothesis finds 10ppm CO_2 oscillations in the last 1000 years were caused by farm abandonment in western Eurasia, due to outbreaks of bubonic plague and the consequences, causing changes, too big to be caused by external forcing (solar/volcanic), (Ruddiman, 2003).

These impacts can be understood by noticing the gradual CH_4 and CO_2 Holocene increases, permitting the climate system to reach thermal equilibrium with radiative forcing. For example, the early anthropogenic estimated CH_4 increases of 250ppb and CO_2 increases of 40-ppm would have caused global warming of 0.25°C + 0.55°C, by 1800 totaling 0.8°C. To compare, since 1850, warming has reached 0.6°C, anthropogenic activity is attributed to 0.45°C, the remainder due to solar and volcanic variability. These early anthropogenic increases are incompatible, but should take into consideration the oceans long-term thermal response. More recent CH_4 and CO_2 increases not yet registered within the thermal system, can take decades (Ruddiman, 2003). Modelling past scenarios (see Mischler et al, 2009), can assess future feedbacks with or without past anthropogenic activity (Kutzbach et al, 2010), providing evidence for an anomalously warm oceanic process causing feedbacks supporting the 40ppm CO_2 anomaly (Ruddiman et al *in press*, 2010). This provides opportunities to re-organize climate knowledge and how anthropogenic activity is captured in the oceans.

Little Ice Age Evidence

A reliable picture of the temperatures during the Little Ice Age is drawn from proxy data and historical records (Table.1), which in this case Reiter's (2000) evidence is redrawn from Lamb (1995), to represent the past climate, (Fig 12).

Table - 1 Evidence Examples

Little Ice Age Evidence	**Examples *(Used in this essay)***
Private diaries	From instrumental measurements to daily visual weather records, descriptive accounts of weather or extreme events can be found.. A police lieutenant's recorded 15 pages of his account of the terrible 1783/1784 winter, including details of snow, freezing days and high levels of water and flooding. (Brázdil et al, 2010). John Evelyn wrote in his diary 'Streetes of Boothes were set upon the Thames... all sorts of Trades and shops furnished, & full of Commodities..." (MOL, 2010).
Ships' logs	A project (CLIWOC), gathered data from "ship logbooks from the colonial powers of Europe" and with 281,920 records from 1662–1855, with the majority from 1750–1855. Most records came from the North Atlantic (Kuttel et al, 2010).
Military campaign accounts	In (Reiter, 2000)
Descriptions of wind direction/speed	A French bookseller made 90 hydrometeorological readings from December 1783 to 31 March 1784 (Brázdil et al, 2010).
Descriptions of cloud formations/other weather indicators	Cornish Antiquarian and Reverend William Borlase (1696-1772) wrote, "in short, the atmosphere is such a various irritable mixture…and the action of the heavenly bodies so perpetually shifting, that nothing permanent and sure is expected; no apparently similar circumstances will always produce the like, nor is anything to be foretold from analogy or review" Jankovic, V. (2001).
Dated annals/chronicles	Floods broke bridges and torrents of water were brought upon the landscape (Neve, 1709). Rev. W. Derham FRS, wrote about Thames wall breaches (Derham, 1712). De la Pryme reviewed the items found in drained lands; canoes, brass kettles, a Hippopotamus's head and human bodies. These were found with seeds, shrubs, leaves and Roman coins surrounding old tree roots. The trees had grown where they were found. They had been destroyed because, according to the Roman writers, the wild Britons ran into the "fastnesses of miry woods and low watery forests" fleeing the Romans armies, who's only resolve was to destroy all the forests in Britain to find them. "Emperor Severus lost 50,000 of his men in a few years time, in cutting down the woods, and cleansing the fens and morasses of the country". History repeated itself later on; Edward I set fire to the woods in Wales and Henry II cut down woods in Ireland. (De la Pryme, 1701).
Audited accounts	In (Reiter, 2000) and (Grove, 2004)
Newspapers	In 1748, a letter from Spišská Sobota was printed in *The Wiener Zeitung*, describing recent weather "Quite recently the snow fell so frequently that a neighbour had to open an exit from the house. The violent storm wind that has raged uninterruptedly for three days and threatened every moment the roofs of the houses has finally died down without having caused considerable damage in our area. The sadder is the news that we received from other areas. People say that in Stoß [Štós], a village at the border between the Zips [Spiš] and Abaujwarer [Abov] County, the upper half of the city tower collapsed and brought by this much damage to other houses and to the people. At Joß [Jasov], a place in the last named County, many houses were partly ruined and their roofs were taken away. With fear one sees now everywhere approaching a sudden thaw in the weather." (Brázdil et al, 2010)
Agricultural records	The growing season in the summer was 5 weeks shorter than 20thC. During 1683-4 top meter of ground was frozen (Reiter, 2000).
Tax ledgers	Grove used Scandinavian tax records during the Little Ice Age to reconstruct the environment to realize the rates went down because farmers land was affected by snowfall and flooding increase causing crop failure with less revenue to tax (Grove, 2004).
Weather Archives	5km sea ice belts lined the English Channel Coast (Reiter, 2000).
Glacial morphology	Records left in debris-flows from 17^{th}-19^{th} centuries show during the Little Ice Age, high magnitude events occurred (Passmore et al, 2008).
Lake & ocean sediments	Shell calcite ratios and planktonic foraminifera in diatomaceous sediments, dating 1300-1850 (Grove, 2004). In southern Poland the Little Ice age started in the 13thC and was an unstable and relatively long period. The first half was dry and cold, the second after 1540 was cold and humid, terminating in the mountain region in the early 20thC.
Pollen strata	Sediments (cladocera, chironomid, and diatom analyses), in a Polish lake identify the Little Ice Age (Gasiorowski & Sienkiewicz 2010).
Deposits of insects	In (Reiter, 2000) & (Gasiorowski & Sienkiewicz 2010).
Tree rings	A 200-year tree-ring chronology covering 1695 - 1496 BC, shows one major event, with a growth depression dated to 1637 BC (+/-65). This event can be linked with a Californian phenomenon that caused frost damage in trees and a European oak growth depression in 1628/27 (Grudd et al, 2000).
Coral structure	Radiocarbon dates show Costa Rican coral reefs experienced Little Ice Age climate conditions showing a large-scale mortality event from 1650-1800 (Hendy et al, 2003).
Speleothems	Chinese oxygen isotope variations in a 2-3yr record from a stalagmite show Asian summer monsoon precipitation variations over the past 750 years. Since 1249 precipitation gradually increased in the summer, peaking between 1535–1685 and then decreasing. Three periods of high rates were recorded in 1535–1685, 1755–1835, and 1920–1970 indicating a wetter climate during the Little Ice Age (Tan et al, 2009).
Ice cores/oxygen isotopes	In (Reiter, 2000) & (Grove, 2004) Drops in heavier methane from biomass burning, when populations dropped quickly in America in the 16thC are evident in isotopic records (Mischler et al, 2009).
Archaeological sites	In (Reiter, 2000)
Pressure series	Recorded as early as 1755 (Grove, 2004).
Dendroclimatic data	Can be reconstructed from 16-20thC (Grove, 2004).

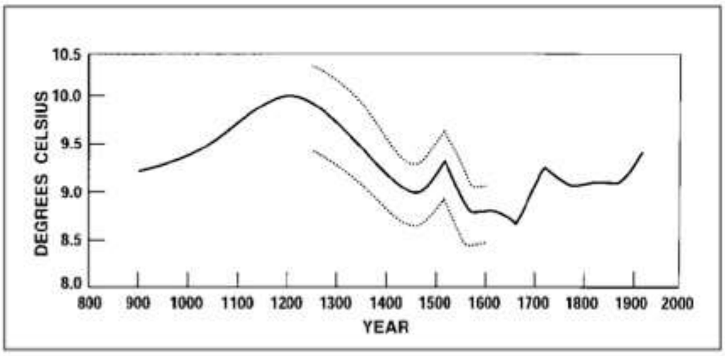

Figure 10 50-year mean annual temperature (estimated), based on proxy data uncertainty range (Reiter, 2000).

Gaps remain in the evidence, e.g. for Asian climate change, despite a surge of recent interest. Archival investigation has not rivaled European research, however contrasts in topography and sea distances must be considered. Evidence is clear in China, e.g. where crop boundaries were further North before the Little Ice Age around 1264 and oranges used to be grown where the current climate no longer permits (Grove, 2004).

Conclusion

Even if Ruddiman is wrong, the hypothesis provokes consideration (White 2006), to the extent anthropogenic activity can alter land sufficiently to change the climate (Pongratz, et al 2008). This paper has revealed this ability in the past through the Ruddiman debate, suggesting large scale climate change can be caused by small scale land-use and applied its theory to the Little Ice Age being caused by forest re-growth.

If small-scale anthropogenic activity did cause the climate to change on a global-scale it alleviates concerns about definitions of climate change. They consider 'dangerous' climate change accounts might affect mitigation and adaptation policies (Piekle, 2005) and (Lowe et al, 2006), whereas *this* 'small-scale anthropogenic activity = global-scale climate change' knowledge provides clarity on human impacts on global systems. This coupled with the current larger-scale anthropogenic activity and the inertia of past activity locked up in the oceans (Kutzbach et al, 2010), could be the 'different knowledge' capable of providing constructive learning. This could turn fear that arises from ineffective communication (Hulme, 2009) and lack of control on climate change of this scale (White 2006) into constructive change assisting faster policy action.

The evidence used in this paper contributes to a robust understanding that humans can change climate on global scales and suggests that lack of understanding is a contributing factor to 'departures from the norm' and continued climate change. By illustrating the direct links between land-use change and the Little Ice Age could help decelerate future climate change.

Social scientists have shown that climate change education to the layperson is better received at regular-intervals (Lorenzoni et al, 2007; Moser and Dilling, 2004) and could augment action. This account is very communicable in comparison to most climate change scenarios, the roots of which are liked by the press and widely-used websites (Table 2), and could help visualize anthropogenic activities and consequences, sourced through scientific and logical underpinning of evidence (Sheppard, 2005).

Table 2 Examples of acceptance of Ruddiman's hypothesis in the public domain

Nature:	"exciting but controversial" (Charlson 2005)
Science:	"If you're not familiar with Ruddiman's hypothesis you should be" (White 2006)
Amazon Review:	"but I stand with Ruddiman: the simultaneous upward departures of CO2 and CH4 from climate indicators unique in 420, 000 years is probably an early footprint of humankind." (James Hansen (NASA) in Science/Amazon 2009).
Real Climate Blog:	Strange Bedfellows (2005) Here's a curious observation. Some commentators who for years have been vocally decrying the IPCC consensus are lining up to support the 'Ruddiman' hypothesis. A respected paleoceanographer, Bill Ruddiman has recently argued that humans have been altering the level of important greenhouse gases since the dawn of agriculture (5 to 8000 years ago), and in so doing have prevented a new ice age from establishing itself. This intriguing idea is laid out in a couple of recent papers (Ruddiman, 2003; Ruddiman et al, 2005) and has received a fair degree of media attention.
Powells Review:	"First came "Rats, Lice and History"--next, "Guns, Germs, and Steel." Now we have "Plows, Plagues, and Petroleum," a book sure to inspire further thinking about the nature of anthropogenic climate change. Even those who question Ruddiman's central thesis--that pre-industrial humans caused enough climate change to head off a minor glaciation--will find that it serves as a great organizing principle for a thoroughly delightful and accessible romp through the physics of climate."--Ray Pierrehumbert, Professor of Geophysical Sciences, University of Chicago "Bill Ruddiman has long been considered one of the world's top paleoclimatologists. In "Plows, Plagues, and Petroleum," he caps a career at the cutting edge with a great new scientific debate. The book makes for good reading, too. Humans have a long record of altering their climate system and are now changing the climate system like never before. What's more, we're doing it knowingly."--Jonathan T. Overpeck, Director, Institute for the Study of Planet Earth and Professor of Geosciences, University of Arizona ""Plows, Plagues, and Petroleum" boldly and creatively revisits the role of humans in climate change. Progress in science requires innovation, and when dealing with science, Ruddiman is world-class. This book is certain to be controversial, but even if all the bold new ideas presented here don't survive intact, it will have substantially moved our dialogue on the Earth forward and focused a bright light on the role of humans--for better or for worse--in taking control over our planet."--Stephen H. Schneider, Melvin and Joan Lane Professor for Interdisciplinary Environmental Studies and Co-Director, Center for Environmental Science & Policy at the Stanford Institute for International Studies, Stanford University "Bill Ruddiman, one of the giants of climate history, presents a controversial hypothesis for early human influence on Earth. Our ancestors clearly altered their environment in many ways, and Ruddiman proposes that humans even affected the composition of the atmosphere. Vigorous research is testing this new idea, and should lead to an improved understanding of the world, and of ourselves."--Richard Alley, Evan Pugh Professor of Geosciences, Pennsylvania State University, author of "The Two-Mile Time Machine" "This book represents a major and welcome endeavor to bridge the gap between the sciences and history. The two are brought together to achieve a greater understanding of climate change, which seems to be of increasing importance to our species. Few persons could accomplish these goals, but Ruddiman does so, and he does it well."--David C. Smith, Professor Emeritus of History at the Climate Change Institute, University of Maine, author of "H. G. Wells: Desperately Mortal"

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