

## Early Anthropogenic Overprints on Holocene Climate

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PAGES research on Holocene climate rests in part on the implicit assumption that humans had negligible effects on large-scale climate until the industrial era, followed by large and accelerating impacts during the last 200 years. With this two-part division, scientists use pre-industrial climatic proxies to define the natural state of the climate system, and thereby to isolate and quantify the anthropogenic overprint during the last 200 years.

A paper recently published in the journal *Climatic Change* (Ruddiman, 2003) suggests that this basic premise is flawed. The interval between 8000 years ago and the industrial era was a time of significant and slowly increasing human impact on greenhouse-gas concentrations and global climate, and the cumulative impact of these changes by 200 years ago was equivalent to the subsequent impacts during the industrial era.

Long-term orbital-scale cycles predict ongoing decreases in CO<sub>2</sub> and methane through the entire Holocene, but ice-core trends show a ~100-ppb rise in atmospheric methane during the last 5000 years and a 20-25 ppm rise in CO<sub>2</sub> during the last 8000 years. Natural orbital-scale variations cannot account for these increases.

I attribute these anomalous increases to early anthropogenic activity. The CO<sub>2</sub> rise occurred during a time of large-scale deforestation in southern Eurasia, as agriculture advanced from the primitive practices of the late Stone Age to the much more sophisticated package of skills in the early Iron Age. The methane increase correlates with an interval in which wet-rice irrigation began in the lowlands of Southeast Asia and later spread to hillside rice paddies.

The observed increases are only part of the story, because the full anthropogenic signal must also include the natural decreases that should have happened but did not.

I estimate the total anthropogenic anomalies by the start of the industrial era at 40 ppm for CO<sub>2</sub> and 250 ppb for methane (Fig. 1). For the 2.5°C IPCC (2001) estimate of global climate sensitivity to CO<sub>2</sub> doubling, the pre-industrial global-mean warming effect from anthropogenic sources would have been ~0.8°C, about the same size as estimates of the greenhouse-gas contribution to the measured industrial-era warming. The pre-industrial warming at high latitudes would have been larger (~2°C) because of amplification by snow and sea ice feedback. This large signal has escaped notice until now because

of an even larger natural cooling caused by decreasing insolation. In summary, humans were altering global climate well before we built cities, discovered writing, or founded religions.

In addition, I investigated relatively rapid CO<sub>2</sub> oscillations of 5-10 ppm found in high-resolution ice-core records of the last 2000 years from Antarctica. Natural variations (solar-volcanic forcing) do not appear to be capable of explaining such large CO<sub>2</sub> changes. Simulations with the Bern carbon-cycle model (Gerber et al., 2003) indicate that each 1-ppm change in CO<sub>2</sub> in response to solar-volcanic forcing

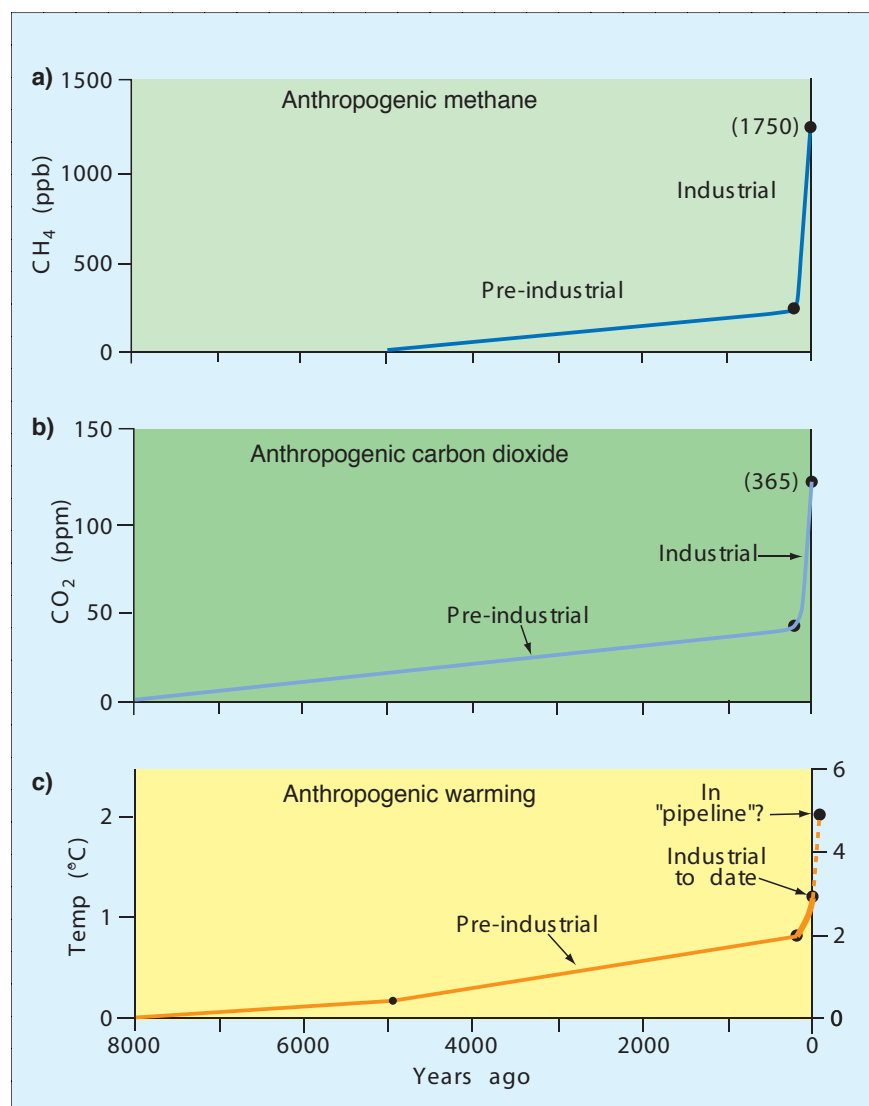


Fig. 1: Anthropogenic changes in (a) CH<sub>4</sub>, (b) CO<sub>2</sub>, and (c) global and high-latitude temperature, based on the IPCC (2001) estimate of the sensitivity of the climate system. Pre-industrial anthropogenic changes rival those of the industrial era.

should be accompanied by a 0.08°C change in global temperature. If so, a 10-ppm CO<sub>2</sub> drop requires a global cooling of 0.8°C. Yet, reconstructed temperature changes for the northern hemisphere (for example, Mann et al., 1999) only permit a cooling of ~0.2°C over intervals of many decades to centuries, enough to explain only 2-3 ppm of the 10-ppm CO<sub>2</sub> decreases.

Because these CO<sub>2</sub> drops are superimposed on a slow background increase attributed to deforestation, I propose that they result from intervals of reforestation tied to human history. Within the large uncertainties of the ice-core dating, the three CO<sub>2</sub> drops correlate with bubonic plague pandemics that caused enormous levels of human mortality in western Eurasia from 200-600, 1300-1400, and 1500-1720 AD. In addition, major depopulation of native communities across the Americas occurred in the 1500's and 1600's as a result of diseases contracted from initial contact with Europeans. In both cases, historical documents reveal massive

abandonment of rural farms and villages after these pandemics.

Trees and shrubs will re-occupy untended farms and sequester atmospheric carbon in amounts equivalent to full reforestation levels within just 50 years, and this mechanism can explain the 10-ppm size of the CO<sub>2</sub> drops. CO<sub>2</sub> decreases caused in this way would then produce a global-mean cooling of 0.15-0.2°C (again using the 2.5°C IPCC sensitivity estimate), a value that does not violate the hemisphere-wide reconstructions of temperature change. Once the series of plagues abated, the farms were re-occupied, the newly grown forests were cut, and CO<sub>2</sub> returned to its long-term rising trend.

The major implications for PAGES are these:

- The underlying long-term climatic trend for the last 8000 years of the Holocene is not natural. Rather than a climate held nearly stable by natural processes, Holocene temperature stability reflects an accidental balance between a large natural cooling and an

almost equally large anthropogenic warming.

- During the last 2000 years, shorter-term (decadal- and century-scale) climatic oscillations were not entirely natural. Deforestation episodes, linked to anomalously high human mortality caused by disease, played a significant role in reducing CO<sub>2</sub> and cooling climate.
- Distinguishing natural from anthropogenic forcing of Holocene climate will be more difficult than PAGES had thought.

#### REFERENCES

- Gerber, S., Joos, F., Brugger, P., Stocker, T. F., Mann, M. E., Sitch, S., and Scholze, M., 2003: Constraining temperature variations over the last millennium by comparing simulated and observed atmospheric CO<sub>2</sub>. *Climate Dynamics*, **20**, 281.
- Intergovernmental Report on Climate Change, 2001: *Third assessment of the IPCC*. Cambridge Univ. Press, Cambridge, UK.
- Mann, M.E., Bradley, R.S., and Hughes, M.K., 1999. Northern hemisphere temperatures during the past millennium. *Geophysical Res. Lett.* **26**, 59.
- Ruddiman, W.F., 2003: The Anthropogenic Era Began Thousands of Years Ago. *Climate Change*, **61**, 261.



## GLOBEC Investigation of Interdecadal to Multi-Centennial Variability in Marine Fish Populations

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The overarching goal of the Global Ocean Ecosystem Dynamics Project (GLOBEC) of IGBP is to advance our understanding of the structure and functioning of the global ocean ecosystem and its response to physical forcing, and to work towards developing a predictive capability to forecast the regional responses of marine ecosystems to global change. In the past several decades, we have witnessed fundamental changes in the organization and dynamics of large marine ecosystems, which have been manifested in the abundance, diversity and productivity of animal populations, with changes in dominant species. The interaction of climate variability and fishing has also lead to dramatic changes

in the abundance and distributions of marine fish populations.

Investigating the nature and cause of these remarkable changes is a formidable challenge because of the need for sampling the ocean over scales of 1000's of square kilometers and for periods of at least several decades. GLOBEC has, therefore, actively encouraged the development of information on ecosystem history contained in the natural, high-resolution archives of marine sediments found in rare locations associated with mid-water oxygen minima in the eastern boundary current regions of the North and South Pacific, and in the South Atlantic, as well as from the glacial fjords located on the poleward edges of these systems in the

Pacific. This information allows us to examine the nature of large-scale variability over a hierarchy of time scales from interannual through interdecadal and centennial. Retrospective research directed toward both paleo- and modern sources, integrated with comparative studies of large ecosystems, provides the historical perspective and framework to describe the underlying natural modes of variability affecting their structure and dynamics. These studies are particularly important for distinguishing the direct effects of human intervention resulting from harvesting or habitat modification, from the natural variability in these systems.

One of the sources of information of particular interest to GLOBEC