

that could become important air emission components. Field measurements and modeling analyses are needed to estimate deposition of nitrogen and sulfur compounds in the vicinity of CAFOs. Improved coupled multimedia (air, water, and soil) models are needed to predict movements and dispersion of air pollutants. Studies of methods for reducing emissions of gaseous and particulate air pollutants and for developing best management practices and best available control technologies are critical for technology transfer from research to application.

Agricultural air quality also can vary regionally, due to differing animal and crop production or farming activities and regional climates. Recently, several U.S. multistate and other large projects [e.g., Project OPEN (Odors, Pathogens, and Emissions of Nitrogen) in North Carolina, the National Air Emissions Monitoring Study, multistate air quality projects, and so forth] have been undertaken to bring together multidisciplinary experts to address regional variations.

#### Educational and Outreach Needs

Programs are also needed that reach out to citizens, regulators, the agricultural industry, and farm operators, and increase their understanding of issues related to air quality and public health. The success of these programs can be evaluated based on the implementation of farm best management practices for controlling emissions and improvements in regulations and enforcement programs.

Research on agricultural air quality also creates tremendous opportunities for the development of field-research classes in areas of current environmental concern. Students in such courses could visit research sites, help record observations, and incorporate data from ongoing research into reports, theses, and

dissertations on different aspects of air quality issues. Environmental curriculum in primary and secondary education should show the relationships between human food production and its effects on the air and water pollution and biodiversity.

#### Assessing the Future of Agriculture and Air Quality

Insufficient scientific knowledge about nitrogen, volatile organic compounds, sulfur, and particulate matter emissions from intensively managed agriculture and the ultimate fate of these compounds are directly comparable to the situation in the 1980s with regard to agricultural nonpoint sources of nutrient contamination of water. There is just enough information for researchers and policy makers to recognize a serious problem, but not enough information for them to understand the extent of the problem or to make scientifically credible recommendations about potential solutions, which may ultimately influence air, soil, and water quality, human health, and the economy of agricultural regions.

Scientists, industry, policy makers, and regulators need to make optimal choices about issues confronting U.S. agriculture in order to maximize the benefits and reduce the detrimental effects of food production activities. Improvements are needed in agricultural air pollutant emission inventories, measurement and monitoring methodologies, modeling, and best management/production practices to mitigate air pollutant emissions from agricultural sources.

An upcoming meeting, called the Workshop on Agricultural Air Quality: State of the Science, will be held 5–8 June 2006 in Potomac, Md. (near Washington, D.C.). The meeting will address these issues and provide an opportunity for all concerned to share information. For further

information, visit the Web site: <http://www.esa.org/AirWorkshop>

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## The Holocene $\text{CO}_2$ Rise: Anthropogenic or Natural?

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In view of the wide attention received by the suggestion that the rise in atmospheric carbon dioxide ( $\text{CO}_2$ ) over the last 8000 years is anthropogenic rather than natural in origin [Ruddiman, 2003], this claim should be carefully examined. The basis for the claim is that following each of the three preceding glacial terminations, the  $\text{CO}_2$  content of the atmosphere peaked early on and then underwent a steady decline. By contrast, following the end of the last glacial period, while it also peaked early, the decline bottomed out around 8000 years ago, and since then the atmospheric  $\text{CO}_2$  content has steadily risen.

By analogy with previous interglaciations, Ruddiman estimates that in the absence of human activity, the  $\text{CO}_2$  content of the atmosphere would have dropped to 240 ppm. Instead it has risen to 280 ppm. In a recent

article, Ruddiman [2005] proposes that this 40 ppm human-induced rise prevented the onset of another ice age.

However, a 40 ppm increase in atmospheric  $\text{CO}_2$  content over an 8000-year time interval requires an enormous amount of deforestation: Not only must the atmosphere's  $\text{CO}_2$  inventory be increased, but also the ocean's dissolved inorganic carbon inventory. Unlike the present fossil fuel-driven increase in which the ocean has taken up only about two-thirds of the amount that has accumulated in the atmosphere, under Ruddiman's scenario the amount taken up by the ocean would have exceeded that which accumulated in the atmosphere by at least a factor of five.

The difference has to do with the sluggish rate of ocean mixing. During the course of the Holocene, the extra  $\text{CO}_2$  has had adequate time to equilibrate with the entire ocean, whereas the fossil fuel-derived  $\text{CO}_2$  has been

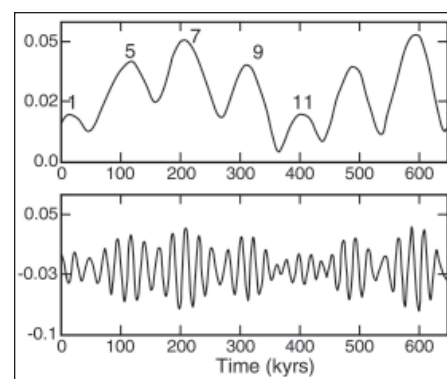


Fig. 1. (top) Magnitude of the eccentricity of the Earth's orbit over the last 650,000 years and (bottom) the consequent amplitude of the precession component of insolation seasonality. The times of the last five interglacials are shown. Note that during stage 11 and stage 1, the amplitude of the precession-related cycle in seasonality was much smaller than that during stages 5, 7, and 9.

able to equilibrate with only about 15 percent of the ocean's volume. The ocean uptake would likely have exceeded this factor of five because,

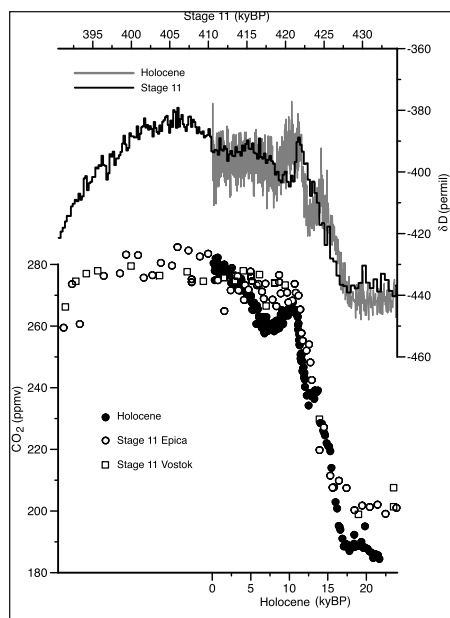


Fig. 2. Comparison of the deuterium ( $\delta D$ ) and  $CO_2$  records for stage 11 with those for the Holocene. The stage 11 record was created from data by EPICA Community Members [2004], Siegenthaler et al. [2005], and Raynaud et al. [2005]. The Holocene record is from Monnin et al. [2001].

on the timescale of 8000 years, the extra  $CO_2$  reaching the deep sea would be partially neutralized by interaction with seafloor calcium carbonate ( $CaCO_3$ ), thus increasing the ocean's capacity for uptake.

Without interaction with sedimentary  $CaCO_3$ , Ruddiman's scenario requires a release of about 570 gigatons of terrestrial carbon (GtC). Model simulations that include interaction with sedimentary  $CaCO_3$  increase this requirement to 700 GtC [Joos et al., 2004]. If correct, then the forest biomass 8000 years ago must have been more than double that in the year 1800 A.D.

The proof, however, lies in carbon isotope measurements. The release of 700 GtC from the terrestrial biosphere would lower the  $^{13}C$  to  $^{12}C$  ratio in the entire inventory of ocean-atmosphere carbon by about 0.45 per mil. Indermühle et al. [1999] interpreted carbon isotope measurements made on eight samples of  $CO_2$  recovered from Antarctic ice to suggest a 0.2 per mil  $^{13}C$  decline over the last 8000 years.

However, Broecker et al. [2001] challenged the validity of this  $^{13}C$  decline. They pointed to a Holocene record of  $^{13}C$  to  $^{12}C$  ratio in planktonic foraminifera from the equatorial Pacific that showed no downward trend over the last 8000 years. But, as a single site in the surface ocean need not typify the atmosphere, these results were inconclusive. Hence, while  $^{13}C$  offers a firm answer, the final word awaited more extensive and accurate carbon isotope measurements on  $CO_2$  trapped in bubbles in polar ice. Recently, the Bern group made 22 such measurements covering the last 7000 years on  $CO_2$  extracted from a new Antarctic ice core [Eyer et al., 2004]. The absence of any measurable downward trend in these new

measurements appears to firmly rule out such a large release of terrestrial carbon.

Broecker et al. [1993] proposed instead that the post-8000-year  $CO_2$  rise was the result of  $CaCO_3$  compensation triggered by the extraction of  $CO_2$  from the ocean to create the early Holocene increase in forest biomass. The rationale is as follows. With the onset of warm conditions, the forests and bogs destroyed during glacial time reformed. On the basis of the  $^{13}C$  record kept by the benthic foraminifera, this re-growth sequestered about 500 GtC [Curry et al., 1988]. The removal of this amount of  $CO_2$  from the ocean-atmosphere reservoir would not only have lowered the atmosphere's  $CO_2$  content but it would also have increased the carbonate ion content of ocean water. Such an increase would have deepened the transition zone that separates mid-depth sediment rich in  $CaCO_3$  from abyssal sediment that had lost its  $CaCO_3$  to dissolution. This downward shift would have unbalanced the ocean's carbon budget. More calcite would have accumulated in sediment than was being supplied to the ocean by continental weathering and volcanic emissions. As a result, a gradual drawdown of carbonate ion content of ocean water would have occurred. This drawdown would have caused the sediment transition zone to shoal with a time constant of about 5000 years. As the carbonate ion concentration dropped, the  $CO_2$  content of ocean water (and also of the atmosphere) would have risen.

Thus, the drop in atmospheric  $CO_2$  caused by the re-growth of forests would have been followed by a recovery related to a readjustment of the ocean carbonate chemistry. As  $CaCO_3$  has nearly the same carbon isotope composition as seawater, compensation would not produce any  $^{13}C$  change.

One check on the Broecker et al. scenario is whether it can be demonstrated that a deep-sea carbonate ion maximum occurred about 8000 years ago. Both fragmentation and shell weight indices of  $CaCO_3$  dissolution show an early Holocene preservation maximum followed by a pronounced increase in the extent of dissolution [Broecker et al., 2001].

But, as Ruddiman's scenario also calls for a preservation event, this result does not allow the two scenarios to be distinguished. It does, however, rule against explanations involving a weakening of the ocean's biological pump or a warming of the sea surface.

Ruddiman's reply to this would surely be, **But what about the previous interglacials? Why do they not show a rise in atmospheric  $CO_2$  content as a result of calcium carbonate compensation? The explanation likely lies in the current small magnitude of the eccentricity of the Earth's orbit compared with that during the previous three interglacials (see Figure 1).** A smaller eccentricity reduces the impact of the 20,000-year precession cycle on seasonality. It is the decline in Northern Hemisphere summer insolation associated with the 20,000-year cycle that appears to have brought on the demise of full interglacial conditions following the previous three terminations. So the explanation for the absence of a  $CO_2$  plunge during the present interglacial is that the

20,000-year cycle is too weak to initiate a rapid decline toward glacial conditions and thus to produce a 'short' interglacial period. Hence, while in three previous interglacials the  $CO_2$  decrease driven by the 20,000-year precession cycle overwhelmed the upward trend due to calcium carbonate compensation, during the present one this has not happened.

A test of the orbital explanation was provided recently by the stage 11  $CO_2$  record from the Dome Concordia (Antarctica) [EPICA Community Members, 2004] with that from Vostok [Siegenthaler et al., 2005]. Unlike stages 9, 7, and 5, stage 11 occurred during a time of small orbital eccentricity (see Figure 1). The Vostok record ends in mid-marine isotope stage 11 (MIS 11). However, new  $CO_2$  measurements on the EPICA ice core now cover all of stage 11 (see Figure 2). This spliced record shows that atmospheric  $CO_2$  stayed above 270 ppm for about 28,000 years, from about 420 thousand years before present (kyrB.P.) to 392 kyrB.P. The early part of MIS 11 is similar to that for the Holocene.

It is evident that MIS 11 was a long interglacial that was not brought to an end by the precession cycle nor will the Holocene be (MIS 1). Hence, the cause for the  $CO_2$  rise during the last 8000 years was 'natural' and not 'anthropogenic.'

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# NEWS

## Studies Examine Bangladesh Arsenic Contamination Problem

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Between 35 and 77 million Bangladeshis (out of a population of 125 million) are at risk of drinking water contaminated with arsenic levels above the World Health Organization (WHO) guideline of 0.01 milligrams per liter (mg/l), according to the WHO. A British Geological Survey study in 1998 found that 35 percent of shallow tubewells sampled had arsenic levels above 0.05 mg/l (the maximum concentration allowed in Bangladesh) and 8.4 percent had levels above 0.3 mg/l.

Some recent research focusing on this problem could help Bangladesh provide clean water to these people.

Only a few thousand of the approximately 12 to 18 million tubewells in the country have been reliably tested for arsenic, according to Faisal Hossain, a native of Bangladesh who is a civil and environmental engineering professor at Tennessee Technological University, Cookeville. Hossain said that he ranks arsenic contamination—and its poisoning of millions of Bangladeshis—as one of the top problems facing the country.

Because dependable test results are rare, Hossain is developing a mapping scheme that he hopes could predict with this small amount of data where arsenic-contaminated wells are more likely to be found so that reliable testing may be optimized in those areas.

In a poster presentation at the December 2005 AGU fall meeting in San Francisco, Calif., Hossain and his colleagues proposed combining a more traditional geostatistical approach for spatial mapping with a nonlinear

technique based on chaos theory that looks at patterns in the data. He argues that that because there are better-understood physical mechanisms behind the distribution of arsenic in the region, traditional spatial mapping methods that assume its distribution is random are inadequate.

#### A Natural Man-made Problem

Arsenic is found naturally in most basins derived from Himalayan sediment, explained Scott Fendorf, a biogeochemist at Stanford University, Calif. The arsenic is attached to iron oxide within the sediment. Under anaerobic conditions and in the presence of carbon, bacteria underground will respire on the iron oxide, releasing the arsenic into the water.

Until recently, it was thought that this process took place within the aquifers, that the arsenic-laced iron oxide was found there, and that the carbon had to be transported into the aquifer to start the process. However, Fendorf and his colleagues proposed in a December 2005 article in the *Proceedings of the National Academy of Sciences* that because the iron oxides in the aquifers appear to already have been reduced, this process must be taking place near to or at the surface. Under this scenario, the arsenic—and not carbon—is transported into the aquifer and is a continuous source of contamination.

By studying the hydrological cycle of the arsenic, “maybe we will decipher what the key mechanism is and where it resides, where the arsenic is coming off. Then we can do something about that,” such as changing land use

practices, Fendorf said.

Charles Harvey, a groundwater hydrologist at the Massachusetts Institute of Technology, Cambridge, and Fendorf’s colleague, added, “If we understand how [arsenic] moves through the aquifers, then we can, with confidence, say where is it a good idea to put in a well and where it could conceivably be dangerous.”

Arsenic contamination is a problem in many parts of Asia, but it is most widespread in Bangladesh. In the 1970s, the United Nations launched a program there to end reliance on microbially-contaminated surface waters by drilling shallow tubewells. However, none of the wells were checked for arsenic contamination. In the 1990s, health officials, first in West Bengal, India and then in Bangladesh, began finding an increasing number of cases of arsenic poisoning and arsenic-related diseases, including skin lesions and cancers.

Richard Wilson, a Harvard University physicist who is president of the Arsenic Foundation, said that “the right solution, of course, is to get good water to people.”

However, getting good water to the Bangladeshis has proven problematic. For example, affordable methods to treat the arsenic-contaminated water, such as filtering it through iron-coated sand, tend not to be used for very long, as people find the filters to be too bothersome to use and clean, said Harvey.

Another solution may be digging deep wells, such as those that have served the city of Dhaka for ages. These wells, which are thought to be safer (when installed properly) than shallow tubewells, can be drilled for about US \$200 to \$300 each and serve around 300 people, said Wilson. He also advocated helping Bangladeshis move back to using surface waters, although he admits that, in this tropical setting, it is difficult to maintain bacteria-free wells.

—SARAH ZIELINSKI, Staff Writer