On “The Holocene CO_2 Rise: Anthropogenic or Natural?”

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Because the rising carbon dioxide (CO_2) trend in the late Holocene differs markedly from the natural CO_2 drops that occurred during the three previous interglaciations, I proposed that the Holocene increase is anthropogenic [*Ruddiman,* 2003]. *Broecker and Stocker* [2006] recently proposed using the stage 11 interglaciation (the fourth one before the present) as a potentially better analog for the Holocene because low orbital eccentricity produced similar insolation trends. They aligned termination V (the deglaciation that led into stage 11) with termination I (the most recent deglaciation) and counted forward in ‘elapsed time’ (Figure 1a). They noted that trends in CO_2 and deuterium (δD) remained at full interglacial levels early in both interglaciations and on that basis concluded that the late Holocene warmth is not only natural in origin but is also likely to last thousands of years into the future.

But the Broecker-Stocker approach has a major flaw (Figure 1b): It aligns the present-day Northern Hemisphere summer insolation minimum with a stage 11 insolation maximum (as did *EPICA Community Members* [2004]). This choice contradicts their own goal of finding an insolation analog in stage 11; it is actually the single worst insolation analog available within that entire interglaciation. The insolation difference in watts per square meter between the stage 11 maximum they chose and the current minimum amounts to ~60% of the mean range of variation over the past 400,000 years.

This Broecker-Stocker choice also contradicts the two best established theories in the field of orbital-scale climate: *Milankovitch*’s [1941] theory that northern summer insolation forces ice sheets, and *Kutzbach*’s [1981] theory that northern summer insolation forces tropical monsoons. Their inverted (minimum-on-maximum) alignment implicitly dismisses the insolation-driven responses that are central to both of these theories. Because the rationale for my early anthropogenic hypothesis was tied directly to the insolation forcing invoked by these theories, the inverted Broecker-Stocker alignment shown in Figure 1b cannot be regarded as a valid test of my hypothesis.

An obvious insolation analog to the late Holocene does exist in stage 11, the one previously chosen by *Berger and Loutre* [2003] and *Ruddiman* [2005]. Although not an exact match to the current insolation minimum, the minimum just after 400,000 years ago (Figure 1d) is the best analog available within interglacial stage 11.

Three independent timescales published for Vostok ice [*Petit et al.,* 1999; *Shackleton,* 2000; *Bender,* 2002] show that large decreases in δD, CO_2, and methane (CH_4) were under way by this point in stage 11. These drops reached approximately 35 parts per million for CO_2 and –255 parts per billion for CH_4 within the interval between 400,000 and 390,000 years ago. The sizes of these decreases match the ones during the early-interglacial parts of stages 5, 7, and 9. The best analog to the Holocene in stage 11 thus indicates that CO_2 and CH_4 concentrations should have dropped by now and that substantial climatic cooling should already have occurred (Figure 1c), consistent with the early anthropogenic hypothesis.

Broecker et al. [2001] proposed a natural (ocean-chemistry) origin for the Holocene CO_2 rise. This hypothesis predicts that CO_2 increases should have occurred early in previous interglaciations, but *Broecker and Stocker* [2006] acknowledged that the last three interglaciations instead show downward CO_2 trends. They claimed that stage 11 supports the ocean-chemistry hypothesis, but the correct insolation alignment (Figure 1d) indicates the same downward CO_2 trend as in interglacial stages 5, 7, and 9. In short, none of the last four interglaciations supports the ocean-chemistry hypothesis. Thus, the upward Holocene CO_2 trend is unique, unnatural, and anthropogenic.

Important issues remain unresolved. *Joos et al.* [2004] noted that carbon-budget and carbon-13 (^{13}C) constraints argue against the early-anthropogenic hypothesis, and *Broecker and Stocker* [2006] revisited those arguments. I have acknowledged [*Ruddiman,* 2005] that I initially erred in suggesting that the entire CO_2 anomaly could have been caused by emissions from early deforestation and from preindustrial burning of coal and peat. By my best current estimate, the direct anthropogenic contribution can only explain a fraction of the full CO_2 anomaly, roughly 9–10 parts per million. Yet the evidence from stage 11 adds further support to my original claim that the anthropogenic Holocene CO_2 anomaly is large. This presents an interesting problem: How can a large CO_2 anomaly (35–40 parts per million) be reconciled with small direct emissions of CO_2 (9–10 parts per million)?

The answer probably lies in the ocean’s response to early-anthropogenic emissions of CH_4 and CO_2 [*Ruddiman,* 2005]. Both the Southern Ocean and the deep ocean cooled by large amounts in the early stages of all four previous interglaciations, but little if any during the Holocene. This anomalously warm Holocene behavior points to an anthropogenic overprint. Such a warm overprint could have caused the Holocene ocean to release CO_2 through two mechanisms: (1) reduced CO_2 solubility in warmer deep-ocean waters, and (2) the failure of the Southern Ocean to shift toward a glacial state as it had early in the previous interglaciations. Relationships quantified by *Martin et al.* [2005] suggest that CO_2 releases from an anomalously warm ocean could have accounted for the remaining approximately 75% of the 35–40 part per million Holocene CO_2 anomaly.

Ocean feedbacks may also explain why the $\delta^{13}CO_2$ response to anthropogenic forcing was

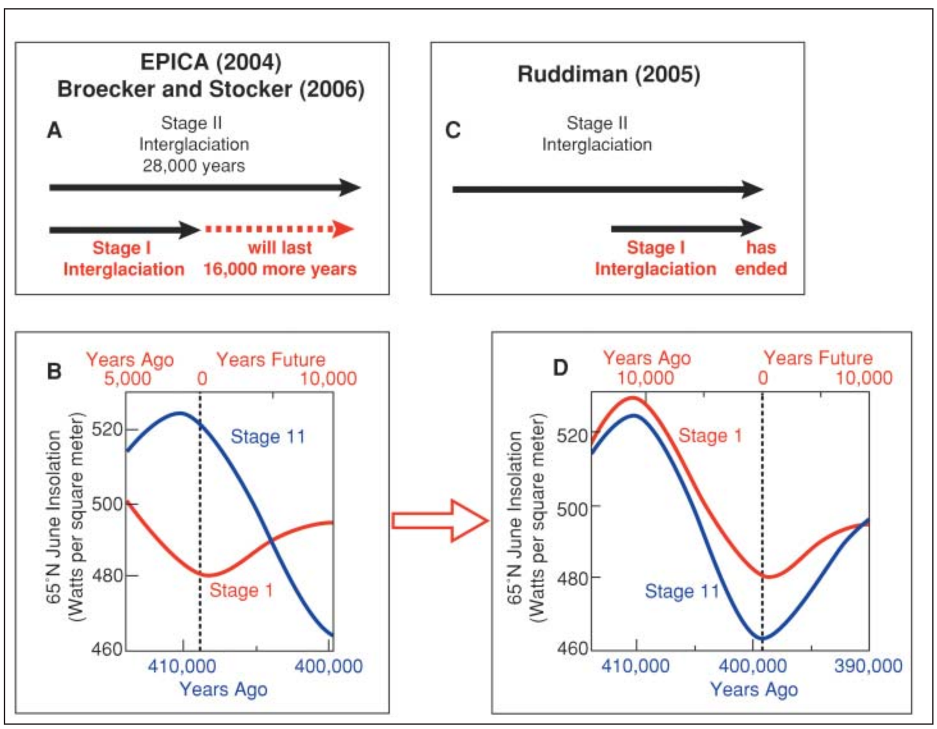

Fig. 1. (a) The juxtaposition of stages 1 and 11 from EPICA Community Members *[2004] and* Broecker and Stocker *[2006] results in an inverted alignment of 65°N summer insolation trends (b). Alignment of the current insolation minimum with the most similar minimum in stage 11 (d) indicates that the current interglaciation should have ended by now (c).*

so small. During the late Holocene, the ocean absorbed most of the anthropogenic emissions of terrestrial carbon ($\delta^{13}C$ = ~ –25‰), but it also returned a large amount of inorganic carbon ($\delta^{13}C$ = ~0‰) to the atmosphere as a result of its anomalous warmth. If one quarter of the anthropogenic anomaly consisted of highly negative (–25‰) terrestrial carbon, while the other ~75% was oceanic carbon generated by feedbacks, the net isotopic effect on natural atmospheric CO_2 ($\delta^{13}C$ = –6.5 ‰) would have been small.

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—William F. Ruddiman, Department of Environmental Sciences, University of Virginia, Charlottesville; E-mail: wfr5c@virginia.edu

About AGU

Hispanic Scientist of the Year

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Inés Cifuentes, AGU's Education and Career Services Manager, has been named the 2006 National Hispanic Scientist of the Year by the Museum of Science and Industry in Tampa, Fla.

The award recognizes Hispanic scientists "who promote a greater public understanding of science and motivate Hispanic youths' interest in science." Cifuentes will receive the award at a 28 October 2006 ceremony.

Cifuentes, an AGU member since 1981, joined the AGU staff in February, having been director of the Carnegie Academy for Science Education (CASE) at the Carnegie Institution of Washington for the previous 10 years. That program teaches science, mathematics, and the use of technology to public elementary school teachers in Washington, D.C., and provides them with scientific content as well as relevant classroom investigations, such as analyzing tap water in their school and dissecting a diaper.

Cifuentes, the daughter of United Nations economists, spent her early years in Latin America before her family moved to Washington, D.C. She became interested in science as a young child after receiving a book on astronomy from her grandfather. Her parents encouraged their children to become scientists. "My father loved mathematics, and he used to play math games with us," Cifuentes said. "It made it OK as a girl to do math."

As an undergraduate at Swarthmore College, she majored in physics. She had intended to study astrophysics, but instead pursued less 'esoteric' graduate study in geophysics. "I wanted to go back to Latin America to work and be of use," Cifuentes explained.

After receiving her master's degree at Stanford University, Cifuentes worked for the U.S. Geological Survey in Menlo Park, Calif., with David Harlow and Randy White examining earthquakes in Nicaragua and Guatemala. However, she realized that a Ph.D. was required in order to pursue anything interesting in seismology. After meeting some seismologists at an AGU Fall meeting, she chose to study at Columbia University.

At Columbia, she studied the 1960 Chilean earthquake—which had caused some damage even in Santiago, Chile, far from the epicenter, where her family had lived at the time—and became the first woman to earn a Ph.D. in seismology from the university.

Cifuentes then directed the CASE program, where she nurtured more than 50 mentor teachers who taught others during summer sessions. Among them are two Milken Educator Award recipients and a Presidential Awardee for Mathematics and Science Teaching.

A key goal in AGU's strategic plan is to increase the number and diversity of young space and Earth scientists. Cifuentes said that to accomplish this, AGU needs to reach out to students from groups not typically represented in these sciences, including African-American and Latino students, as well as students from outside the United States.

Cifuentes plans to take advantage of programs that already exist, such as the Minorities Striving and Pursuing Higher Degrees of Success (MS PHD'S) in Earth System Science Initiative, which is run by University of South Florida chemical oceanographer Ashanti Pyrtle. In addition, Cifuentes wants to expand AGU's Geophysical Information For Teachers (GIFT) workshops to reach more minority students through their teachers.

In addition to diversity issues, Cifuentes also is concerned about leadership roles for women in Earth and space sciences. She said. "We need to [ask]: Why are there still so few women in leadership positions in our field?"

Mentoring may be one way for AGU to promote both objectives of increasing diversity and promoting women in leadership. "AGU can play a role in mentoring, and that seems to be something that works very well at all levels, both for college students [and scientists]," Cifuentes said. AGU also may be able to assist existing programs, she suggested, such as the Mentoring Physical Oceanography Women to Increase Retention program (see *Eos 87*(12), 2006).

"It is a good time for AGU to be looking at how to reach more students, because there is a focus on science nationally," Cifuentes said. In addition, "a lot of the science that we do are things that young people actually care about and are fascinated by," such as natural disasters and the environment. "We should take advantage of that."

—Sarah Zielinski, Staff Writer