In this response, we are not commenting on caveats such as aerosols, other greenhouse gases, lags, feedbacks, ice sheets, etc. The topic of *Shaviv and Veizer* [2003] was the "primary" climate driver on Phanerozoic time scales, with no space, or need, for any more discussion than that. Furthermore, we fail to see how any of the above would make CO_2 the "driver" in the Antarctic cores, when the temperature rises preceded those of CO_2 by centuries. We not only never denied but specifically highlighted the qualifying proposition that CO_2 may act as an amplifier.

In conclusion, the above response demonstrates that the "critique" of *Rahmstorf et al.* [2004] has little substance, in addition to the fact that it deals with time scales that are not even discussed in *Shaviv and Veizer* [2003]. Moreover, the statistical argument advanced in this issue of *Eos* as disproving the validity of the CRF/paleotemperature correlation is simply invalid (for details, see http://www.phys.huji.ac.il/~shaviv/ClimateDebate/).

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Reply

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In our analysis [*Rahmstorf et al.*, 2004], we arrived at two main conclusions: the data of *Shaviv and Veizer* [2003] do not show a significant correlation of cosmic ray flux (CRF) and climate, and the authors' estimate of climate sensitivity to CO_2 based on a simple regression analysis is questionable. After careful consideration of Shaviv and Veizer's comment, we want to uphold and reaffirm these conclusions.

Concerning the question of correlation, we pointed out that a correlation arose only after several adjustments to the data, including shifting one of the four CRF peaks and stretching the time scale. To calculate statistical significance, we first need to compute the number of independent data points in the CRF and temperature curves being correlated, accounting for their autocorrelation. A standard estimate [*Quenouille*, 1952] of the number of effective data points is

$$N_{EFF} \cong \frac{N}{1-2\sum_{k-1}^{N} r_1(k) r_2(k)}$$

where N is the total number of data points and r_1, r_2 are the autocorrelations of the two series. For the curves of *Shaviv and Veizer* [2003], the result is $N_{EFF} = 4.8$. This is consistent with the fact that these are smooth curves with four humps, and with the fact that for CRF, the position of the four peaks is determined by four spiral arm crossings or four meteorite clusters, respectively; that is, by four independent data points. The number of points that enter the calculation of statistical significance of a linear correlation is (N_{EFF} - 2), since any curves based on only two points show perfect correlation; at least three independent points are needed for a meaningful result.

Shifting one of the four peaks to fit climate data reduces the number of independent points by one, and tuning the time scale to improve the fit uses up another degree of freedom, leaving between zero and one independent points in the significance calculation. Hence, no correlation is significant after the tuning steps of *Shaviv and Veizer* [2003]; given the few degrees of freedom in the data, the data were over-tuned. The fact that their tuning is within data uncertainty is irrelevant to statistical significance. It just means that a correlation might be possible without contradicting the data.

The consistency of the periods presented is still not convincing, since these periods are only averages of a few points with high variability. While it is possible that better data will demonstrate a correlation of cosmic rays and climate, our conclusion is that the data presented by *Shaviv and Veizer* [2003] are insufficient for this. As an aside, we did not confuse the exposure ages and real ages of meteorites.

Concerning the regression analysis to estimate climate sensitivity, Shaviv and Veizer write in their Comment, "we are not going to comment on caveats such as aerosols, other greenhouse gases, lags, feedbacks, ice sheets, etc." This is unfortunate, since these issues are not caveats, but central to the determination of climate sensitivity to CO_2. As we pointed out, the strength of any individual forcing factor can only be estimated by a regression analysis if it is statistically independent from other forcings, which is very unlikely for the examples mentioned, or if these other forcings are explicitly taken into account, as in *Lorius et al.* [1990]. Since this was not done, we maintain that the regression is questionable.

Finally, it is worth pointing out areas of agreement.

Shaviv and Veizer state, "we fail to see how any of the above would make CO_2 the 'driver' in the Antarctic ice cores." We fully agree that CO_2 is not the driver of the climate variability seen in these cores. There is a host of excellent empirical evidence and widespread agreement that climate variability on glacial-interglacial time scales is driven by variations in the Earth's orbit, the Milankovich cycles, with CO_2 responding as a positive feedback.

The earliest analysis of Antarctic cores, and the derivation of climate sensitivity from these data, was already based on this premise (see *Lorius et al.* [1990]). Hence, climatologists have long expected a time lag of CO_2 behind temperature in the ice core data, and some of us were involved in pioneering the measurement of this lag using a gas-based temperature proxy that resolves the problem of the age difference between gas bubbles and the surrounding ice [*Caillon et al.*, 2003]. The result is a lag of 800 years at termination III (240,000 yr B.P.), a warming that occurred over a 5000-yr period.

This means that one-sixth of the warming at the end of this glacial period occurred before the CO_2 feedback started to be felt. This is consistent with recent climate model simulations of glacial cycles, which show that CO_2 changes are not required to explain the initiation of glaciation or deglaciation, but that the CO_2 feedback is needed to explain their full extent [*Yoshimori et al.*, 2001; *Meissner et al.*, 2003]. The time lag in ice core data gives no information about the climate sensitivity to a given CO_2 change, such as that caused by anthropogenic emissions.

We also fully agree with Shaviv and Veizer that their results, even if they were correct, apply only to the multi-million-year time scale and cannot be applied to shorter time scales. We are glad they have clarified this point. Their media releases as well as their paper, in which they compare their climate sensitivity with the range given by the Intergovernmental Panel on Climate Change (which applies to modern climate and centennial time scales [*IPCC*, 2001]), could have been misunderstood in this respect.

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SECTION NEWS

SPACE PHYSICS & AERONOMY

Section President, *Michael J. Mendillo;* **Section Secretaries**, *Gang Lu, William S. Kurth, and Michelle F. Thomsen*

Murr Receives 2004 F. L. Scarf Award

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David Murr has been awarded the F. L. Scarf Award given annually to a recent Ph.D. recipient for outstanding dissertation research that contributes directly to solar-planetary sciences. Murr's thesis is entitled "Magnetosphere-ionosphere coupling on meso- and macro-scales." He will be formally presented with the award on 14 December during the 2004 AGU Fall Meeting, which is held 13–17 December in San Francisco, California.

Murr received his B.S. in physics from Augsburg College, Minneapolis, Minnesota, in 1992 under the direction of Mark Engebretson. After spending two years in the Peace Corps and an additional two years working in industry, he returned to the field of space physics as project manager for the MACCS (Magnetometer Array for Cusp and Cleft Studies) array of magnetometers at Boston University. Supervised by W. J. Hughes, he earned his Ph.D. at Boston University in 2003. Also in 2003, he received the National Science Foundation Geospace Environment Modeling (GEM) postdoctoral researcher award.

Murr currently works with William Lotko at Dartmouth College, Hanover, New Hampshire, studying the transient response of the dayside magnetosphere to rapid solar wind forcing and the outflow of ionospheric plasma into the magnetosphere.

BOOK REVIEW

Measuring the Oceans from Space

IAN S. ROBINSON

Springer-Praxis; New York; ISBN 3-540-42647-7; xlv+669 pp., 23 color plates; 2004; $189.

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Given the growth in the number and complexity of ocean satellite systems since the launch of Seasat in 1978, combined with the fact that about twenty-five countries are now involved in such observations, this is an appropriate time for a new book on satellite oceanography. (Disclosure: the book reviewer has also just published an ocean remote sensing book.). The present book is an expanded version of Robinson's 1985 book, *Satellite Oceanography*.

It consists of two parts: fundamentals of satellite oceanography and remote sensing techniques. Although Robinson originally planned to include a third part on ocean applications, because of the length of the current book, that section will be published separately in 2005. The present book discusses for the ice-free ocean "what is measured and how it is done."

The five chapters in Part I occupy about a quarter of the text. The topics covered include a history of satellite oceanography, the electromagnetic spectrum, the different kinds of sensors, and a qualitative introduction to atmospheric radiative transfer. Topics also include platforms, orbits and their scales of temporal and spatial coverage, data encoding, and image processing.

Part II contains seven chapters: six on the various instruments, and a conclusion. The instrument chapters cover the visible (ocean color), infrared sea surface temperature (SST), passive microwave, scatterometry, synthetic aperture radar (SAR), and altimetry.

Each chapter discusses the form of the atmospheric radiative transfer equation appropriate to the instrument, the interaction of this radiation with the ocean surface and interior, and how the instrument retrieves the property in question. The chapters next consider past, present, and near-future instruments, with particular emphasis on European instruments, continue with applications, and