Vjushin *et al.* Reply: Analysis of a large number of observational records around the globe shows that the fluctuations of continental temperature data around their seasonal mean, separated by a lag time t, are long-term correlated [1–4]. The autocorrelation function $C(t)$ decays as $t^{-\gamma}$, with an exponent $\gamma = 0.7 \pm 0.06$ that does not change significantly with the location and does not depend on the distance from the ocean [4,5]. In [6], we applied this kind of "universal" scaling to test the performance of two scenarios of the global climate models [(i) greenhouse-gas forcing only and (ii) greenhouse-gas plus aerosol forcing] for seven leading models at six continental sites, including three coastline stations. Both scenarios strongly underestimated the long-term persistence of the atmosphere, with a slightly better performance of the second scenario.

The globally averaged temperature data to which Ritson [7] refers are characterized by a stronger persistence, with γ close to 0.4. There is, however, no discrepancy between both results. The value of 0.4 is close to the average exponent that was found to govern the persistence of sea surface temperatures [2,8]. Since about 2/3 of the globe is covered by the oceans, the persistence of the oceans governs the persistence of the global temperature, with $\gamma \cong 0.4$ instead of $\gamma \cong 0.7$.

When comparing model data obtained for grid points with observational data at a given site, we first interpolated the model data from the four nearest neighbor grid points of the site. We agree that for coastal stations some of the grid points are in the oceans. Since ocean sites generally show a stronger persistence than continental sites, we expected the models to overestimate the persistence in the coastal area (when performing well). The fact that both scenarios underestimated the persistence also in the coastal areas makes our conclusion, that they failed to describe the long-term memory of the atmosphere properly, even stronger—a finding which is not based on any claim of universality.

Finally, the Comment addresses the important question whether external natural forcing of the climate system (by volcanic eruptions and/or solar luminosity changes) might be responsible for the observed atmospheric scaling behavior. In fact, we explicitly stated this possibility in [6], but refrained from drawing sweeping conclusions, since the data available at the time seemed not sufficient for testing that hypothesis. We were, of course, aware of the HadCM2 runs, which succeeded in reproducing the rough shape of the global mean temperature curve over the past 140 years by including (partially offline) solar and volcanic forcing and which are summarized in Fig. 12c of the IPCC TAR WG I contribution. Since these data were only annually resolved, we did not include them in our analysis.

Very recently, daily simulation records have been made available from the NCAR PCM, with various scenarios, including solar, sulfate, ozone, greenhouse gas, and volcanic forcings. Using the same type of analysis as in [6], we analyzed the scaling performance of these scenarios at 16 continental sites (including sites deep in the continents). We found [9] that only those scenarios that included the volcanic forcings show long-term persistence with an exponent γ close to 0.7, similar to those in the real records. If all forcings were included, the performance was best. For ocean sites (where the exponents vary more than over the continents), the scaling performance of the models was also improved when the volcanic forcing was considered, but still the average persistence is underestimated by the model.

Regarding Ritson's arguments on detrended fluctuation analysis (DFA) detrending at the end of the Comment, there seems to be a misunderstanding. Of course, DFA does not remove natural solar and volcanic forcings. Thus, it can be used to learn how the persistence in the simulations is influenced by the various natural forcings. Indeed, as mentioned above, in particular, volcanic forcing modifies the DFA results by contributing to long-term persistence. DFA only eliminates polynomial trends leading to systematic warming or cooling of the atmosphere, such as urban and greenhouse-gas induced global warming, and therefore is an ideal tool to distinguish between systematic trends and natural persistence.

This work has been supported by the Deutsche Forschungsgemeinschaft and the Israeli Science Foundation.

D. Vyushin,[1,2] A. Bunde,[2,*] St. Brenner,[3] S. Havlin,[1]
R. B. Govindan,[1,2] and H.-J. Schellnhuber[4]
[1]Minerva Center and Department of Physics
Bar-Ilan University, Ramat-Gan 52900, Israel
[2]Institut für Theoretische Physik III
Universität Giessen, D-35392 Giessen, Germany
[3]Department of Geography
Bar-Ilan University, Ramat-Gan 52900, Israel
[4]Tyndall Center
Norwich, NR4 7JD, England

Received 16 June 2003; published 16 April 2004
DOI: 10.1103/PhysRevLett.92.159804
PACS numbers: 92.60.Wc, 02.70.Hm, 64.60.Ak, 92.60.Bh

*Electronic address: bunde@uni-giessen.de

[1] E. Koscielny-Bunde *et al.*, Phys. Rev. Lett. **81**, 729 (1998).
[2] J. D. Pelletier and D. L. Turcotte, Adv. Geophys. **40**, 91 (1999).
[3] P. Talkner and R. O. Weber, Phys. Rev. E **62**, 150 (2000).
[4] J. Eichner *et al.*, Phys. Rev. E **68**, 046133 (2003).
[5] A. Bunde *et al.*, Phys. Rev. Lett. **92**, 039801 (2004).
[6] R. B. Govindan *et al.*, Phys. Rev. Lett. **89**, 028501 (2002).
[7] D. Ritson, preceding Comment, Phys. Rev. Lett. **92**, 159803 (2004).
[8] R. A. Monetti *et al.*, Physica (Amsterdam) **320A**, 581 (2003).
[9] D. Vyushin *et al.*, Geophys. Res. Lett. (to be published).

