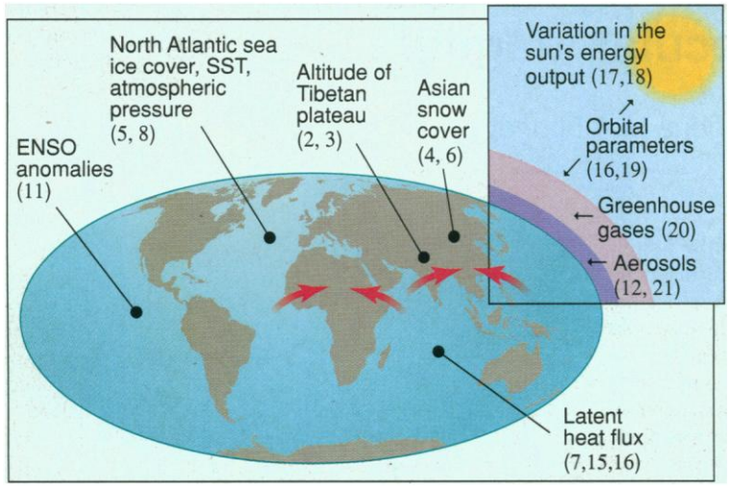
Past and Present Subtropical Summer Monsoons

Frank Sirocko

Monsoons are the seasonal rainbearing winds best known for their sometimes devastating effect on India and southern Asia. Our ability to forecast their timing and severity depends on understanding the factors that control them. Several mechanisms were found to be responsible (1–6). Changes in mountain topography have altered airmass flow patterns. Variations of the solar heating and continental ice sheets influenced the heat budget in the Northern Hemisphere. In addition, changes in snow cover on the continents, sea surface temperatures of the North Atlantic, and El-Niño anomalies in the sea surface temperatures of the equatorial Pacific all contribute to monsoon behavior (see figure).

Research on monsoon variability during the Quaternary period (2.6 million years ago to present) has focused mostly on the Northern Hemisphere ice sheets and insolation. Clemens *et al.* now reveal important subtleties in this relation (*7*). They report that the ice-sheet extent and size determine the rate of melting and thus the lag interval for the monsoons to react to insolation changes. In addition to this northern component in monsoon forcing, Clemens *et al.* (*7*) take a new perspective by highlighting the role of insolation and sea surface temperatures also on the Southern Hemisphere, proposing that low July insolation resulted in low surface temperatures in the southern Indian ocean, strong winds, and strong transequatorial latent heat transport, intensifying the Northern Hemisphere summer monsoon.

A connection between the summer monsoon and the Southern Hemisphere is not only unique to records on the Milankovitch time scale but is also apparent in some abrupt century-scale events during the early part of the last deglaciation (*8*), as well as in the annual-scale rainfall anomalies over the subtropical northern during the last century (*9–11*). The rainfall anomalies reveal the monsoons as an internal part of the Southern Oscillation (linking climate anomalies from the equatorial Pacific to Australia, the Indian Ocean, tropical and subtropical Africa, the Asian continent, and back to the Pacific). Latent heat transport is one parameter in this system; sea surface temperature variations in the Pacific (ENSO: the El Niño–Southern Oscillation), sea ice cover around Antarctica, and snow cover in Asia are other parameters involved (see figure) (*6*, *12–14*). All of these connections have been observed in meteorological data and have been successfully reproduced by general atmospheric circulation models, and most of them have been found also in the geological record.



Processes associated with the monsoonal circulation at modern and past times. Inset shows the various processes controlling the amount of solar radiation received at Earth's surface. Arrows indicate monsoon feedbacks: water vapor export into Northern Hemisphere continents, with further feedbacks through vegetation buildup and soil moisture content (*22*). SST, sea surface temperature.

The next step to further improve our understanding of monsoon dynamics should be to quantify the role of each of these processes, today and during the past, and how low-frequency variations determine the high-frequency components of monsoon variability. General atmospheric circulation models may be the appropriate tool for this task, and all of them are capable of producing strong monsoons during times of intense solar insolation during boreal summers. All of the other processes involved have been studied in single sensitivity experiments. The real world, however, is more complex, and it may require quite a few subtle refinements in the boundary conditions (high temporal resolution for Asian snow cover, sea ice cover around the Antarctic, and sea surface temperature in the equatorial Pacific and north Atlantic) to reproduce the complete succession of monsoon events as observed, for example, in the long Plio-Pleistocene records from the Arabian Sea.

There are various tracers of dust and upwelling in the sediments of the deep ocean to reconstruct past monsoon strength, and when compared to the modern sediment flux, their records appear to be easily interpretable [see figure 2 in (*7*)]. On long time scales, however, they show a rather different behavior, and apparently, the present is not always a direct guide to the past. Clemens *et al.* (*7*) attack this problem by using a multitracer approach, a technique that is not entirely satisfying but probably the only achievable way to overcome this problem.

The nonstationarity of monsoon response to insolation changes, with time lags of several thousand years, is, however, also a challenge for the modeling community because it will require time-transient models of a coupled ocean-atmosphere system, allowing at least the ocean surface temperatures to respond to solar insolation changes. Phase relations between climate-related parameters in archives of ice, sediment, tree rings, and so forth—diagnostic of climate system dynamics—are the other appropriate tool to study the forcing of the past monsoons. The success of this approach depends highly on the reliability of the chronology for past climate changes. In this context, the nonstationarity of the lead and lag relations between ice-sheet extent (recorded in the oxygen isotope $\delta^{18}O$ composition of the world ocean) and monsoon strength has another important aspect. If the lead and lag relations of a single component of Earth's climate system (for example, the summer monsoons) are nonstationary with respect to the marine $\delta^{18}O$ fluctuation, the proxy parameters from this component (for example, dust) cannot be used directly to date the section by tuning the orbital

The author is at GeoForschungsZentrum Potsdam, Telegrafenberg A17, 14473 Potsdam, Germany. E-mail: sirocko@gfz-potsdam.de

parameters of precession or obliquity. Using cost-effective proxy records instead of marine $\delta^{18}O$ variations is tempting, but as Clemens *et al.* (*7*) show, it may be a misleading stratigraphical tool, particularly when using the lead and lag relations as being diagnostic for the dynamics of a climate system.

Thus, the report of Clemens *et al.* (*7*) is of twofold importance. It highlights the need for increasing the precision of stratigraphical techniques, but also shows that the monsoon is a very complex system, which provides a serious challenge for future modeling efforts if the natural succession of the observed monsoon oscillations is to be reproduced. The realization of both concepts would, however, be an important step in understanding the physical mechanisms of drought and floods in Asia and Africa, past and present.

References

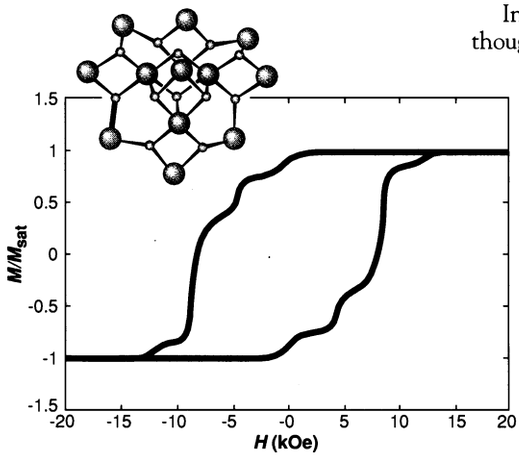
1. W. L. Prell and J. E. Kutzbach, *J. Geophys. Res.* **92**, 8411 (1987).
2. P. B. deMenocal and D. Rind, *ibid.* **98**, 7265 (1993).
3. W. L. Prell and J. E. Kutzbach, *Nature* **360**, 647 (1992).
4. J. Overpeck, D. Anderson, S. Trumbore, W. Prell, *Clim. Dyn.* **12**, 213 (1996).
5. C. R. V. Raman and J. A. Maliekal, *Nature* **314**, 430 (1985).
6. T. P. Barnett, L. Dümenil, U. Schlese, E. Roeckner, M. Latif, in *Teleconnections Linking Worldwide Climate Anomalies*, M. H. Glantz, R. W. Katz, N. Nicholls, Eds. (Cambridge Univ. Press, Cambridge, 1991), pp. 191–225.
7. S. C. Clemens, D. W. Murray, W. L. Prell, *Science* **274**, 943 (1996).
8. F. Sirocko, D. Garbe-Schönberg, A. McIntyre, B. Molfino, *ibid.* **272**, 526 (1996).
9. G. T. Walker, *Mem. Indian Meteorol. Dept.* **24**, 75 (1923).
10. J. Bjerknes, *Mon. Weather Rev.* **97**, 163 (1969).
11. R. S. Bradley, H. F. Diaz, G. N. Kiladis, J. K. Eischeid, *Nature* **327**, 497 (1987).
12. H.-F. Graf, *Clim. Dyn.* **7**, 19 (1992).
13. H. F. Diaz and V. Markgraf, Eds., *El Niño* (Cambridge Univ. Press, Cambridge, 1992).
14. P. Gloersen, *Nature* **373**, 503 (1995).
15. S. Hastenrath and P. J. Lamb, *Phys. Oceanogr.* **10**, 649 (1980).
16. S. Clemens, W. Prell, D. Murray, G. Shimmield, G. Weedon, *Nature* **353**, 720 (1991).
17. J. Haigh, *Science* **272**, 981 (1996).
18. M. Stuiver, T. F. Branziunas, B. Becker, B. Kromer, *Quatern. Res.* **35**, 1 (1991).
19. P. deMenocal, *Science* **270**, 53 (1995).
20. J. Chappellaz *et al.*, *Nature* **366**, 443 (1993).
21. M. R. Rampino and S. Self, *ibid.* **359**, 50 (1992).
22. D. Rind *et al.*, *ibid.* **349**, 500 (1991).

Quantum Hysteresis in Molecular Magnets

Eugene M. Chudnovsky

Magnetic materials are marked by hysteresis: their response to an increasing magnetic field is different from their response to a decreasing field. Elementary science textbooks always show smoothly shaped magnetic hysteresis loops; the stepwise magnetization curve in the accompanying figure is therefore extraordinary. The measurement was made at a temperature below a few kelvin in a crystalline organic compound, Mn_{12} acetate, and the steps are caused by a quantum mechanical effect amplified to a macroscopic level. This quantum magnetic hysteresis has recently been reported by Friedman *et al.* (*1*) and confirmed (*2*, *3*) by several groups. The findings are an important landmark in the search for macroscopic quantum tunneling of the magnetic moment.

The chemical formula of the crystal that exhibits the effect is $[Mn_{12}O_{12}(CH_3COO)_{16}(H_2O)_4]\cdot 2CH_3COOH\cdot 4H_2O$. In chemistry this compound is a teenager (*4*), and intensive research of its physical properties began only a few years ago (*5*). It consists of weakly interacting molecules of spin 10, arranged in a tetragonal lattice. Each molecule is formed by 12 Mn ions of mixed valence, interacting through oxygen bridges (see figure, inset). The four Mn ions of the central tetrahedron have spin $^3/_2$ and form a ferromagnetic cluster of total spin 6. The eight Mn ions of the crown have spin 2 and form another ferromagnetic cluster of total spin 16. The total spin of the molecule results from the antiferromagnetic interaction between the clusters: 16 – 6 = 10. All the interactions are so strong that the Mn_{12} molecule is effectively a single spin 10 object; in magnetic measurements one does not detect the effects of the individual atomic spins. In a Mn_{12} acetate crystal, the symmetry axes of all Mn_{12} molecules are aligned in one direction, making the crystal highly anisotropic: individual magnetic moments have a strong preference to look along the anisotropy axis.



Quantum magnetic hysteresis in Mn_{12} acetate. The inset shows the structure of the Mn_{12} molecule. Only Mn ions (large circles) and oxygen ions (small circles) are shown. [Courtesy of the authors of (*1*)]

According to quantum mechanics, the projection of spin 10 on a certain axis, say the anisotropy axis z of the crystal, can take only discrete values: $m = -10, -9, \ldots, -1, 0, 1, \ldots, 9, 10$. At zero magnetic field the two levels of the minimal energy belong to the two opposite orientations of the spin along the anisotropy axis, with $m = -10$ and $m = 10$, respectively. Other values of m numerate excited levels.

In classical terms, an m level can be thought of as the precession of the magnetic moment of the Mn_{12} molecule about the z axis, with the amplitude of the precession increasing with decreasing $|m|$. At $H = 0$, the energy barrier between the states with $m = -10$ and $m = 10$ is about 60 K in temperature units. This observation can be attributed to the anisotropy of the molecule. The separation between the levels is about 12 K at the bottom of the spectrum and about 0.6 K at the top. Imagine now that the crystal is cooled down to a few kelvin and put in a strong magnetic field applied in the negative z direction. Such a field makes the state with $m = -10$ energetically more favorable than the $m = 10$ state, resulting in the negative magnetization of the crystal. If the field is now quickly removed, most of the molecules will occupy the $m = -10$ level, which corresponds to the lower part of the hysteresis loop in the figure. The negative magnetization of the crystal decays with time as a result of the rotation of individual molecular moments. By absorbing phonons (oscillations of the crystalline lattice), a Mn_{12} molecule can go up the staircase of the excited levels until it reaches the top of the energy barrier. Then, by emitting phonons, it goes down the staircase, finally switching the spin projection from $m = -10$ to $m = 10$. Each phonon can change the m number by 1. Consequently, in zero field, the molecule must

The author is in the Physics Department, City University of New York Lehman College, Bronx, NY 10468–1589, USA. E-mail: chudnov@lcvax.lehman.cuny.edu