MEETINGS

Twenty Years of Nonlinear Dynamics in Geosciences

Twenty years ago, the basic ideas of what is now known as 'nonlinear geophysics' had matured to the point that they were generating great excitement, motivating the first workshops on the theme. The ideas instigated new approaches to addressing problems of geophysics covering different disciplines, and they led to the publication of several important papers.

A conference entitled '20 Years of Nonlinear Dynamics in Geosciences' was held in Rhodes, Greece, from 11 to 16 June 2006 to mark this progress. The aim of the conference was to bring together scientists from all areas of geosciences to discuss problems, review advances, and look toward the future. About 80 scientists from around the world participated in the meeting. This article provides a brief review of the key historical developments that laid the foundations for nonlinear geophysics and gives an overall summary of the meeting.

A Short History of Nonlinear Dynamics in Geosciences

Nonlinear problems and complex dynamics, such as turbulence and the three-body problem, have teased physicists for decades. Physicists had been looking for new kinds of dynamics that would explain irregularity in nature while at the same time, mathematicians were exploring sets with fractional dimensions. *Lorenz* [1963] showed that the dynamical instabilities of nonlinear systems investigated by French mathematician Henri Poincaré and others led to limits of predictability due to sensitivity to the initial conditions, now known as 'chaos.'

A surprising consequence was that the attractor, which described the evolution of that system, was a fractal set. *Mandelbrot* [1967], building on the work of Jean Perrin, Lewis Fry Richardson, and others, proposed that irregular, sparse geometric sets are fractals. *Mandelbrot and Van Ness* [1968] introduced fractional Brownian motion exhibiting statistical self-similarity. It was applied to model the 'Hurst effect' that H. E. Hurst discovered from paleohydrologic and other data sets, particularly from the Nile River. These early developments established a link between dynamics, geometry, and statistics and provided the building blocks for new theories of nonlinear geophysics.

During the 1970s, the discovery of 'metric universality' by *Feigenbaum* [1978] and others allowed scientists to suggest models of low-dimensional chaos for real-world dynamical systems. Similarly, by the mid 1980s the advent of computer graphics enabled the visualization of complex sets. *Bak et al.* [1987] proposed a new class of avalanche-like models that combined fractal structures with extreme (algebraic) probability distributions. Self-organized critical (SOC) processes have not only extremes, but also entire structures determined by them. During the 1990s, this classical SOC was contrasted with SOC produced in (multifractal) cascade processes, and applications were found in turbulence, earthquakes, solar activity, and rainfall.

Highlights From the Conference

The conference opened with a retrospective on nonlinear geosciences written by Edward Lorenz, a physicist from MIT and one of the field's founders. Lorenz famously stated that the flapping of a butterfly's wings in Tokyo can cause a tornado in Texas, stressing how important initial conditions are to final outcomes.

The highlight of the conference was the breadth of the topics covered. Sixty talks, nine of which were keynote seminars summarizing advances in specific areas, and 20 posters covering meteorology, oceanography, hydrology, climate dynamics, space physics, landscape dynamics, natural hazards, river networks, marine ecosystems, and material sciences were presented. Topics included state space reconstruction, statistical self-similarity and its dynamical origins, stochastic cascade models, models of nonlinear dynamics, complex systems approaches, issues with ensemble prediction and limitations in predictability, analysis of extreme events, fractals and multifractals, network theory, nonlinear prediction, nonlinear interactions, and self-organized criticality.

According to the design of the conference, there were no parallel sessions and the presentation of the talks had no particular order. The idea was for everyone to be exposed to all of the various scientific problems presented and to allow them to see how different disciplines approach common themes. The conference provided a unique interdisciplinary forum that is seldom seen in geophysics meetings. Evening social events provided opportunities to further discuss issues but in a more relaxing environment.

Keynote talks at the conference provided overviews of the advances in geosciences made through the use of nonlinear dynamics and related approaches. Observational studies of earthquakes, river flows, and climate variations demonstrated long-range correlations underlying the clustering of extreme events. Results were shown to have implications for climate change and hazard risk management. Frequency-magnitude statistics of natural hazard models were shown to follow universal power laws, exhibiting features of complex behavior including self-organized criticality.

Various talks and posters addressed aspects of complex landscape patterns, and Earth surface and hydrologic processes. Presentations highlighted the fractal (self-similar, self-affine, multifractal) characteristics of many of these patterns and processes. Phenomena included precipitation, floods, river networks, shoreline-change dynamics, and wildfires.

Other presentations demonstrated that advances in the past 20 years would lead to new predictive and diagnostic approaches that exploit how patterns, processes, and probabilities are mutually coupled. Nonlinear phase locking was used to explain glacial cycles. For example, it was shown how chaotic dynamics can be exploited to reduce forecast error, to understand atmospheric flow transitions, to analyze atmospheric variability in Intergovernmental Panel on Climate Change models, and to explain atmospheric and oceanic teleconnections. Another presentation demonstrated how nonlinear aspects of the climate can regulate El Niño's background state and how nonlinear dynamical approaches to data analysis, which are becoming increasingly popular, can be used to check the consistency of general circulation models in the representation of fundamental statistical properties of the atmosphere.

One speaker demonstrated that current computational resources allow investigations of the attractor from increasingly complex models. The resulting statistical properties seem to obey self-scaling behaviors with respect to the external forcing parameters. It was also shown that nonlinear dynamical techniques are capable of identifying critical trajectories of advective pathways in the Gulf of Mexico.

The interrelationship between global and multiscale phenomena, with implications for the predictability of the geospace environment, was a key issue in space physics. Nonlinear dynamical predictions have played an important role in space weather studies, and the spatiotemporal dynamics of geospace share many features with atmospheric variability. In particular, how disturbances originating from the Sun affect the near-Earth environment was examined using wavelet analysis and state space methods.

The meeting culminated with an open discussion in which participants concluded that despite the significant advances that nonlinear dynamics and complex-systems approaches have spurred in geosciences, the unique approaches and the promise they hold for future discoveries need to be further developed and broadcast to the broader geosciences communities. Toward this goal, a book edited by the conference organizers will be prepared for the general geosciences audience. The book will include peer-reviewed papers from the meeting and will be published by Springer in 2007. A follow-up conference in 2 or 3 years was strongly suggested.

The conference '20 Years of Nonlinear Dynamics in Geosciences' was held 11–16 June 2006 in Rhodes, Greece. Anastasios A. Tsonis and James B. Elsner organized the conference, and it was sponsored by Aegean Conferences and endorsed by the American Meteorological Society (AMS) and the European Geosciences Union (EGU).

References

Bak, P., C. Tang, and K. Wiessenfeld (1987), Self-organized criticality: An explanation of 1/f noise, *Phys. Rev. Lett.*, *59*, 381–384. Feigenbaum, M. (1978), Quantitative universality for a class of nonlinear transformations, *J. Stat. Phys.*, *19*, 25–52.

Lorenz, E. (1963), Deterministic nonperiodic flow, *J. Atmos. Sci.*, *20*, 130–141.

Mandelbrot, B. B. (1967), How long is the coast of Britain? Statistical self-similarity and fractional dimension, *Science*, *155*, 636–638.

Mandelbrot, B. B., and J. W. Van Ness (1968), Fractional Brownian motions, fractional noises and applications, *SIAM Rev.*, *10*, 422–437.

—James B. Elsner, Florida State University, Tallahassee; Vijay K. Gupta, University of Colorado, Boulder; Shaun Lovejoy, McGill University, Montreal, Canada; Valerio Lucarini, University di Camerino and Consorizio Interuniversitario Nazionale per la Fisica delle Atmosphere e delle Idrosphere, Camerino, Italy; A. Brad Murray, Duke University, Durham, N.C.; A. Surjalal Sharma, University of Maryland, College Park; Sarah Tebbens, Wright State University, Dayton, Ohio; Anastasios A. Tsonis, University of Wisconsin–Milwaukee; and Dimitris Vassiliadis, NASA Goddard Space Flight Center, Greenbelt, Md.