EGS Richardson AGU Chapman NVAG3 Conference: Nonlinear Variability in Geophysics: scaling and multifractal processes

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D. Schertzer and S. Lovejoy*

Laboratoire de Météorologie Dynamique, Université Pierre et Marie Curie, 4 Place Jussieu, 75252 Paris Cedex 05, France
*on leave from the Physics Dept., McGill University

1 The conference

The third conference on "Nonlinear VAriability in Geophysics: scaling and multifractal processes" (NVAG 3) was held in Cargèse, Corsica, Sept. 10-17, 1993. NVAG3 was a joint American Geophysical Union Chapman and European Geophysical Society Richardson Memorial conference, the first specialist conference jointly sponsored by the two organizations. It followed NVAG1 (Montreal, Aug. 1986), NVAG2 (Paris, June 1988; Schertzer and Lovejoy, 1991), five consecutive annual sessions at EGS general assemblies and two consecutive spring AGU meeting sessions.

As with the other conferences and workshops mentioned above, the aim was to develop confrontation between theories and experiments on scaling/multifractal behaviour of geophysical fields. Subjects covered included climate, clouds, earthquakes, atmospheric and ocean dynamics, tectonics, precipitation, hydrology, the solar cycle and volcanoes. Areas of focus included new methods of data analysis (especially those used for the reliable estimation of multifractal and scaling exponents), as well as their application to rapidly growing data bases from in situ networks and remote sensing. The corresponding modeling, prediction[2] and estimation techniques were also emphasized as were the current debates about stochastic and deterministic dynamics, fractal geometry and multifractals, self-organized criticality and multifractal fields, each of which was the subject of a specific general discussion.

The conference started with a one day short course on multifractals featuring four lectures on a) Fundamentals of multifractals: dimension, codimensions, codimension formalism b) Multifractal estimation techniques: (PDMS, DTM), c) Numerical simulations, Generalized Scale Invariance analysis, d) Advanced multifractals, singular statistics, phase transitions, self-organized criticality and Lie cascades (given by D. Schertzer and S. Lovejoy, detailed course notes were sent to participants shortly after the conference). This was followed by five days with 8 oral sessions and one poster session. Overall, there were 65 papers involving 74 authors. In general, the main topics covered are reflected in this special issue: geophysical turbulence, clouds and climate, hydrology and solid earth geophysics.

In addition to AGU and EGS, the conference was supported by the International Science Foundation, the Centre Nationale de Recherche Scientifique, Météo-France, the Department of Energy (US), the Commission of European Communities (DG XII), the Comité National Français pour le Programme Hydrologique International, the Ministère de l'Enseignement Superieur et de la Recherche (France). We thank P. Hubert, Y. Kagan, Ph. Ladoy, A. Lazarev, S. S. Moiseev, R. Pierrehumbert, F. Schmitt and Y. Tessier, for help with the organization of the conference. However special thanks goes to A. Richter and the EGS office, B. Weaver and the AGU without whom this would have been impossible[3]. We also thank the Institut d'Etudes Scientifiques de Cargèse whose beautiful site was much appreciated, as well as the Bar des Amis whose ambiance stimulated so many discussions.

2 Tribute to L. F. Richardson

With NVAG3, the European geophysical community paid tribute to Lewis Fry Richardson (1881-1953) on the 40th anniversary of his death. Richardson was one of the founding fathers of the idea of scaling and fractality, and his life reflects the European geophysical community and its history in many ways. Although many of Richardson's numerous, outstanding scientific contributions to geophysics have been recognized, perhaps his main

[2]The weather did indeed display an unforecast high order singularity during the barbecue, although the boat excursion was accompanied by a weak order (sunny) event that was quite accurately forecast.

[3] We acknowledge conference advertizing by B.B. Mandelbrot.

Correspondence to: D. Schertzer

contribution concerning the importance of scaling and cascades has still not received the attention it deserves.

Richardson was the first not only to suggest numerical integration of the equations of motion of the atmosphere, but also to attempt to do so by hand, during the First World War. This work, as well as a presentation of a broad vision of future developments in the field, appeared in his famous, pioneering book "Weather prediction by numerical processes" (1922). As a consequence of his atmospheric studies, the nondimensional number associated with fluid convective stability has been called the "Richardson number". In addition, his book presents a study of the limitations of numerical integration of these equations, it was in this book that - through a celebrated poem[4] — that the suggestion that turbulent cascades were the fundamental driving mechanism of the atmosphere was first made. In these cascades, large eddies break up into smaller eddies in a manner which involves no characteristic scales, all the way from the planetary scale down to the viscous scale. This led to the Richardson law of turbulent diffusion (1926) and to the suggestion that particles trajectories might not be describable by smooth curves, but that such trajectories might instead require highly convoluted curves such as the Peano or Weierstrass (fractal) curves for their description. As a founder of the cascade and scaling theories of atmospheric dynamics, he more or less anticipated the Kolmogorov law (1941). He also used scaling ideas to invent the "Richardson dividers method" of successively increasing the resolution of fractal curves and tested out the method on geographical boundaries[5] (as part of his wartime studies). In the latter work he anticipated recent efforts to study scale invariance in rivers and topography.

His complex life typifies some of the hardships that the European scientific community has had to face. His educational career is unusual: he received a B. A. degree in physics, mathematics, chemistry, biology and zoology at Cambridge University, and he finally obtained his Ph.D. in mathematical psychology at the age of 47 from the University of London. As a conscientious objector he was compelled to quit the United Kingdom Meteorological Office in 1920 when the latter was militarized by integation into the Air Ministry. He subsequently became the head of a physics department and the principal of a college. In 1940, he retired to do research on war, which was published posthumously in book form (Richardson, 1963). This latter work is testimony to the trauma caused by the two World Wars and which led some scientists including Richardson to use their skills in rational attempts to eradicate the source of conflict. Unfortunately, this remains an open field of research.

[4]"Big whorls have little whorls that feed on their velocity, and little whorls have smaller whorls and so on to viscosity - in the molecular sense."

[5]This idea was already expressed by Perrin (1913) on the now famous question of the fractality of Brittany.

3 The contributions in this special issue

Perhaps the area of geophysics where scaling ideas have the longest history, and where they have made the largest impact in the last few years, is turbulence. The paper by Tsinober is an example where geometric fractal ideas are used to deduce corrections to standard dimensional analysis results for turbulence. Based on local spontaneous breaking of isotropy of turbulent flows, the fractal notion is used in order to deduce diffusion laws (anomalous with respect to the Richardson law). It is argued that this law is ubiquitous from the atmospheric boundary layer to the stratosphere. The asymptotic intermittency exponent (D_∞) is hypothesized to be not only finite but to be determined by the angular momentum flux.

Schmitt et al., Chiriginskaya et al. and Lazarev et al. apply statistical multifractal notions to atmospheric turbulence. In the former, the formal analogy between multifractals and thermodynamics is exploited, in particular to confirm theoretical predictions that sample-size dependent multifractal phase transitions occur. While this quantitatively explains the behaviour of the most extreme turbulent events, it suggests that — contrary to the type of multifractals most commonly discussed in the literature which are bounded — more violent (unbounded) multifractals are indeed present in the atmospheric wind field. Chiriginskaya et al. use a tropical rather than mid-latitude data set to study the extreme fluctuations from yet another angle: that of coherent structures, which, in the multifractal framework, are identified with singularities of various orders. The existence of a critical order of singularity which distinguishes violent "self-organized critical structures" was theoretically predicted ten years ago; here it is directly estimated. The second of this two part series (Lazarev et al.) investigates yet another aspect of tropical atmospheric dynamics: the strong multiscaling anisotropy. Beyond the determination of universal multifractal indices and critical singularities in the vertical, this enables a comparison to be made with Chiriginskaya et al.'s horizontal results, requiring an extension of the unified scaling model of atmospheric dynamics.

Other approaches to the problem of geophysical turbulence are followed in the papers by Pavlos et al., Vassiliadis et al., Voros et al. All of them share a common assumption that a very small number of degrees of freedom (deterministic chaos) might be sufficient for characterizing/modelling the systems under consideration. Pavlos et al. consider the magnetospheric response to solar wind, showing that scaling occurs both in real space (using spectra), and also in phase space; the latter being characterized by a correlation dimension. The paper by Vassiliadis et al. follows on directly by investigating the phase space properties of power-law filtered and rectified gaussian noise; the results further quantify how low phase space correlation dimensions can occur even with very large number of degrees of freedom (stochastic) processes.

Voros et al. analyse time series of geomagnetic storms and magnetosphere pulsations, also estimating their correlation dimensions and Lyapounov exponents taking special care of the stability of the estimates. They discriminate low dimensional events from others, which are for instance attributed to incoherent waves.

While clouds and climate were the subject of several talks at the conference (including several contributions on multifractal clouds), Cahalan's contribution is the only one in this special issue. Addressing the fundamental problem of the relationship of horizontal cloud heterogeneity and the related radiation fields, he first summarizes some recent numerical results showing that even for comparatively thin clouds that fractal heterogeneity will significantly reduce the albedo. The model used for the distribution of cloud liquid water is the monofractal "bounded cascade" model, whose properties are also outlined. The paper by Falkovich addresses another problem concerning the general circulation: the nonlinear interaction of waves. By assuming the existence of a peak (i.e. scale break) at the inertial oscillation frequency, it is argued that due to remarkable cancellations, the interactions between long inertio-gravity waves and Rossby waves are anomalously weak, producing a "wave condensate" of large amplitude so that wave breaking with front creation can occur.

Kagan et al., Eneva and Hooge et al. consider fractal and multifractal behaviour in seismic events. Eneva estimates multifractal exponents of the density of micro-earthquakes induced by mining activity. The effects of sample limitations are discussed, especially in order to distinguish between genuine from spurious multifractal behaviour. With the help of an analysis of the CALNET catalogue, Hooge et al. points out, that the origin of the celebrated Gutenberg-Richter law could be related to a non-classical Self - Organized Criticality generated by a first order phase transition in a multifractal earthquake process. They also analyse multifractal seismic fields which are obtained by raising earthquake amplitudes to various powers and summing them on a grid. In contrast, Kagan, analysing several earthquake catalogues discussed the various laws associated with earthquakes. Giving theoretical and empirical arguments, he proposes an additive (monofractal) model of earthquake stress, emphasizing the relevance of (asymmetric) stable Cauchy probability distributions to describe earthquake stress distributions. This would yield a linear model for self-organized critical earthquakes.

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