Eos, Transactions, American Geophysical Union, Vol. 73, No. 49, December 8, 1992, Page 532.

Self-Similarity: Theory and Applications in Hydrology

There is a range of spatial and temporal scales over which measurements are difficult to make and interpret. Understanding, modeling, and prediction of hydrologic processes are needed for this broad range. Questions concerning quantitative interscale relationships of atmospheric, surface, and subsurface processes are at the heart of hydrologic research and are expected to play a key role in understanding large-scale behavior of hydrologic fluxes and processes. A special session, "Self-Similarity in Hydrologic Processes: Identification, Estimation, and Use in Modeling/Measurement/Prediction," was held at the AGU 1991 Fall Meeting to address scaling issues in hydrologic phenomena.

The session was composed of two parts: the first consisted of a series of five invited lectures, and the second included twenty-four contributed papers. The scope of the lectures was tutorial, with emphasis on the basic theoretical ideas of self-similar processes and illustration of their connection to physical processes and hydrology. The papers reported research on several aspects of scaling in space-time rainfall, river flows, river network structures and landforms, porous media, and transport.

Stanley Williams (Mathematics Department, Utah State University) gave the first lecture, "Scaling and Fractals." He introduced the concepts of Hausdorff and fractal dimension and made the connection between statistical scaling and the geometrical notion of dimension. Ed Waymire (Mathematics Department, Oregon State University) followed with "Simple Scaling Processes." Waymire built on the notion of simple scaling and presented examples of simple scaling processes with emphasis on connection of statistical theory with physical characterization, for example, Kolmogorov's 5/3 law, Holtsmark distribution, and the Hurst effect. He also discussed methods of identifying the presence of scaling and estimating scaling exponents. Waymire continued with the third lecture, "Multiscaling and Random Cascades." Starting with an example from Global Atmospheric Tropical Experiment (GATE) rainfall data he discussed simple versus multiscaling properties of moments and correlations, intermittency properties of cascade distributions, and scaling exponents and dimensions of random cascades.

The fourth lecture, "Analysis, Modeling, and Simulation of Multifractal Fields," was given by Shaun Lovejoy (Physics Department, McGill University) and was co-authored by Daniel Schertzer (Météorologie Nationale). Lovejoy presented a classification of multifractals and discussed modeling of passive scalar clouds and rain using continuous cascades and universal multifractals. He also presented methods for nonspecific multifractal analysis based on moments and histograms and discussed applications to rain, clouds, and turbulence. The fifth lecture, "Scaling Exponents in Hydrology: From Observation to Theory," was given by Vijay Gupta (Cooperative Center for Research in Environmental Sciences, University of Colorado, Boulder). Gupta concentrated on two main problems: the Hurst effect in paleohydrologic time series, and scaling in river networks and annual flood quantiles with its relevance to flood prediction and ungaged basins.

Several papers examined scaling in porous media structures and subsurface processes. M. Rieu and G. Sposito presented a fractal model of aggregate and pore-space properties for structured soils based on the representation of a soil as a fragmented fractal porous medium. S. W. Wheatcraft, K. E. Brewer, and S. Y. Chung reported on their effort to establish robust effective parameters and scaling rules for fluid flow and transport in three-dimensional porous media. G. E. Urroz and M. W. Kemblowski presented results from numerical simulations of flow and transport in stratified three-dimensional aquifers characterized by self-similar hydraulic conductivity distribution and showed that macrodispersion estimates (based on second moment analysis of the contaminant's plume) grow with increasing long-conductivity variance and decrease with increasing values of fractal dimension. Similar conclusions were reached by Kemblowski, J. C. Wen, and C. M. Chang for effective flow and transport properties in saturated and unsaturated soils and with self-similar permeability distribution.

R. Beckie, A. A. Aldama, and E. F. Wood presented a new formulation for groundwater flow based on the large eddy simulation method used in turbulence modeling and demonstrated the effects of small-scale dynamics upon large-scale dynamics. E. Poeter and P. Zlatev used two-dimensional fractal models of aquifer heterogeneities to investigate the use of sparse one-dimensional sampling to characterize the two-dimensional hydraulic conductivity distribution. C. Doughty, Loug, and K. Hestir presented work on characterization of heterogeneous geologic media using inverse methods and reported that using models with self-similar structure for hydrological properties shows promise as it alleviates some disadvantages of the inversion process, such as large numbers of parameters and nonuniqueness.

Regarding scaling in rainfall, P. Kumar and E. Foufoula-Georgiou presented a method for defining rainfall fluctuations—small-scale features—in inhomogeneous anisotropic fields based on multiresolution wavelet transforms. They reported evidence of scaling in rainfall fluctuations where the range and type of scaling was storm and direction dependent. Y. Tessier, Lovejoy, and D. Schertzer analyzed in situ and remotely sensed rain fields to test the universality hypothesis and estimate multifractal parameters of rain in space and time. They found $\alpha \approx 1.5$ in space and $\alpha \approx 0.5$ in time and discussed the significance of these results for space-time transformations. T. M. Over and Gupta used the theory of random cascades to represent a multifractal rainfall field and compute its spatial correlation. They showed that the theoretical cross moment exhibits power law behavior and tested this expression against GATE rainfall data. C. E. Puente et al. reported the results of a multifractal analysis of LIDAR measured water vapor. By comparing multifractal spectra and codimension functions for stable and unstable atmospheric stability conditions, they examined the space and time-scale relations of turbulent flow in the lower atmosphere. Lawford examined the spatial and temporal structure of precipitation patterns on the Canadian prairies and tried to relate it to land surface characteristics and correlations with larger-scale phenomena, such as changes in the upper air circulation patterns.

Regarding scaling in river networks and landforms, D. R. Montgomery and W. E. Dietrich proposed a method for differentiating between hillslope and channel scales in a landscape, based on empirical evidence from field observations. They argued that the hillslope length defines the limit over which drainage network models based on self-similarity are applicable. I. Rodriguez-Iturbe, E. Ijjasz-Vasquez, and R. L. Bras used multifractal formalism to study the scaling behavior in space of energy expenditure, slopes, and mean annual discharges. They reported "universality" of the multifractal spectra of those variables across various basins in the U.S.

Ijjasz-Vasquez, Bras, and Rodriguez-Iturbe explored the possibility that river basins belong to a class of self-organized critical systems that evolve naturally toward a critical state characterized by power-law distributions in space and time. Based on the observed scaling relationships, a three-dimensional model of river basin evolution was developed and tested against DEM data. K. R. Helmlinger, Kumar, and Foufoula-Georgiou dwelled on the definition, interconnection, and estimation of several fractal dimensions of a river network (for example, those of rivers, branching structure, and river network). They also used generated fractal trees of known fractal dimension to test the interpretation of estimated fractal plots from low-order networks.

On the subject of scaling in basin response and rainfall/runoff transformations,

0096/3941/7349/92/532/$01.00.

Smith compared characteristic temporal and spatial correlation scales for rainfall and runoff processes. Smith also studied the relative importance of land surface and rainfall characteristics on the produced runoff as a function of scale using data from catchments ranging from several acres to more than 100 km^2. D. C. Goodrich, D. A. Woolhiser, and S. Sorooshian examined the relative importance of climatic scales in relation to basin attenuating factors. They explored the sensitivity of basin response as a function of scale to scaled rainfall inputs and parameters associated with various hydrologic processes. C. J. Duffy reported research on the interpretation and analysis of precipitation, recharge, and runoff in mountainous terrains based on the assumption of locally self-affine topography. This assumption leads to the construction of normalized shape functions of altitude versus map distance, which can be used to develop simplified nonlinear dynamical models of precipitation-recharge-runoff relationships.

Sorooshian and J. D. Michaud studied the uncertainties involved in distributed rainfall-runoff simulation of floods from several sources. These included model structure, numerical error, parameter estimation, and resolution of the rainfall spatial distribution. W. A. Battaglin and R. S. Parker examined the effects of spatial scale on one component of the water balance: the potential evapotranspiration (PET). They found that PET variability is related to topography variability and is decreased in mountain environments because methods of land-surface generalization tend to smooth the topography. Finally, O. J. Mesa and Poveda debated the standing problems of the Hurst phenomenon. They presented a new statistical test that when applied to several geophysical time series showed no evidence of the Hurst phenomenon, although other traditional tests have shown otherwise.

The session was well attended. Lecture notes prepared by the researchers were available at the meeting, and more than 170 copies were distributed. A few copies are still available and can be obtained by contacting the organizer (Efi Foufoula-Georgiou, tel. 612-6274595; fax 612-6274609; e-mail efi@mykonos.safhl.umn.edu). The session was cosponsored by the Precipitation Committee, the Remote Sensing Committee, the Large-Scale Field Experimentation Committee of the AGU Hydrology Section, and the AMS Committee on Hydrology. Travel funds for the invited lecturers and funds for copying and distributing lecture notes were provided by the National Science Foundation under a joint grant from the Continental Hydrology Program in the Division of Earth Sciences and the Statistics and Probability and Applied Mathematics programs in the Division of Mathematical Sciences.—*Efi Foufoula-Georgiou, St. Anthony Falls Hydraulic Laboratory, University of Minnesota.*