Hydrology and Earth System Sciences Discussions

Interactive comment on "Extended power-law scaling of heavy-tailed random fields or processes" *by* A. Guadagnini et al.

Anonymous Referee #2

Received and published: 10 August 2012

General comments

The reviewed paper is aimed at the analysis of the scaling behavior of two log permeability data sets from pneumatic air injection tests, which were conducted (a) in six boreholes drilled in unsaturated fractured tuff at the University of Arizona Apache Leap Research Site (ALRS) near Superior, Arizona, and (b) along the two horizontal transects on the outcrop of lower shoreface bioturbated sandstone near Escalante, Utah. These two sites represent two different subsurface environments – unsaturated fractured tuff, and sediments that were impacted by depositional and biological processes.

The authors clearly demonstrated that the data sets from both sites showed heavy-tailed frequency distributions, which are consistent with sub-Gaussian random fields

subordinated to tfBm, as well as provided maximum likelihood estimates of parameters characterizing the corresponding Lévy stable subordinators and tfBm functions. The paper fully corresponds to the scope of HESS, and would be of interest to its readers involved in the statistical analysis of field permeability tests.

Specific comments:

The authors refer to "the heavy-tailed frequency distributions in three and two spatial dimensions," which were obtained at the two sites. It is the opinion of this reviewer that the notion of the three and two spatial dimensions is not clearly presented in the reviewed paper. It seems that the authors refer to different types of experiments at the field sites – 3D configuration of injection intervals in slanted and vertical boreholes at the ALRS, and the 2D transects at the Utah outcrop. It is apparent that the real air-flow dimensions resulting from pneumatic tests were not determined–it could be 2D, 3D, or fractional-dimension flow (e.g., Marechal et al., 2004, Chakrabarty, 1994; Chang et al., 2011).

The analysis of the air permeability tests from the ALRS continues a series of publications stemming from a series single-hole and cross-hole pneumatic injection tests, which were conducted the ALRS. On Page 11, the authors indicate that their analysis is based on the log k values obtained by Guzman et al. (1996) from steady-state interpretation of 184 pneumatic injection tests in 1-m long intervals along 6 boreholes. However, Neuman et al. (2001) indicated that over 270 single-hole tests were conducted in 6 vertical and inclined boreholes at the site by Guzman et al. (1996). Did the authors of the reviewed paper use a subset of tests conducted Guzman et al. (1996)?

Neuman et al. (2001) showed that at the ALRS the air permeability values represented directional values. They also showed that k derived from cross-hole tests were much higher than those from the smaller-scale single-hole tests. In other papers, a pronounced k scale effect was determined from single- and cross-borehole pneumatic injection tests (for example, Illman and Neuman, 2001, 2003; Vesselinov et al., 2001;

Neuman and Di Federico, 2003). Illman (2004) suggested that air permeability tests in single boreholes with limited fracture connectivity near the injection interval exhibited 2D flow, while cross-hole tests involved 3D air flow within a highly connective fracture network.

For the Utah outcrop test, the authors analyzed permeability measurements, which were taken from the two lower transects, and found (Page 14) that the data collected along the vertical profiles were poorly suited for an analysis of vertical log permeability scaling. It would be useful for a reader to explain why the conclusions of the reviewed paper cannot be used for vertical direction at this site. Note that in their paper, Castle et al. (2004) indicated that fractal-based statistical analysis of the horizontal log k increments yielded nearly identical results for both the bioturbated facies and the cross-bedded facies, possibly suggesting an underlying statistical commonality in the formation of both facies. Also, Castle et al. (2010) analyzed the data from the lower portions of the vertical wells in association with the data from the horizontal transects, but the authors of the reviewed paper did not use these data. On Page 14 of the reviewed paper, the authors referred to the total number of measurements (515) collected along the vertical and horizontal cross-sections, while they analyzed only the data along two horizontal transects. In the list of References (Page 19, lines 368-370), the authors give the title of the paper by Castle et al. (2004) "Sedimentology and facies-dependent permeability,..." It was the working title of the paper, and then it was published under the title "Sedimentology and fractal-based analysis of permeability data,..." in the Journal – see the citation below.

In their explanation of the ESS expression (3), the authors refer to the classical case of turbulent velocities with the reference to Chakraborty et al. (2010). It seems it would be important to explain for the readers what is common between turbulent velocities and air permeability tests in fractured rock and sediments.

The paper is entitled, "EXTENDED POWER-LAW SCALING OF HEAVY-TAILED RANDOM FIELDS OR PROCESSES." It is the opinion of this review that this title is too

general, and it should be designed to let readers anticipate the content of the paper, which is specifically focused on the analysis of the scaling behavior of air permeability in fractured rock and sediments. For example, "Extended power-law scaling of heavy-tailed random fields of air permeability in fractured porous media."

Comments to the figure captions: Fig. 1 – cite the reference to the plot. Fig. 8. The caption indicates that the figure is modified after Castle et al. (2004). I compared Fig. 8 with the original figure in the paper by Castle et al. and did not see any modification, except a different font of labels. What is modified?

Comment to Fig. 7: Would it be useful to find an analytical expression to describe the computed values given by squares?

References: Castle, J.W., F.J. Molz, S.Lu, and C.L. Dinwiddie, Sedimentology and fractal-based analysis of permeability data, John Henry Member, Straight Cliffs Formation (Upper Cretaceous), Utah, U.S.A., Journal of Sedimentary Research, 74(2):270-284, 2004.

Chang, Y.-C., H.-D. Yeh, K.-F. Liang, and M.-C. T. Kuo, Scale dependency of fractional flow dimension in a fractured formation, Hydrol. Earth Syst. Sci., 15, 2165–2178, 2011.

Chakrabarty, C., A note on fractional dimension analysis of constant rate interference tests, WRR 30(7), 2339, 1994.

Illman, W.A., Analysis of permeability scaling within single boreholes, Geophysical Review Letters, 31, L06503, 2004.

Illman, W. A., and S. P. Neuman. 2000. Type-Curve Interpretation of Multirate Single-Hole Pneumatic Injection Tests in Unsaturated Fractured Rock. Groundwater, v. 38, no. 6, p. 899 - 911.

Marechal, J. C. and B. Dewandel, K. Subrahmanyam, Use of hydraulic tests at different scales to characterize fracture network properties in the weathered-fractured layer of a hard rock aquifer, WRR, 40, W11508, doi:10.1029/2004WR003137, 2004.

Neuman, S.P., W.A. Illman, V.V. Vesselinov, D.L. Thompson, G.Chen, and A.Guzman, Lessons from Field Studies at the Apache Leap Research Site in Arizona, In "Conceptual Models of Flow and Transport in the Fractured Vadose Zone, âĂĺCommission on Geosciences, Environment and Resources (CGER), 2001.

Neuman, S.P., V. Di Federico, Multifaceted nature of hydrogeologic scaling and its interpretation, Reviews of Geophysics, 41, 1014, 2003.

Vesselinov, V., and S. P. Neuman. Numerical Inverse Interpretation of Single-Hole Pneumatic Tests in Unsaturated Fractured Tuff. Groundwater, 39 (5), 685 – 695, 2001.

Vesselinov, V.V., S.P. Neuman, and W.A. Illman, Three-dimensional numerical inversion of pneumatic cross-hole tests in unsaturated fractured tuff: 1.Methodology and borehole effects, Water Resour. Res., 37(12), 3001–3017, 2001.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 7379, 2012.

C3720