December 15, 2014

To: Jesus Carrera
Editor
Hydrology and Earth System Sciences

Re: Revised Manuscript "Hydrol. Earth Syst. Sci. Discuss., 11, C5366–C5371, 2014" - Authors' replies to Reviewer No. 3

Extreme Value Statistics of Scalable Data Exemplified by Neutron Porosities in Deep Boreholes

by A. Guadagnini, S.P. Neuman, T. Nan, M. Riva, and C.L. Winter

Dear Editor:

We appreciate the efforts you and the Reviewers have invested in our manuscript. Following is an itemized list of the comments of Reviewer No. 3 together with our response to these. Comments are reported in blue and our responses in black font.

Sincerely,

Alberto Guadagnini, Shlomo P. Neuman, Tongchao Nan, Monica Riva, and C. Larrabee Winter

Comments by Reviewer No. 3

The manuscripts reports on a statistical analysis of neutron porosity data using the framework developed by the authors. This framework models the porosity increments as the product of a truncated fractal Brownian motion with lag-dependent variance and a random variable, which here is modeled either by an alpha-stable or lognormal random variable. The variogram of the fractal Brownian motion is modeled as a truncated power variogram. Sections 3-5 are concerned with the estimation of the parameters of the increment models and the determination of sample structure functions. Sections 6 and 7 provide an analysis of the frequency distribution of peak over threshold of the porosity increments and their structure functions. The paper provides an interesting statistical analysis that sheds light on spatial porosity patterns, which may give insight into the spatial distribution of hydraulic conductivity.

We thank the Reviewer for his/her positive comments.

In order to improve the readability of the manuscript it may be useful to provide a glossary with the abbreviations used throughout the manuscript.

We will include a glossary with all abbreviations used in the manuscript to the extent that this is in line with HESS editorial standards.

p. 11639, lines 25-27: How fundamental is "fundamental importance"? The remark on "fundamental importance" to fluid flow and transport seems to be a bit overstated.

Spatial variability of porosity is known to control fluid flow velocity distribution in geologic media. As such, it has also an impact on the dynamics of solute concentrations. This is evidenced in several works, including recent studies by, e.g., Riva et al. (2008, 2010 and references therein), where it is clearly shown that taking into account random spatial variability of porosity allows capturing (in a Monte Carlo framework) the main features of solute breakthrough curves in field scale tracer tests. Documenting and interpreting the way statistics of porosity scale will hopefully lead to improved methods of generating random porous media to be employed in uncertainty assessment analyses. We will clarify our view in the revised manuscript and follow the Reviewer's suggestion to de-emphasize some sentences.

References

Riva M., A. Guadagnini, D. Fernandez-Garcia, X. Sanchez-Vila, T. Ptak (2008), Relative importance of geostatistical and transport models in describing heavily tailed breakthrough curves at the Lauswiesen site, *J. Contam. Hydrol*, 101, 1-13, doi:10.1016/j.jconhyd.2008.07.004.

Riva M., L. Guadagnini, A. Guadagnini (2010), Effect of uncertainty of lithofacies, conductivity an porosity distributions on stochastic interpretations of a field scale tracer test, *Stochastic Environmental Research and Risk Assessment*, 24, 955-970, doi:10.1007/s00477-010-0399-7.

p. 11648, lines 20-22: Could the authors be more specific on who is subordinated here to who? Or in other words, which process is the subordinated and which is the subordinator?

The subordinator is $W^{1/2}$ and the subordinated process is tfBM. We will clarify this point in the revised manuscript.

p. 11644, line 21: The scale parameter sigma is a function of the stability parameter. Thus, the estimates for sigma should coincide with sigma(alpha). Have the authors tested this property?

The Reviewer is referring to Appendix A, where we define the scale parameter σ_S of the subordinator as a function of the stability index, α, of the porosity increments. The scale parameter of the porosity increments, which we term σ, is independent from α, as we clarify in the body of the text.

p. 11645, lines 21-23 and p. 11654, lines 5-10: This is indeed an interesting observation. Do the authors have an explanation for this observation? Also, what specific surface area do the authors refer to here specifically?

The specific surface area (SSA) is the interfacial area between pores and solid matrix per unit volume. Siena et al (2014) analyzed sample structure functions of specific surface area, porosity and pore-scale Lagrangian velocities in two different rock samples, Bentheimer sandstone and Estaillades limestone, which were digitally imaged at the micron resolution scale for a total size of 1 to 3 mm. These authors noticed that a single power-law scaling regime is observed for porosity and SSA of the Bentheimer sandstone sample. Otherwise, two distinct power-law trends are identified in the Estaillades limestone sample. The authors interpreted these two diverse power-law regimes as being related to two overlapping spatially correlated structures. In their case, the emergence of an additional correlation structure is likely to be associated with microporosity in the pore structure and affects the behavior of sample structure functions at small lags.

In our analysis we observe two power-law scalings that we interpret to represent variability within and across sedimentary layers.

p. 11646. line 16 and p. 11654, lines 23-24: What do porosity increments have to do with the Burger's equation for fluid turbulence?

The reviewer is correct in observing that porosity increments and the Burger's equation have nothing in common, from a physical point of view. In the manuscript we quote the work of Chakraborty et al. (2010) because, in spite of several attempts to explain the success of ESS in extending power-law scaling regime to all lags, in the past only Chakraborty et al. (2010) provide a theoretical reason for this in the special context of the one-dimensional Burger's equation. In Siena et al. (2012) and Neuman et al. (2013) we explained why and how our theory provides a theoretical basis for ESS.

p. 11653, lines 11-13: The authors stress the generality of their results and the statistical representation of increments of natural processes. It would be interesting if the authors could discuss why the proposed increment process is a good representation of a variety of spatial and temporal processes.

Statistical scaling behaviors of the type we observe and interpret in this work are known to be exhibited by a wide variety of earth, environmental and other variables (including ecological, biological, physical, astrophysical and financial). These variables exhibit (a) persistence (tendency for large and small values to alternate mildly) or antipersistence (tendency for large and small values to alternate rapidly); (b) symmetric, non-Gaussian frequency distributions characterized by heavy tails that often decay with separation distance or lag; (c) nonlinear power-law scaling of sample structure functions (statistical moments of absolute increments) with lag in a midrange of lags, with breakdown in such scaling at small and large lags; (d) extended power-law scaling (linear relations between log structure functions of successive orders) at all lags; and (e) nonlinear scaling of power-law exponent with order of sample structure function. We will include appropriate references to these findings in the revised manuscript.