Geophysical Research Abstracts, Vol. 8, 03627, 2006
SRef-ID: 1607-7962/gra/EGU06-A-03627

Ergodicity in the large sense and stochastic modeling of transport in heterogeneous aquifers

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Ergodicity in the strict sense is a property of measurable dynamical systems which allows equating time averages with averages over the space of states. The ergodicity concept, its extensions to stationary stochastic processes or to statistically homogeneous random space functions, as well as the self-averaging property of transport in random environments, share a similar physical meaning: the fact that at large times (distances) the system explores all its possible states, so that its evolution can be described by averages over ensembles of identical systems. In hydrogeological literature, "ergodicity" has different meanings, which in general do not match the ergodic properties above and, in most cases, refer to the ability of the stochastic model to describe the transport in actual aquifer systems. We propose a unifying view on previous approaches to the issue of ergodicity in stochastic modeling of transport in heterogeneous systems, based on a concept of ergodicity in the large sense. This is done by the definition of "ergodicity within a range of uncertainty", which quantifies the mean square deviation of a given observable from the solution of the stochastic model. The ergodicity range can be estimated from the deviation of the mean value of the observable and from its standard deviation. When the observable is the actual concentration, this definition, applied for an arbitrary small range, corresponds to the asymptotic ergodicity of the transport process. This strong property is equivalent to the existence of an up-scaled "macrodispersion" solution for the ensemble averaged concentration and a self-averaging property, namely the convergence of the actual concentrations to their ensemble average. Using ensembles of global random walk numerical simulations, we investigate ergodicity in the large sense of the advection-dispersion process

in heterogeneous aquifers. The analysis of the numerical results indicates that the purely advective transport is not ergodic, which is in agreement with a known result concerning the non-ergodicity of the dynamical system generated by Darcy flow. A numerical evidence is supplied that, in the presence of a local dispersion mechanism, the transport in groundwater flows modeled by random fields with finite correlation lengths behaves asymptotically ergodic.