H62E MCC: Hall C Saturday 1330h

Twenty-Two Years of Stochastic Groundwater Hydrology II Posters

Presiding: **V Tidwell,** Sandia National Laboratories**; R Holt,** University of Mississippi

H62E-0897 1330h POSTER

Testing a Gaussian assumption on the stochastic Buckley–Leverett equation

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We analyze a multivariate Gaussian assumption for transformations of saturation and flux using Monte Carlo simulations of the stochastic Buckley–Leverett equation. The Gaussian assumption is of interest both for closure of moment equations and for estimating the size of third- and higher-order moments, and is commonly invoked in stochastic subsurface models. Random permeability fields are generated from a multivariate log-Gaussian distribution using a Fast Fourier Transform method. Flux and saturation fields are numerically solved on a simplified 2-D domain. Using chi-square tests we find that a Gaussian approximation is inappropriate for transformations of saturation. We suggest a mixture model for distribution of saturation near a saturation front.

H62E-0898 1330h POSTER

Gaussian finite element closure of steady state unsaturated flow in randomly heterogeneous soils

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We present a new method for the solution of stochastic unsaturated flow problems in randomly heterogeneous soils, which avoids linearizing the governing flow equations or the soil constitutive relations, and places no theoretical limit on the variance of constitutive parameters. The method applies in principle to a broad class of soils with unsaturated properties that scale according to a linearly separable model, provided that pressure head has a near-Gaussian distribution. We apply the method to soils whose relative hydraulic conductivity varies exponentially with pressure head. The flow domain is a checkerboard of uniform subdomains within each of which the soil hydraulic properties are random constants. Across the flow domain, these properties are spatially auto- and cross-correlated. Flow is described by means of finite element equations with spatially-correlated random coefficients. Averaging the finite element equations in probability space, while treating dimensionless pressure head as a multivariate Gaussian function, yields a system of partially coupled nonlinear algebraic equations that can be solved numerically for the ensemble mean, variance and covariance of pressure head across the domain. We do so for two-dimensional flow in a bounded vertical domain under coupled mean uniform and convergent flows, and compare the results with those of standard Monte Carlo simulations.

H62E-0899 1330h POSTER

Inverse Modeling of Spatial Correlation of Permeability in Sediments with Hierarchical Organization

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The spatial covariance of ln(K) can be modeled with a hierarchical organization that corresponds to the organization of bedding within cross-bedded sediments. Such a model accounts for the spatial correlation of ln(K) within and across bedding units defined at one level. This is related to correlation of ln(K) at a higher level (larger scale) through the spatial correlation of indicator variables representing the proportions, geometry and juxtaposition patterns of the units at the lower level. In this paper the fitting of the components of the hierarchical model, written as nested functions, is considered in developing a hierarchical covariance model for use in estimation, simulation, or analytical derivation of macrodispersivity models. The components include the auto- and cross-correlation functions for both permeability and the indicator variables. The least square criteria, along with parameter prior information and other weighted constraints, are used as the objective functions of the inverse problem, which is solved by the Gauss-Newton-Levenverg-Marquart method. The method is tested on synthetic data and illustrated with real data from the Hamilton site, Ohio, with glaciofluvial sand and gravel deposits. The final global semivariogram and covariance obtained from model fitting produce good fits to the sample ones. The model results have also been used to examine alternative assumptions about correlation between facies, specifically the relative importance of auto- and cross-covariances. For the model semivariogram the variograms across facies are striking and cannot be ignored. For model covariance, the covariances across facies are indistinctive and the auto-covariances dominate over the cross-covariance.

H62E-0900 1330h POSTER

Effect of Construction Water on Chlorine-36 Studies at the Exploratory Studies Facility at Yucca Mountain, Nevada: Model Development and Uncertainty Analysis

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Chlorine-36 from nuclear tests in the 1950s and 1960s has been used to identify fast flow paths along fault and fracture zones at Yucca Mountain, the proposed U.S. repository for high-level nuclear waste. During the excavation for the Exploratory Studies Facility (ESF) at Yucca Mountain, construction water traced with lithium bromide was used as circulation fluid. After construction, rock samples taken along the wall were leached and found permeated to varying degrees by this circulation fluid. Fabryka-Martin et al. (1998) corrected bomb-pulse signal ^{36}Cl/Cl ratio through determinaion of the amount of chlorine contributed from the circulation fluid through a linear two-member mixing model of the Br/Cl ratio. However, this effort to quantify the presence of construction water is complicated by the presence of chemical heterogeneity in pore waters of rock samples, as well as by variability in Cl^- and Br^- concentration in the circulation fluid. Thus, the effect of this circulation fluid on samples is inherently associated with great uncertainty. In this work, we first develop a mixing model that accounts for the amounts of circulation fluid, Br^-, and Cl^- carried by the construction fluid. Then we quantify the chemical uncertainty of matrix pore water and circulation fluid and estimate the impact of this uncertainty on bomb-pulse signal ^{36}Cl/Cl.

H62E-0901 1330h POSTER

Eulerian Spatial Moments for Solute Transport in Three-dimensional Heterogeneous, Dual-permeability Media

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A Eulerian analytical method is developed for nonreactive solute transport in heterogeneous, dual-permeability media where the hydraulic conductivities in fracture and matrix domains are both assumed to be stochastic processes. The analytical solution for the mean concentration is given explicitly in Fourier and Laplace transforms. Instead of using the Fast Fourier Transform method to numerically invert the solution to real space, we apply the general relationship between spatial moments and concentration to obtain the analytical solutions for the spatial moments up to the second for a pulse input of the solute. Owing to its accuracy and efficiency, the analytical method can be used to check the semi-analytical and Monte Carlo numerical methods before they are applied to more complicated studies. The analytical method can be also used during screening studies to identify the most significant transport parameters for further analysis.

In this study, the analytical results have been compared with those obtained from the semi-analytical method and the comparison shows that the semi-analytical method is robust. It is clearly shown from the analytical solution that the three factors, local dispersion, conductivity variation in each domain and velocity convection flow difference in the two domains, play different roles on the solute plume spreading in longitudinal and transverse directions. The calculation results also indicate that when the log-conductivity variance in fractures is 10 times larger than its counterpart in matrix, it will hardly influence the solute transport, whether the conductivity field is matrix is treated as a homogeneous or random field.

H62F MCC: 103 Saturday 1330h

State-of-the-Art in Ecohydrology II

(joint with B, GC)

Presiding: **D Mackay,** University of Wisconsin**; C Luce,** USDA Forest Service

H62F-01 1330h INVITED

Darwinian Expression of Vegetation Form and Function

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The vertical fluxes of light and momentum in vegetation canopies are idealized to demonstrate that maximum absorption of solar energy occurs when the absorption coefficients of light and of horizontal momentum are equal. This reveals the structural conditions producing maximum nitrient flux in cylindrical crowns, and allows direct comparison of carbon demand by and atmospheric carbon supply to the canopy.

Stomatal response to light and to available water are idealized and a preferred state of zero leaf stress is assumed. Scaled to the full canopy these lead to the two dimensions of a feasible habitat space for a given C_3 plant species at the stable limit of which are the maximally-productive "climax" canopies.

Maximum net primary productivity is expressed as separate functions of both light-stimulated carbon demand and turbulence-diffused atmospheric carbon supply which are compared. Productivity is shown to have a broad global maximum containing those species that are not seriously water-limited or carbon-limited, thereby supporting the underlying assumption that nature selects for maximum productivity.

H62F-02 1425h INVITED

Hydrologic and Vegetation Changes in the Northwestern U.S. and Their Role in Shaping Past and Future Fire Regimes

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Fire is an important element of disturbance regimes that both responds to and shapes ecological and hydrological processes. The co-occurrence of high fuel accumulation, low fuel moisture, and fire-conducive weather patterns in recent years has given rise to large fires in the western U.S. The size and severity of these conflagrations have prompted a national debate over the causes and proper response to wildland fires. Examination of modern climate data during high-fire years reveals the importance of regional- and synoptic-scale climate anomalies that occur over months and seasons

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for determining the severity of a fire year. These seasonal anomalies are in turn embedded in longer-term climate variations that occur on decadal, centennial, and millennial time scales. In the western U.S., these long-term variations influence the strength, intensity, and location of precipitation regimes that shape regional differences in moisture availability and consequently vegetation and fire regimes.

Holocene fire-climate-vegetation interactions are reconstructed from an analysis of charcoal, pollen, and other fire proxies at several sites in the northwestern U.S. In the Pacific Northwest and summer-dry regions of the northern Rockies, highest fire activity is registered in the early Holocene with the expansion of the northeast Pacific subtropical high. In summer-wet areas of the northern Rockies, fires were most frequent in the last 7000 years when onshore flow of moisture in summer was reduced from an early-Holocene maximum. Superimposed on these trends are centennial variations in climate, most notably the Medieval Warm Period, when drought and fire are recorded in all regions. Simulations of potential future climate and vegetation suggest that future fire conditions in some parts of the northwestern U.S. will likely be more severe than they are today. Examination of the effects of greater-than-present summer drought in the past helps assess the possible nature of fire-hydrology-vegetation interactions in the future.

URL: http://geography.uoregon.edu/envchange

H62F-03 1445h

On the Links Between Photosynthesis and Soil Water Balance

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The equations of soil moisture dynamics and a model of leaf gas exchange and water transport through the Soil-Plant-Atmosphere Continuum (SPAC) are coupled to explore the dependence of plant CO_2 assimilation on soil moisture. The model is also coupled with a daily growing boundary layer model, that gives the values of air specific humidity and potential temperature during the day.

Two different approaches for modeling stomatal conductance g_s are implemented and compared. One is the mixed-empirical formulation of stomatal conductance used by Jarvis (1976), who assumed a multiplicative relationship among the main environmental factors affecting stomatal movement; the other one is the empirical relationship between stomatal conductance and assimilation introduced by Ball et al. (1987) and modified by Leuning (1990, 1995), that assume a direct dependence of stomatal movement on the assimilation rate. This second approach is extended to include drought conditions and the common bases underlying the two approaches are elucidated.

The model also gives the soil moisture value below which plants are under stress and the moisture content at the wilting point. These are used to evaluate the probability distribution of soil moisture, carbon assimilation by photosynthesis and plant water stress, thus providing a more physical basis to a previous stochastic model of soil moisture by the authors.

H62F-04 1505h INVITED

On The Temporal Dynamics Of Coupled Water And Carbon Exchange: Implications For Predictions Over Meteorological And Climate Time Scales.

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Short term water and carbon exchanges between vegetation and the atmosphere are strongly coupled through the stomatal function of plants. These high-frequency exchange rates are modulated by the lower-frequency variability in vegetation cover, as it responds to changes in forcing, such as water availability, across a range of time scales. Furthermore, the relative fractions of the dominant plant functional groups on the landscape possess different sensitivities and strategies (i.e. niches) with respect to environmental variables. An example of this is the classical difference in rooting depth (reservoir size) and wilting points of herbaceous and woody vegetation. Therefore, low frequency changes in the vegetation structure have clear mechanistic impacts on the functional behavior of the landscape in the context of water and carbon cycling. In this talk we highlight the interplay between functional dynamics and structural dynamics, with a focus on water and carbon exchange in a semi-arid context. We explore field data and remotely sensed data collected along the Kalahari Transect in southern Africa to gain insights into the processes and there effects on diurnal, inter-storm, seasonal, and inter-annual time scales. In particular, we highlight the hydrological implications of the contrasting frequency response of grasses and woody vegetation in water-limited systems.

H62F-05 1545h INVITED

Hydro-Geomorphic Variability as an Ecological Template for Aquatic and Riparian Ecosystems

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Hydro-geomorphic processes act as ecological disturbances that shape ecosystem characteristics and dynamics and play key roles in creating, modifying, and destroying aquatic habitat. Within the broad regional context set by general patterns of climate, geology, topography, and vegetation, the combined influences of the hydrologic, geomorphic, and vegetation regimes dominate the variability of river systems. Of particular relevance to aquatic and riparian ecosystems are the main processes that transport and store water, sediment, and wood, and how differences in current and potential conditions are related to both local conditions and basin-wide tends. The concept of process domains, distinct areas of a landscape that correspond to different disturbance regimes, provides a framework for integrating the inherent interplay of spatial and temporal variability in channel processes. The intensity of the impact, the size of the area affected, and the frequency of occurrence together define the disturbance regime associated with particular hydro-geomorphic processes. The disturbance regime sets the physical habitat template that influences potentially successful behavioral and life-history strategies of stream dwelling organisms. The distribution of some organisms is strongly associated with different process domains, whereas that of habitat generalists are not. Three general principles apply to the use of hydro-geomorphic variability as an ecological template for aquatic and riparian ecosystems. (1) What constitutes a disturbance is species specific and will vary according to the system or community under consideration and focusing on needs of a single target species and life stage can unintentionally degrade the system for other species or life stages. For example, river restoration efforts focused on spawning reaches and water levels for chinook salmon may ignore or exacerbate the loss of off-channel habitat such as side channels, groundwater-fed floodplain channels, and ponds, needed by juvenile coho salmon. (2) Connections between hydro-geomorphic processes and ecological systems can be complex. Development of old-growth forests on dynamic, disturbance-prone valley bottoms of the Olympic Peninsula provides an exceptional example of the potential for complex feedback to control self-organization of aquatic and riparian ecosystems. (3) In general, native species are adapted to the natural disturbance regime of an area, which therefore provides a natural guide for environmental management. Environmental considerations in setting instream flows in managed or regulated rivers have focused on setting the minimum flows needed to provide habitat characterized in terms of flow depth or velocity for organisms of interest or concern, usually fishes. Such approaches determine flows needed to maintain the use of habitats but not the habitat themselves, as higher flows are generally required to form and maintain habitat.

H62F-06 1605h INVITED

Integration of Science on Biological and Physical Processes to Understand Ecological Diversity of Stream Fishes

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The integration of biological and physical sciences has been important in efforts to understand and conserve aquatic species such as the stream fishes found in the Pacific Northwest. Traditionally that integration has focused at relatively fine scales and on what were perceived as more or less static conditions of stream habitats to explain the abundance and distribution of select species. Scientists and managers were intent on defining and creating optimal conditions to maximize the abundance of those species. There is growing recognition that habitats are dynamic and that populations of many species may be structured by biological and physical processes operating over much larger spatial and temporal scales. Natural disturbance, hydrology, and geomorphic constraints lead to variation in the distribution, size, and productivity of habitats for different species through time and space. That variation could influence the distribution and persistence of populations and the diversity that is expressed within and among those populations. It may even be critical to long-term evolutionary potential. Metapopulation theory, for example, suggests the geometry and interconnection of habitats will be key to the occurrence and persistence of many populations. Recent work with bull trout and Lahontan cutthroat trout support those predictions and demonstrate that the large-scale geometry of habitat networks is essentially defined by the variation in stream topology and temperature. Life history diversity and phenotypic plasticity are thought to be mechanisms that allow species populations to adapt to, fully exploit, and persist in variable and changing environments. The expression of that diversity may depend on historical patterns of disturbance and the interconnection and diversity of environments that are currently available. Conservation of aquatic biological diversity will depend on our understanding of the processes that generate that diversity. The application of new tools in biology such as molecular genetics and otolith chemistry promise new advances, but the integration with research on the physical processes structuring stream environments will be key as well.

URL: http://www.fs.fed.us/rm/boise

H62F-07 1625h INVITED

Runoff from Semiarid Landscapes: a Key Ecological Process

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The redistribution of water via surface runoff is a fundamental, yet poorly understood ecological as well as hydrological process in semiarid landscapes. For example, the concentration of water by surface runoff in selected landscape locations plays a key role in determining vegetation productivity, patterns and composition. This redistribution of water, although poorly documented likely occurs on the patch, hillslope and landscape scales. Landscape ecologists have argued that when vegetation patterns are disrupted or disturbed, there is less opportunity for runoff to be stored locally and there is a net loss of water. There is the implication then, that disturbance may modify scale relationships of runoff in semiarid landscapes. In Northern New Mexico, we have been monitoring runoff at multiple scales within two pion-juniper hillslope at multiple scales. One of the sites is relatively stable with moderate vegetation cover. The other site has little herbaceous cover and is eroding at high rates. Data collected from these sites since 1993 indicate that scale relationships of runoff are fundamentally different at the two sites with runoff per unit area dramatically decreasing at the stable site (because of hillslope storage). At the disturbed site there is a much smaller decrease in unit area runoff as scale of measurement increases.

H62F-08 1645h

Towards a Scale Invariant Evapotranspiration Equation Using Real-Space Renormalization

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Compelling evidence from studies of drainage density supports the hypothesis that terrain and vegetation are coupled via water and energy fluxes across a broad range of spatial scales. The slope of a classic power law relation between drainage density and water availability reverses sign and changes value where basin-integrated long-term precipitation (P) equals long-term potential evapotranspiration (PET). The change of slope indicates a 'phase transition' from water- to energy-limited vegetation. Milne et al. (2002) defined two dimensionless parameters that describe excess available energy for photosynthesis and soil evap-

oration, and surplus liquid water for terrain formation. Specification of the conditions under which neither parameter changed with spatial scale enabled the derivation of an equation for long-term actual evapotranspiration (AET), $AET/P = a/(b + (P/PET))$, at scales between 2-256 km for the Columbia River Basin in the northwestern US. Here, a and b are two empirical parameters with potential hydro-ecological significance. The relationship contains a fundamental dimensionless parameter, P/PET, for hydro-ecologic and eco-hydrologic studies. This parameter was extensively used by Budyko amongst others in their eco-hydrologic investigations. This equation is similar to an equation for AET obtained by Choudhury (1999), which is given by, $(AET/P)^{\alpha} = 1/(1+(P/PET)^{\alpha})$. It predicts long-term AET at plot scales of the order of 1 sq. km for $\alpha = 2.6$, and for large drainage basins of the order of million sq. km. for $\alpha = 1.8$. Therefore, Choudhury's equation is not scale invariant. A key open problem is to investigate if these two equations can be reconciled in a scale invariant manner. This work represents first steps towards the articulation of a biophysically sound theory about coupled ecology, hydrology, geomorphology and climate of landscapes that respects a conservation law and scale invariance.

H62G MCC: 120 Saturday 1330h

Fundamental Advances in Understanding of Pore-Scale Transport Phenomena in Porous Medium Systems I

Presiding: **M Hilpert,** Johns Hopkins University**; D Zhang,** Los Alamos National Laboratory

H62G-01 1330h

Measurement of Interfacial Area per Volume on Spatially Correlated and Uncorrelated Micro-models

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Recent theoretical developments suggest that interfacial area per volume (IAV) plays an important role in scaling theories for the flow of multiple fluid phases in a porous medium. Many investigations have shown that the values of capillary pressure (Pcap) and saturation (S) do not uniquely specify the state of the system. A single value of relative volume saturation can correspond to infinitely different distributions of two phases within the volume. IAV provides a natural yard-stick for defining the role of scale in multiphase fluid properties. The dimensional units of interfacial area per volume is a spatial frequency (inverse length) that breaks scale invariance. In this study, we investigate whether or not IAV provides a state-function-like description of the flow properties, and if so, what does this function look like.

Measurements of interfacial area per volume as a function of capillary pressure and saturation were made on micro-models of pore structures. Photo-projection lithography was used to make transparent micro-models that were 600 x 600 microns with an aperture of 1.08 microns. Two phase flow measurements were performed on the micro-models using nitrogen gas and decane for a series of drainage and imbibition cycles. The initially decane-saturated micro-models were invaded with nitrogen by the application of pressure in increments. At each pressure increment, the system was allowed to equilibrate, and the saturation and distribution of each phase was digitally imaged and analyzed.

We observed that the Pcap - S - IAV surface appears to be a smooth, single valued surface. Several measurements were made for the same, or nearly the same, values of Pcap and S, and it was observed that the geometrical arrangement of the two phases was visually quite different. However, the value of the IAV in such cases was the same, to within a typical 5% experimental error in analyzing the digital photo-micrographs. We also observed that the magnitude of IAV was significantly different between the two types of models. Correlated micro-models exhibited values of IAV that were smaller by about a factor of 2, than that found for the uncorrelated micro-model.

Acknowledgments: DOE-FE contract DE-AC26-99BC15207. LJPN wishes to acknowledge Purdue University Faculty Scholar.

H62G-02 1345h

The Impact of Network Structure on Pore-scale Simulation of Fluid Transport

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Network modeling techniques for subsurface transport continue to incorporate more detailed physics. Therefore, it is important for networks to reflect the true porous media structure with an appropriate level of detail. Of particular interest, is whether three-dimensional networks created from different algorithms lead to different simulated transport behavior.

In previous work, several methods were used to extract pore networks from well-defined porous media: a medial-axis-based approach (at different resolutions), a Delaunay-tessellation algorithm, and a modified-Delaunay-tessellation algorithm. While these algorithms produce statistically similar networks for a given medium, there are pore-scale differences.

In the current study, we evaluate the impact of network structure on certain transport phenomena. Quasistatic drainage and imbibition simulations were performed on simulated and real systems to obtain capillary pressure versus saturation curves. Significant differences in results are attributed to factors such as variation in local coordination number, errors in determining local pore-body and pore-throat size, and lack of uniqueness in pore location. We tie these morphologic differences to pixelization of the medium, resolution of the digital image, and logic incorporated in the network algorithms. The results provide important information regarding the use of high-resolution tomography to generate network structures.

H62G-03 1400h

Accurate and Efficient Implementation of Pore-Morphology-Based Modeling of Drainage in Totally Wetting Porous Media

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We present a more efficient and accurate numerical implementation of the pore-morphological approach for modeling drainage in totally wetting porous media that was recently developed by Hilpert and Miller. The new approach uses level-sets to represent the phase distribution instead of voxels arranged on a cubic lattice.

H62G-04 1415h

Fluid Interfaces at the Pore-Scale: Trying to Make Observations and Lattice-Boltzmann Simulations Meet

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Recent advances in microtomographic imaging techniques have allowed unprecedented observations of fluid behavior and interfacial geometries at micron sized scales. At the same time, significant progress in the development of numerical models for simulating fluid mechanics allow us to compare observations and model results, potentially providing insight into the scales at which macroscopic properties emerge. One of the promising modeling techniques is the Lattice Boltzmann method that offers a relatively simple means to approximate micro-scale Navier-Stokes flow as well as fluid-fluid and fluid-solid interactions. In this presentation we compare observations of micro-scale fluid saturations and interfacial geometries with simulations of a 3D two-phase Lattice Boltzmann model. The data used in this multidisciplinary study consist of three-dimensional pore-scale images of (air-water) drainage and imbibition experiments in a glass bead porous medium. The images were obtained using the GSE-CARS microtomography beamline at the Advanced Photon Source (Argonne National Laboratory) and form a cube with approximately 300 voxels on each side with a resolution of 17 microns per voxel. The Lattice Boltzmann simulations were carried out in micro porous geometries derived from dry images using high-performance parallel computer hardware at the Danish Technical University. Besides assessing difficulties and potential pitfalls that are inherent to the Lattice Boltzmann Method, we also explore discretization effects on simulated flow and interfacial geometries.

H62G-05 1430h

Determination of capillary pressure-saturation relation by pore-morphology-based and lattice-Boltzmann simulation

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In this study we present two different models for the determination of the capillary pressure-saturation relation in porous media.

The first one is a pore-morphology-based model where we use methods from morphological image analysis to calculate the quasi-static primary drainage curve. Compared to previous publications in this field (Hilpert and Miller 2001), we extended the method to model trapped or irreducible wetting phase (WP). Additionally, we could optimize it in a way that the computing time is significantly reduced.

The second method to determine the capillary pressure-saturation relation is a two-phase lattice-Boltzmann (LB) model. Using a recently developed model for multi-phase flow (Tölke et al. 2001) we simulated the drainage of the porous medium by several pressure steps starting at total saturation.

As test systems, we used generated randomly sphere packages and x-ray images of a sintered borosilicate glass. Our simulations show that the capillary pressure-saturation curves from the both methods are very similar. However the morphological model is orders of magnitude faster than the LB simulation. But we point out that the good agreement strongly depends on the geometry of the investigated porous medium. Due to the model formulation, the pore-morphology-based simulation cannot be applied if the pore structure is strongly anisotropic (e. g. cracks).

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H62G-06 1445h

The Sound of Pore Filling

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