Center for Fluid Mechanics, Division of Applied Mathematics
Fluids, Thermal and Chemical Processes Group, School of Engineering
Joint Seminar Series

TUESDAY – SEPTEMBER 25, 2012
3:00pm
Barus & Holley, Room 190

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Large Rayleigh-Number Porous Medium Convection: Transport, Scale Selection and Asymptotic Structure

Buoyancy-driven convection in fluid-saturated porous media is a key environmental and technological process, with applications ranging from CO2 storage in terrestrial aquifers to the design of compact heat exchangers. Moreover, as a paradigm for forced--dissipative infinite-dimensional nonlinear dynamical systems, porous medium convection exhibits a hierarchy of instabilities, bifurcations, and patterns, culminating in spatiotemporally chaotic dynamics, if not "true'' turbulence. In this talk, the dependence of the convective transport (as measured by the Nusselt number, Nu) on the mean inter-plume spacing (L) in the large forcing (i.e. large Rayleigh number, Ra) limit will be discussed. A complement of direct numerical simulations (DNS) and, especially, asymptotic theory and rigorous upper bound analysis is used to determine Nu=Nu (Ra,L). Matched asymptotic analysis of steady (unstable) convective states reveals an intricate nested boundary-layer (BL) structure with an exceedingly simple; single (horizontal) Fourier-mode solution within the interior. Remarkably, recent DNS confirm that this simple core flow structure is also realized in time-dependent porous medium convection at asymptotically large values of Ra; the bulk of the spatiotemporal complexity is confined to -- and the convective transport ultimately determined by the dynamics of -- the BLs. An adaptation of a variational methodology for obtaining rigorous bounds on heat transport in convective flows is shown to yield quantitatively useful predictions of Nu and to furnish a functional basis that is naturally adapted to the BL dynamics at large Ra. This basis is used to construct, via Galerkin projection, novel, fully a-priori reduced dynamical models. Finally, prospects for developing hybrid models, that blend insights from both the asymptotic and upper bound analyses, will be discussed.