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Double-diffusive sedimentation

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Abstract

When a layer of particle-laden fresh water is placed above clear, saline water, both double-diffusive and Rayleigh–Taylor instabilities may arise. We explore the competition between these instabilities by means of two- and three-dimensional direct numerical simulations (DNS). The initial instability growth in the DNS is seen to be consistent with the dominant modes predicted by the linear stability analysis. The subsequent vigorous growth of individual fingers gives rise to a secondary instability, and eventually to the formation of intense plumes that become detached from the interfacial region, cf. figure 1. The simulations show that the presence of particles with a Stokes settling velocity modifies the traditional double-diffusive fingering by creating an unstable ‘nose region’ in the horizontally averaged profiles, located between the upward-moving salinity and the downward-moving sediment interface. The effective thickness l_s (l_c) of the salinity (sediment) interface grows diffusively, as does the height H of the nose region. The ratio H/l_s initially grows and then plateaus, at a value that is determined by the balance between the flux of sediment into the nose region from above, the double-diffusive/Rayleigh–Taylor flux out of the nose region below, and the rate of sediment accumulation within the nose region. For small values

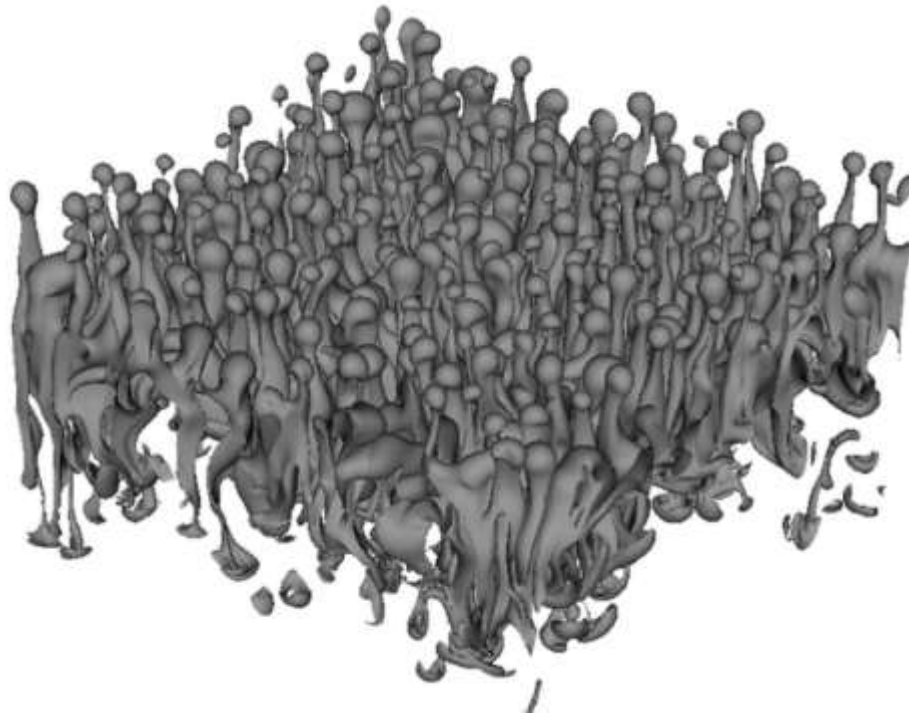


Figure 1: Contours of the sediment field showing upwards propagating fingers.

of $H/l_s < O(0.1)$, double-diffusive fingering dominates, while for larger values $H/l_s > O(0.1)$ the sediment and salinity interfaces become increasingly separated in space and the dominant instability mode becomes Rayleigh–Taylor like. A scaling analysis based on the results of a parametric study indicates that H/l_s is a linear function of a single dimensionless grouping that can be interpreted as the ratio of inflow and outflow of sediment into the nose region. The simulation results furthermore indicate that double-diffusive and Rayleigh–Taylor instability mechanisms cause the effective settling velocity of the sediment to scale with the overall buoyancy velocity of the system, which can be orders of magnitude larger than the Stokes settling velocity. While the power spectra of double-diffusive and Rayleigh–Taylor-dominated flows are qualitatively similar, the difference between flows dominated by fingering and leaking is clearly seen when analyzing the spectral phase shift. For leaking-dominated flows a phase-locking mechanism is observed, which intensifies with time. Hence, the leaking mode can be interpreted as a fingering mode which has become phase-locked due to large-scale overturning events in the nose region, as a result of a Rayleigh–Taylor instability.