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Mixing of effluent in tidal coastal waters

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Industrial effluent is commonly released into shallow coastal waters, where it is subsequently transported by tidal currents and dispersed by mixing with the ambient. The buoyancy of an effluent (either positive or negative) plays an important role in its interaction with the surrounding ocean, and leads to the formation of gravity currents, which flow along either the sea bed or surface, depending on the sign of the buoyancy. We present a theoretical study of such gravity currents, including the effects of mixing and/or a flowing ambient on the current dynamics, and find that inclusion of mixing in depth-integrated gravity current models (in particular, the dependence of such mixing, or entrainment, on the bulk Richardson number) results in fundamental changes to the long-time behaviour of currents. For example, the long-time behaviour of an instantaneous release of a fixed volume of dense effluent is similarity solution of the second kind, in which the gravity current spreads as a power of time that is dependent on the form of the entrainment model, approximately as $t^{0.44}$. A diverse range of flow regimes exist in which the effects of buoyancy-driven spreading, mixing and the ambient flow are more or less important, but we find that mixing generically plays an important role in gravity currents at late times.