The effects of rotation on gravity currents: from stable to unstable flow behavior

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Abstract

Gravity currents are flows driven by the density differences in geophysical or oceanographic environments. The density differences behind such flows sometimes arise from thermal variations or compositional differences between fluids. The notable examples are the unstable meanders of the Gulf Stream and of the Kuroshio. In those situations, the warm current interacts with the cold current forming an isolated circulation (or the gyre) due to the Earth's rotation as the geostrophic equilibrium is established. In this study a simplified numerical model is established to investigate the dynamic processes of rotating gravity currents from the stable behavior to the unstable one through high-resolution simulations. The growth of currents is competed by the balance of rotation and buoyancy effects. One non-dimensional parameter is governed the flow morphology, i.e. the ratio of rotating effects and inertia forces, which falls in the range of 0.2 to 1.0. It is shown that the rotation effects eventually become dominant. It was referenced in experimental findings that the formation of stable gravity currents once the critical parameter of governed factor is nearly 0.4. Once the parameter is larger than 0.4, the vortex reaches to a quasi-geostrophic equilibrium state rapidly and becomes unstable. In the stable process, when the denser fluid is released from the cylindrical lock region, the flow structures maintain nearly perfect axisymmetry. Afterwards, three-dimensionality of the flow quickly develops and the outer rim of the spreading denser fluid breaks away from the current body. The flows exhibit a complex contraction–relaxation motion and new outwardly propagating pulses form regularly in a period. After reaching the quasi-geostrophic equilibrium state, the unstable vortex-wandering motions occur. Subsequently, the current breaks up to multiple distinct circulations forming the vortex-splitting configurations with non-asymmetric bulges. The features of upwelling and downwelling motions are persistently observed within the unstable stage. Finally the energy budget information is provided.

Keywords: gravity currents, rotational effect, vortex-wandering, vortex-splitting