Turbulence in geophysical wakes: a parametric study

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Bluff geometries in the ocean and the atmosphere commonly trigger motions of multiple scales, spanning coherent wake eddies, internal waves, hydrodynamic instabilities, and turbulence. Especially about the latter, turbulence generation mechanisms and the interplay of stratification and rotation remain underexplored.

Large-eddy simulations are conducted for stratified rotating flows past a three-dimensional topography. Key parameters include freestream velocity U, buoyancy frequency N, Coriolis frequencies f, and topography base diameter D and height h. Four Froude numbers ($Fr = U/Nh = 0.075, 0.15, 0.30, 0.40$) representative of the flow-around vortex-shedding regime are studied. For each Fr, five Rossby numbers ($Ro = U/fD$) are selected, spanning mesoscale ($Ro = O(0.1)$) to small submesoscale ($Ro = O(5)$).

The parametric dependence of turbulent dissipation reveals intertwined roles of stratification and rotation. Wake turbulence arises from two distinct instabilities: vertical shear-driven Kelvin–Helmholtz instability (KHI) and rotation-induced centrifugal/inertial instability (CI). These two instabilities are mutually modulated by stratification and rotation – strong rotation dampens vertical shear, weakening KHI-driven turbulence, whereas strong stratification constrains vertical length scales, limiting CI-driven turbulence. Rotation plays regime-dependent dual roles. Under moderately strong stratification ($Fr = 0.30, 0.40$), rotation is destabilizing through the CI, leading to peak dissipation at submesoscale Rossby numbers ($Ro = O(0.5)$). Under strong stratification ($Fr = 0.075, 0.15$), the CI is suppressed and rotation acts as a stabilizing factor.

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