Influence of rotation on the vortex dynamics in stratified flow past an underwater hill

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Oceanic mixing at bottom topography in the deep ocean crucially impacts the interior ocean state. Underwater hills are stirring rods that trigger strong vortical motions, intensify turbulence, and hence significantly modify the bottom boundary mixing.

In this study, we conduct large eddy simulations of an idealized physical model: flow past a conical hill submerged in a rotating, stratified fluid. The Reynolds number is set to $Re = UD/\nu = 25\,000$ and the Froude number is $Fr = U/Nh = 0.15$, where D is the base diameter and h is the height of the hill, respectively. Cases at various rotation Rossby numbers, $Ro = U/fD = 1, 25, \infty$, ranging from strongly rotating to non-rotating environments are considered to examine the effect of rotation on the vortex dynamics.

At the relatively strong stratification ($Fr = 0.15$), the fluid predominantly moves around the hill instead of going over it, and von Kármán vortex shedding is observed in all cases. The three-dimensional structures of wake vortices are greatly influenced by rotation. With strong rotation, wake vortices organize into tall columns that align with the rotation axis, which is reminiscent of stratified Taylor columns. As rotation weakens, vortex structures are progressively inclined forward, elongated, and layered due to the increasing relative importance of stratification. With no rotation, those vortices lean towards the direction of the flow at a shallow angle to the horizon that doesn't seem to change during their evolution downstream.

The spatiotemporal coherence of the vortex structures is educed statistically with spectral proper orthogonal decomposition (SPOD). The shedding frequency revealed by SPOD eigenspectra has a constant value near $St = fD/U = 0.27$ throughout the entire height of the hill, regardless of the rotation strength from $Bu = 1$ to $Bu = \infty$, at the present Froude number ($Fr = 0.15$). The dominant SPOD mode is shown to be the primary von Kármán vortex shedding mode at St, accompanied by a hierarchy of subdominant modes at its higher harmonics. The energy of the subharmonics decays as a power law, indicating significant low-rankness in the dynamics of stratified hill wakes and the possibility of reduced-order modeling of such flow.

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