Spatiotemporal analysis of coherent structures in the wake of an underwater hill

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Oceanic stirring and mixing at bottom topography in the deep ocean crucially impacts the interior ocean state. In this study, we conduct large eddy simulations of a canonical problem: flow past a conical hill that is submerged in a rotating, stratified fluid. The Reynolds number is $Re = UD/\nu = 25\,000$ and the Froude number is $Fr = U/Nh = 0.15$. Cases with various levels of rotation strength ranging from none to strong rotation (low value of Rossby number $Ro = U/fD$) are examined.

At the relatively strong stratification of $Fr = 0.15$, the fluid predominantly moves around the hill, and wake eddies, which originate from the von Kármán vortex shedding at the hill, are observed. Spatiotemporal coherent structures are educed statistically with spectral proper orthogonal decomposition (SPOD). The spatial structure of the wake vortices is elucidated with SPOD eigenmodes with a focus on the influence of rotation on the structures. In the case of strong rotation, wake vortices organize into tall columns, 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. The shedding frequency revealed by SPOD eigenspectra has a constant value near $St = fD/U = 0.27$ throughout the entire height of the hill, no matter whether rotation is present or not. Thus, despite the increasing spatial complexity of the SPOD eigenmodes with weakening rotation, the peak frequency of the leading SPOD mode varies little in the examined cases.

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