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Large eddy simulation of the Ekman-Stokes boundary layer

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The study of rotating and oscillating (Ekman-Stokes) boundary layers is relevant for the comprehension of the sea-bottom boundary layer. In the framework of a research aimed at understanding vertical turbulent mixing in shallow water basins, we show here the effect of rotation in a purely oscillating boundary layer. Consistently with Coleman *et al.* (JFM, 213, 1990), both the vertical and the horizontal components of the rotation vector were considered in the governing equations.
The first significant result of the present study is that the rotation of the frame of reference breaks the symmetry between the two half cycles of the oscillation period. The mean profile of the non-zero mean cross-stream velocity, originated by the cross-stream pressure gradient associated to the Coriolis force, oscillates during the cycle. The amplitude of such velocity is about one order of magnitude smaller than that of the streamwise component, in agreement with the DNS results obtained by Coleman *et al.* (1990) for the steady Ekman layer, but phase-shifted due to the oscillating motion. Thus, narrow elliptic paths characterize the water column, with the major axis decreasing in amplitude and rotating going from the surface toward the bottom.

Rotation has a not symmetric effect on the system dynamics: in the first half cycle, corresponding to forcing from SW to NE, the mean vorticity (related to the mean vertical shear) is parallel to the background vorticity and consequently turbulence tends to be stabilized and its activity decreases; conversely, in the second half period, where forcing goes from NE to SW, the mean vorticity is opposite to the background one and thus turbulence tends to be destabilized and its activity increases. Turbulence activity increases when compared to the pure oscillating case, in particular in the bottom half of the water column and during the decelerating phases of the cycle, being always more intense in the second half period. Such a stabilizing/destabilizing effect,

confirmed also by the evolution of the Bradshaw number throughout the cycle, agrees with theory (Hopfinger and Linden, 1990, JFM 211; Coleman *et al.*, 1990) and emphasizes the importance played by the horizontal component of the Earth rotation vector in simulations of turbulent Ekman layers.

Our results show also non-zero correlations between horizontal velocity fluctuations (τ_{12}) and between spanwise and vertical components (τ_{23}), and also an increase of the vertical and cross-stream turbulence intensities when compared to the pure oscillating flow. This picture describes thus a highly three-dimensional character of turbulence, affecting all the three spatial directions.