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Secondary instability of Ekman layer rolls

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Lilly established that the neutrally-stratified Ekman flow is subject to an inflexion point instability (Lilly, 1966). The rolls often observed in the neutral PBL are usually interpreted as the outcome of this instability. However important characteristics of its non-linear development remain unclear and are investigated in this work :

(i) Does the instability saturate, like the convective instability ? Coleman (1990) runs direct numerical simulations at Re=400 and finds no equilibrated rolls, unlike Foster (2005) who performs high-order amplitude expansions at Re=500. We run a 2D DNS similar to Coleman's at Re=500. The instability grows with a time scale T. After a few T, nonlinear interactions become dominant and drive the flow to a travelling quasi-equilibrium, presenting slow oscillations with a period of several tens of T. These oscillations decay but even more slowly. Using a Newton's method, very small corrections are enough for us to find an exactly equilibrated flow. Hence the equilibrated rolls exist, and are reached very closely, although not exactly, after a small random initial perturbation to the Ekman flow has evolved. Interestingly, while the observations mention contra-rotationg rolls, these equilibrated rolls are co-rotating.

(ii) How stable or unstable are the equilibrated rolls with respect to three-dimensional perturbations ? Plane KH rolls in neutral stratification suffer from elliptic and hyperbolic instabilities (Peltier 2003). Unlike KH rolls, saturated Ekman rolls have along-roll velocity, like swirling jets, which are subject to other types of instabilities. Using matrix-free Krylov methods, we find that Ekman rolls suffer from a secondary instability of hyperbolic type.

(iii) How sensitive is the secondary instability to latitude ? The horizontal component of the Coriolis vector and the direction of the geostrophic wind are known to influence the primary stability domain. We investigate their influence on the secondary instability as well.