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Turbulence production in stratified Ekman flow

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Although a stable stratification should suppress vertical motions and turbulence, significant turbulence is observed in nocturnal or polar atmospheric boundary layers (ABLs), and often presents a high degree of instationarity or intermittency. In this work we use the Ekman flow as a prototype flow to explore possible dynamical mechanisms generating this turbulence.

The linear instability of neutral and stratified Ekman flow has been studied theoretically and experimentally (Lilly, 1966 ; Brown, 1972). The fastest growing infinitesimal perturbations equilibrate nonlinearly in the form of longitudinal roll vortices which are close analogues of circulations found in neutral and weakly convective ABLs (Brown, 1970 ; Young, 2002). Therefore a secondary instability mechanism must be invoked for three-dimensional (3D) turbulence to be generated. Through such a mechanism, which is known to exist in the neutral case (Dubos et al., 2008), infinitesimal 3D perturbations to the equilibrated rolls grow and eventually lead to turbulence through nonlinear interactions.

Vortices and stratified shear flows present various types of secondary instability (Godeferd et al., 2001 ; Peltier and Caulfield, 2003). We perform the secondary stability analysis of stratified Ekman boundary layer rolls for a few values of the Reynolds, Richardson and Prandtl numbers. For this, we first compute the equilibrated rolls and discuss their structure. Especially their exists a range of intermediate Richardson numbers for which locally unstable stratification is present in the vortex core. This feature provides a potential mechanism and energy source for the secondary instability. The energetics of the growth of three-dimensional perturbations are discussed for a few representative values of the control parameters.