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Statistical-mechanical approach to study the hydrodynamic stability of the stably stratified atmospheric boundary layer

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Numerical weather prediction or climate models represent mixing in the atmospheric boundary layer (ABL) through a turbulence closure model or ABL parametrization. In contexts of stable density stratification such as the nocturnal or polar boundary layer, existing parametrization are not necessarily appropriate. The order of the turbulence closure and the use of local or nonlocal mixing approaches are the two main points faced in the choice of an ABL parametrization scheme. In cases where the turbulence is weak, localized wind shear accelerations can trigger intermittent turbulence and turbulence can become highly nonstationary. We propose a data-driven approach to study the hydrodynamic equilibrium properties of the stably stratified atmospheric boundary layer.
Our approach is based on a combination of dynamical systems techniques and statistical analysis. The main idea is to measure the deviations from the behaviour expected by a turbulent observable when it is close to a transition between different metastable states. We first assess the performance of our method on the Lorenz attractor, then on a laboratory turbulent flow. We then show results from measurements of stably stratified ABL turbulence obtained in the Snow-Horizontal Array Turbulence Study campaign at the Plaine Morte Glacier in the Swiss Alps. The results show that the method recognizes subtle differences among different stable boundary layer turbulence regimes and may be used to help characterize their transitions. They further highlight the necessity to model the very stable ABL by using high order stochastic processes, differently from the weakly stable ABL.