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Dynamics of the very stable boundary layer with large-eddy simulations

Maria J. Chinita (1,3), Georgios Matheou (3), and Pedro M.A. Miranda (2)

(1) Instituto Dom Luiz, Faculdade de Ciências da Universidade de Lisboa, Portugal (mjchinita@fc.ul.pt), (2) Instituto Dom Luiz, Faculdade de Ciências da Universidade de Lisboa, Portugal, (3) Jet Propulsion Laboratory, California Institute of Technology, USA

The stable boundary layer is ubiquitous and typically forms at night when the ground radiatively cools and in polar regions throughout the day. Stable stratification and the associated reduction in the energetic scales in combination with the large anisotropy of turbulent motions challenge numerical models. This modeling difficulty also affects large-eddy simulation (LES) methods leading to scarce LES results for very stable conditions. In contrast, the NWP of convective flows has greatly benefited from the ample availability of high quality LES data. To overcome these limitations, a novel LES model setup is developed to enable the modeling of very stable boundary layers. Large-eddy simulations at high latitude of Ekman layer-type boundary layers at various weak geostrophic winds are presented. A temperature surface condition is applied in the LES. The surface heat flux is dynamically computed by resolving the surface layer since the often-used Monin–Obukhov similarity theory breaks down in very stable conditions. Depending on the conditions, the LES gracefully transitions to a direct numerical simulation (DNS) where the flow becomes fully resolved. Two stability regimes can be discerned based on vertical profiles of the Richardson number. Overall, the model predicts that turbulence is very resilient with respect to stability. Temperature and velocity fluctuations persist even at high Richardson numbers. The nature of the small-scale and non-stationary turbulence of these very stable regimes is discussed. Scaling relations, spectra and influence of Earth's rotation are also presented and discussed.

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