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Challenges of turbulence modelling over realistic terrain

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Parametrization of surface turbulent exchange in almost all Earth System Models rely on statistical representations valid only in highly restrictive conditions not often encountered in the atmosphere (flat and horizontally homogeneous terrain, stationarity, moderate stratification). Under strong stratification over flat and homogeneous terrain, and over complex terrain the parametrizations of surface turbulent exchange fail, with no alternative to replace them. This failure is a cause of large uncertainties in the estimation of surface fluxes coupling the atmosphere to the underlaying surface. Recent research has shown that this failure of parametrizations can be ameliorated by adding the information on turbulence anisotropy. Anisotropy quantifies the directionality of turbulence exchange and is associated with differences in transport efficiently of turbulence, not accounted for in classic parametrizations.

Here we explore the characteristics and drivers of turbulence anisotropy in unstable atmospheric surface layer, over terrain ranging from flat to highly complex, using reduced variance budgets and machine learning, with the aim to develop a new generation of turbulence parametrizations valid over both flat and complex terrain. The results highlight the systematic differences in turbulence over complex terrain compared to flat terrain, but also show that anisotropy can be described by the same non-dimensional ratios for flat and complex terrain. Given the ever increasingly recognized importance of turbulent exchange on weather and climate at all scales, the improved parametrizations are necessary for reducing the uncertainty in weather, climate, and air-pollution models, particularly in polar regions and over complex terrain.

Primary author: STIPERSKI, Ivana (University of Innsbruck)

Co-authors: Prof. KATUL, Gabriel G. (Duke University); Mr MOSSO, Samuele (University of Innsbruck)

Presenter: STIPERSKI, Ivana (University of Innsbruck)

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