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A Case Study of Clear-Air Turbulence at Upper Levels

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Because of the technical difficulties of achieving measurements at high altitudes, it is not clear how well turbulent phenomena are represented in the upper levels of current Numerical Weather Prediction (NWP) operational models.
Indeed, turbulence in strongly stable conditions near the tropopause is known to be particularly difficult to correctly parameterize. The constraining buoyancy forces on the vertical lead to anisotropic turbulence, potentially inhibiting turbulent production in NWP models.
Partial information for high altitude turbulence events is nonetheless available in the form of in-situ measurements from aircrafts. However, it only allows for qualitative comparisons with model outputs.
This study focuses on a turbulent episode induced by a winter upper-level jet above east Belgium on January 27, 2018, for which in-situ EDR (Eddy Dissipation Rate) reports indicate moderate-or-greater turbulence levels. Numerical simulations are performed with the Météo-France operational model AROME, and with the mesoscale research model MesoNH (Laero/CNRM), at the same horizontal grid resolution (1.3km). These two models also use the eddy-diffusivity turbulence scheme of Cuxart et al (2000), a 1.5 order closure scheme based on a prognostic Turbulent Kinetic Energy (TKE) evolution equation, with a diagnostic computation of the mixing length.
TKE budgets, as well as stability indices and gradient-based quantities (Richardson number, vertical wind shear) are computed from the model outputs, and qualitative comparison with in-situ data is presented. Time evolution of the turbulent event over Belgium is well captured by both models, agreeing with EDR data.
Several sensitivity tests on the vertical resolution, on the mixing length formulation and on the parameters of the TKE equation are then performed. Most notably, the use of an increased vertical resolution near the tropopause greatly enhances the turbulent fluxes in both operational and research models. Secondly, comparison of various expressions of the mixing length shows that the Bougeault and Lacarrere (1989) formulation produces the higher amount of subgrid TKE and turbulent mixing. A decreased turbulent dissipation parameter also significantly increases the amount of subgrid TKE. On the contrary, the use of a 3D turbulence scheme appears to have very limited impacts on the turbulent flow at this kilometer-scale horizontal resolution.
On a second part of this study, results from ongoing Large Eddy Simulations (LES) will be presented. These simulations aim at representing small-scale features of the turbulent flow. They will be used as a reference for the computation of turbulent fluxes at kilometer-scale resolution using a coarse-graining method, allowing for a comparison with the parameterized fluxes from the turbulence scheme. In particular, the dissipation term of the TKE equation will be examined. These results are expected to give insight on the leading turbulent mechanisms for which the current turbulence parameterization can be improved in stable conditions.