Project: **1096**
Project title: **Turbulence resolving simulation of atmospheric boundary layer processes**
Principal investigator: **Juerg Schmidli**
Report period: **2023-11-01 to 2024-10-31**

The goal of this project is to improve the representation of the ABL in weather and climate models with a focus on: 1) scale-adaptivity, and 2) complex-terrain boundary layers. For this purpose experiments on Levante were performed according to the proposal of the project. Here we present a selection of substantial results following from the simulations. Further results can be found in our new publications listed on the DKRZ project website.

a) Development of a scale-adaptive unified parametrization for ABL turbulence and boundary layer clouds

a.1) The representation of transitional atmospheric boundary layers

In a first phase we aim to investigate the life-cycle of shallow cumulus clouds (SCC) using high-resolution LES with the ICON model. The focus is on SCC formation, evolution, and dissipation under various environmental conditions, while assessing the sensitivity of cloud characteristics to model resolution. As a first step a cloud tracking algorithm has been adopted and used to analyze cloud and cloud lifetime statistics. This will help improve the representation of SCC in models by examining cloud fraction, spatial patterns, and boundary layer interactions.

a.2) The impact of small-scale dynamics on UTLS transport and mixing

Interactions in the upper troposphere-lower stratosphere (UTLS) are critical for climate predictions, influencing the distribution of greenhouse gases. Turbulence, which mixes tracers, operates on small scales and must be parameterized in models. UTLS turbulence, driven by jet streams, convection, and mountain wave breaking, is less understood due to its anisotropic nature. We compared two turbulence schemes in the ICON model: the operational TKE scheme and the new two-turbulence energies (2TE) scheme (Bašták Durán et al., 2022). Both were tested using mountain wave simulations from the DEEPWAVE and SouthTRAC campaigns. Initial DEEPWAVE results with ICON-NWP at 1 km and 500 m resolution show that while wave patterns are very similar, the magnitude of turbulent kinetic energy predictions vary significantly. The underlying causes of these differences are still under investigation. Additionally, comparison with observations along the flight path suggests that a grid spacing of 1 km or even 500 m is insufficient to accurately simulate the mountain waves. LES at 130 m resolution successfully captured the shorter horizontal wavelengths, as demonstrated by the comparison of different resolutions in Figure 1.

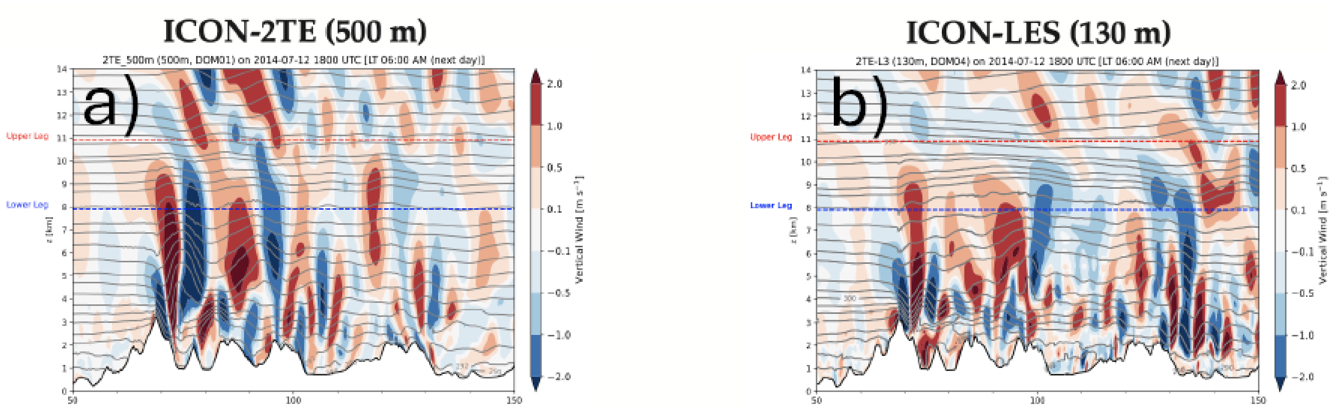

Figure 1: Vertical cross section of vertical velocity along the flight path simulated in ICON (a) at 500m horizontal grid spacing for the 2TE scheme (b) at 130 m in the LES mode.

b) Analysis of complex-terrain ABLs and the development of suitable subgrid-scale (SGS) models

b.1) The impact of small-scale orography on surface drag, momentum flux, and ABL structure

In the first phase of this sub-project, we focused on identifying the conditions under which orographic drag parameterizations had the greatest influence on flow development in the atmospheric boundary layer (ABL) over moderately complex terrain, as well as how these schemes scaled with decreasing grid spacing (Quimbayo-Duarte et al., 2024). In the current phase, we extended the analysis to more complex terrain and evaluated model performance in capturing stably stratified atmospheric conditions. Using the setup established in the previous phase, we conducted a series of simulations over the Alps as part of the TEAMx initiative, employing both ICON-NWP and ICON-LES. This work was carried out within the Cold Air Pooling Processes Model Intercomparison Working Group, which is part of TEAMx. The ICON model was tested in NWP mode, utilizing both the standard TKE turbulence scheme and our custom two-turbulent-energies scheme (Bašták Durán et al., 2022). The model, with both turbulence parameterizations, demonstrated competitive performance compared to the other models involved in the study. Preliminary results from the model intercomparison were presented at the 2024 EMS General Meeting (Lehner et al., 2024).

b.2) Interaction of Foehn flows with the ABL

In the previous phase of this project, issues were identified in simulating foehn events in the COSMO model, potentially related to atmospheric boundary layer (ABL) parameterization. Numerical simulations using the ICON model in NWP mode were conducted to investigate the cold bias observed in COSMO under foehn conditions. ICON showed better representation of foehn flow, particularly in reducing the temperature bias. A sensitivity study based on a comprehensive set of ICON simulations focused on identifying the sources of this bias, and the findings have been submitted to the QJRMS (QJRMS, Tian et al., 2024). This research helps clarify key processes in foehn flow and offers insights for improving boundary layer parameterizations in mesoscale models.

Additionally, large-eddy simulations (LES) with the ICON model were run at grid spacings of 260 m, 130 m, and 65 m to explore the interaction between foehn flows and the ABL during different phases of foehn development, with a focus on grid resolution sensitivity. This work is ongoing and will continue in 2025.

b.3) The impact of thermally driven wind systems on exchange over complex terrain

The researcher previously assigned to this subproject left the group at the end of 2023. A replacement has recently been appointed, and work on this project will resume in 2025.

b.4) Modelling tracer transport and mixing in the ABL over complex terrain

The investigation into the transport and mixing of a passive tracer over complex terrain was conducted using high-resolution numerical simulations with CM1-LES, employing horizontal grid spacings of 5-10 meters to capture the fine-scale processes in idealized scenarios. The study utilized a valley topography resembling that of the Swiss Midlands, providing a robust framework for a comprehensive exploration of key storage and transport mechanisms. It examined the accumulation of the passive tracer in nocturnal cold-air pools and its subsequent depletion during the morning transition. Additionally, the research evaluated the model's sensitivity to variations in background wind speed, wind direction, and valley depth. A manuscript detailing these findings has been submitted to Boundary-Layer Meteorology (Basic et al., 2024).

References

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