Project: **1096**
Project title: **Turbulence resolving simulation of atmospheric boundary layer processes**
Principal investigator: **Juerg Schmidli**
Report period: **2022-11-01 to 2023-10-31**

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 the project proposal. 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

As mentioned in last years report, two articles have been published gathering our recent research outcomes related to parameterization development (Bašták Durán et al., 2022; Reilly et al., 2022). Our new unified turbulence scheme has been positively evaluated for new real-case situations (see project b.4 below). We are continuing our work on an improved parameterization of the turbulence length scale. For this we are persuing two approaches, the development of a new and improved algebraic turbulence length scale and the testing of a prognostic turbulence length scale. Due to staffing issues (position has not been filled) this work has not progressed much during the last year. We are currently still seeking a new staff member.

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

b.1) The impact of thermally driven wind systems on exchange over complex terrain

We continued investigating the thermal plumes in the convective boundary layer over complex terrain. Coherent plume structures in the convective boundary layer over non-flat terrain were investigated using large-eddy simulation (LES). The results of our study have been published in Weinkaemmerer et al. (2023). In related work, the misforecast of simulated diurnal valley winds in a deep Alpine valley was investigated which included a detailed evaluation of a set of simulations against available observations (Schmidli and Quimbayo-Duarte, 2023).

b.2) The impact of small-scale orography on surface drag, momentum flux, and BL structure

The response of the lower atmosphere to resolved versus parametrized orographic drag over moderately complex terrain was investigated. The larger terrain scales may trigger propagating gravity waves and generate flow blocking (SSO), while the smaller scales may modify the turbulent atmospheric boundary layer, which leads to turbulent orographic form drag (TOFD). We performed a set of numerical simulations to evaluate the ability of both SSO and TOFD parametrizations to reproduce the impact of small-scale orographic features on the flow over complex terrain using the ICON model in limited-area mode.The experiments performed covered a wide range of horizontal resolutions, from the hectometre scale (down to 65 m of horizontal grid spacing) to the mesoscale (up to 5 km horizontal grid spacing) scales. The main goal was to asses the performance of both orographic drag parameterizations using a setup close to DWD's operational setup for ICON-D1. The model results were successfully validated against tower and radiosonde data collected during the IOP of the Perdigão field experiment. The influence of the sub-grid-scale orography parametrizations was evaluated near the Perdigão area in the Serra da Estrela, a region that exhibits a more complex topography north of Perdigão. Results suggest that the flow blocking part of the SSO scheme is still required for high-resolution NWP simulations. Its contribution to drag at the surface seems to be beneficial and it is about twice as large as the contribution from the TOFD scheme (see Fig. 1). A manuscript is currently in preparation.

b.3) The interaction of Foehn flows with the ABL

The skill of the COSMO model (v5.7) at 1.1 km horizontal resolution in simulating the near-surface foehn properties and evolution for several south foehn events and a 5-year-long climatology were investigated in the frame of this project. The simulations pointed out to a significant near-surface cold bias during foehn, with an average cold bias of 3 K in the Rhine Valley in five individual foehn cases, and of 1.8 K in the major northern foehn valleys in the 5-year foehn climatology. A manunscript has been accepted for publication in the Quart. J. of the Royal Meteorol. Society.

In addition, we continue our research on the foehn interacting with atmosphetic boundary layer (ABL) using ICON-NWP and -LES modes at several model resolutions (1 km, 200m, and 160m). Extensive work was done to refine the setup of both NWP (1 km) and LES runs (200m and 160m), and it is now ready for production of reliable results.

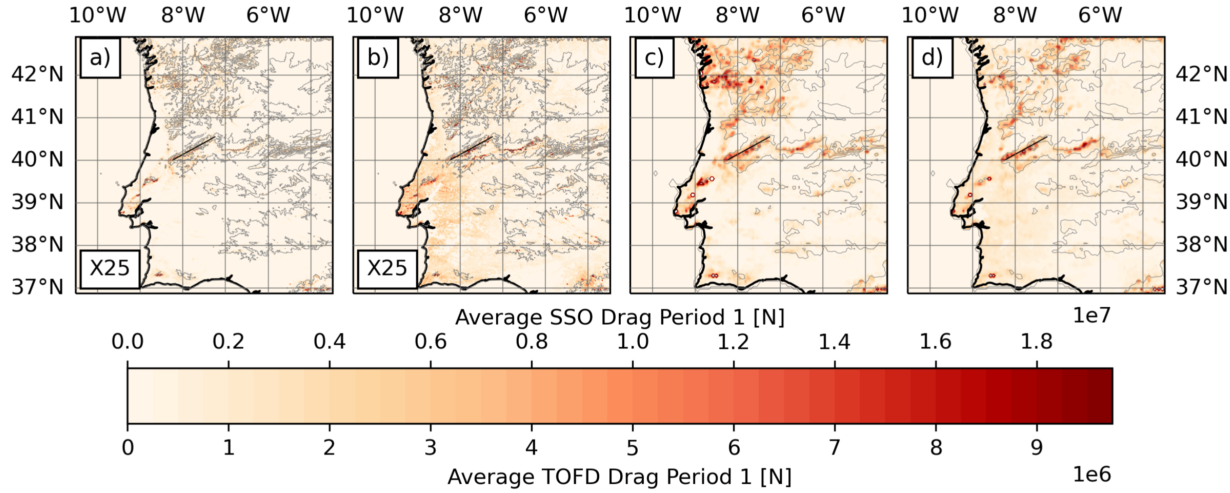

Figure 1: Horizontal cross-section of average drag from TOFD (a and c) and SSO (b and d) from ICON-1k (a and b) and ICON-5k (c and d) simulations over a three-day event selected to evaluate the parametrised and resolved orographic drag (2017-05-15T12:00 - 2017-05-18T12:00, colour contour plot). The grey line contour plot represents the orography in the domain. Note that data of the ICON-1k (a and b) simulations has been multiplied by a factor 25.

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

This study aimed to identify limitations in the operational ICON-NWP model by finding an optimal model configuration that satisfied the performance requirements for atmospheric dynamics and trace gas modelling. The evaluations were done using ICON simulations at a horizontal grid spacing of 1 km, where the model configuration followed the pre-operational setup at the Swiss Federal Office of Meteorology and Climatology (Meteoswiss), Switzerland. The main focus was on optimizing ABL parameterization schemes for different weather regimes. We investigated the performance of the operational TKE-based turbulence parameterization scheme, hereafter ICON-NWP, and our newly developed two-energy scheme (Bašták Durán et al., 2022), hereafter 2TE+APDF.

Radiation fog remains a challenging event to predict by NWP models. Several case studies characterizing persistent radiation fog, nocturnal fog and low level stratus (FLS) were evaluated against measurements at Payerne, Switzerland. The 2TE+APDF scheme performed better during low-wind deep radiation fog cases than ICON-NWP. In addition, the 2TE+APDF scheme performed similar or better than ICON-NWP during high wind fog cases.

b.5) Study of storage and transport processes in an idealized valley.

The investigation into the transport and mixing of a passive tracer over complex terrain was conducted by performing numerical simulations with CM1-LES in the context of idealized scenarios. The idealized valley topography, resembling the Swiss Midlands, provided an excellent platform for a comprehensive exploration of pertinent storage and transport mechanisms. The study explored into several aspects, including the accumulation of a passive tracer in nocturnal cold pools, its subsequent depletion in the morning, and its subsequent transport to higher altitudes, as well as horizontal transport. Furthermore, an evaluation of the model's sensitivity to atmospheric stratification, upper-level winds, and varying model grid spacings was carried out.

References

Bašták Durán, I., M. Sakradzija, and J. Schmidli, 2022: The two-energies turbulence scheme coupled to the assumed PDF method. *Journal of Advances in Modeling Earth Systems*, **14**, 1–19, doi:10.1029/2021MS002922.

Reilly, S., I. Bašták Ďurán, A. Theethai Jacob, and J. Schmidli, 2022: An evaluation of algebraic turbulence length scale formulations. *Atmosphere*, **13 (4)**, 605.

Schmidli, J., and J. Quimbayo-Duarte, 2023: Diurnal valley winds in a deep alpine valley: Model results. *Meteorology*, **2**, 87–106, doi:10.3390/meteorology2010007.

Weinkaemmerer, J., M. Göbel, S. Serafin, I. Bašták Ďurán, and J. Schmidli, 2023: Boundary-layer plumes over mountainous terrain in idealized large-eddy simulations. *Quarterly Journal of the Royal Meteorological Society*.