Project: **1096**
Project title: **Turbulence resolving simulation of atmospheric boundary layer processes**
Principal investigator: **Juerg Schmidli**
Report period: **2021-11-01 to 2022-10-31**

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

Two articles gathering our recent research outcomes related to parameterization development have been published in 2022 (Bašták Durán et al., 2022; Reilly et al., 2022). We are continuing our work on an improved parameterization of the turbulence length scale, applicable also in the large-scale end of the turbulence grey zone. 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. Publication of these results is in preparation.

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

Two articles gathering the research outcomes of the last two years have been published in 2022 (Weinkaemmerer et al., 2022a,b). We continued our work investigating thermal plumes in the convective boundary layer over complex terrain. A conditional sampling method has been implemented into the CM1 model in order to identify and characterize plume structures. Such coherent structures contribute substantially to the vertical turbulent fluxes of heat and moisture. Large-Eddy Simulations (LES) have been performed both over idealized valleys and semi-idealized three-dimensional terrain. Over sloping terrain, the plumes interact with the thermal winds as they are moving uphill in the slope-wind layer. The turbulence statistics have been analysed and compared to convective turbulence over flat terrain. Especially at ridge height, where the updrafts are few but almost stationary, the statistics are fairly different. The results are relevant for parameterization development for Numerical Weather Prediction (NWP) models, especially at resolutions where the orography is insufficiently resolved. Publication of these results is in preparation.

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 has been investigated. The larger terrain scales may trigger propagating gravity waves and generate flow blocking, while the smaller scales (smaller than 5 km) may modify the turbulent atmospheric boundary layer leading to turbulent orographic form drag (TOFD). We perform high-resolution numerical simulations to evaluate the ability of a TOFD parametrization to reproduce the impact of small-scale orographic features on the flow over complex terrain using the ICON model in limited-area mode. A set of simulations using different grid spacings, from the km scale (NWP mode) to the O(100) m scale LES, were carried out to reproduce the intensive observational period (IOP) of the Perdigão field experiment. The LES is used to assess the performance of the TOFD parametrization (used in NWP mode). Initial results of the NWP control simulation show good performance compared to the tower wind observations for the whole IOP. The influence of the TOFD parametrization is evaluated near the Perdigão area and in the Serra da Estrela, a region with more complex topography. A manuscript is currently in preparation. Related to this topic, the impact of a forest parameterization on the BL flow over the Perdigão double hill has been evaluated. The results have been published in Quimbayo-Duarte et al. (2022).

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

We continued the evaluation of simulated north foehn in COSMO-1. Previously we had found a cold and moist bias during Foehn for five different Foehn cases. In the last year, we proceeded with a more in-depth analysis of the five cases and extended the work to include an evaluation of COSMO-1 for a five-year long foehn climatology. The latter being based on COSMO-1 analysis data. The results for the climatology are consistent with the previous results and confirm a cold bias of COSMO-1 during foehn events. The work is currently being written up.

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

An accurate representation of atmospheric boundary layer processes is critical for trace gas simulations and inverse modelling on the regional scale. This project addresses, among others, the problem of too strong mixing in stable boundary layers and the impact of local circulations on trace gas evolution using a combination of idealized process studies and evaluation of real-case simulations, with the goal of developing an optimal model configuation for ICON for both NWP and trace gas simulation. Here we focus on the latter part. Several cases have been investigated using ICON-1 in different configurations. The configurations include a reference setup close to the pre-operational ICON setup at MeteoSwiss using the (operational) TKE-based turbulence parameterization scheme (hereafter ICON-NWP), a setup using our newly developed two-energies turbulence scheme (Bašták Durán et al., 2022), hereafter 2TEAPDF, and a setup that is based on ICON-NWP, but uses smaller minimum turbulence transfer coefficients, hereafter NWP_tkhm. The selected periods range from summer time clear-sky fair-weather situations with a strong diurnal cycle of the GHGs (19 to 26 June 2020, 10 to 17 June 2021, Bise week: 18 to 24 July 2021) to a cloudy period (8 to 12 August 2021) and persistent fog (15 to 17 October 2021 and 11 to 22 Dec 2021) over the Swiss Plateau. Our two-energies scheme (2TEAPDF) usually performs equally well or better than the operational scheme. As an example, we show a case of fog and low stratus over the Swiss plateau, see Fig. 1a. A spatial snapshot of the low-level cloud cover simulated at 06 UTC on 14 Dec 2021 is shown in Fig. 1b. Unlike ICON-NWP, the ICON-2TEAPDF is able to simulate the NE-SW elongated fog layer over the Swiss Plateau. While tuning of the current operational scheme apparently leads to improved results, further investigation reveals that ICON-2TEAPDF is still closer to the observed evolution. Related to this topic, we contributed COSMO simulations to a model intercomparison of radiation fog, the article has been published in 2022 (Boutle and coauthors, 2022).

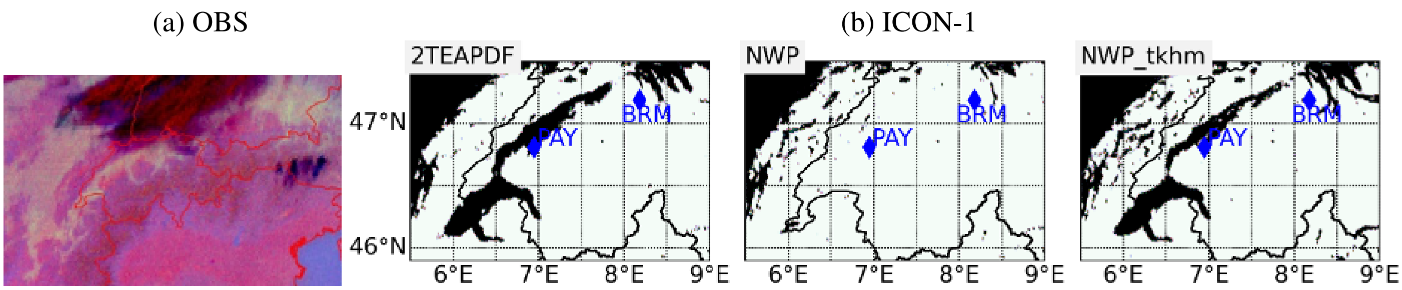

Figure 1: (a) Satellite image from 14 Dec 2021 at 05:45 UTC showing fog over the Swiss platau. (b) Spatial distribution of simulated low level cloud cover (shading) at 06 UTC on 14 Dec 2021 for the three model configurations.

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