Project: **1096**
Project title: **Turbulence resolving simulation of atmospheric boundary layer processes**
Principal investigator: **Juerg Schmidli**
Report period: **2020-11-01 to 2021-08-31**

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 Mistral 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

Our newly developed two turbulence energies scheme (Bašták et al., 2018) combined with the assumed PDF method (Golaz et al., 2002) (2TE+APDF) is able to model both turbulence and boundary layer clouds in a unified framework. Until now, the scheme was only tested in idealized single column model environment. Therefore, the scheme was implemented into the full three-dimensional ICON model and its performance was tested. The tests on several idealized case studies show that the 2TE+APDF scheme outperforms the current ICON turbulence scheme and that it can be used also in the full ICON model. 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

We investigated the vertical heat and mass transfer in the convective boundary layer over mountainous terrain using the CM1 model for idealized large-eddy simulations. Both the turbulent and the advective transport mechanisms by the thermal slope winds were evaluated over a quasi-two-dimensional, periodic valley. The thermal winds were found to export moisture effectively out of the valley while the heating of the valley atmosphere is intensified mainly by the valley-volume effect. Consequently, the nearly horizontally homogeneous temperature distribution is much less affected by a large-scale, upper-level wind compared to the more heterogeneous moisture distribution. The analysis method of decomposing the flow into a turbulent part, a local circulation, and a large-scale mean as well as the results of this work are to be published in Weinkaemmerer et al., 2021 (submitted). Fig. 1 shows the local circulation and key turbulence quantities for the reference case after 4 h, together with the diagnosed mixed layer and boundary layer heights.

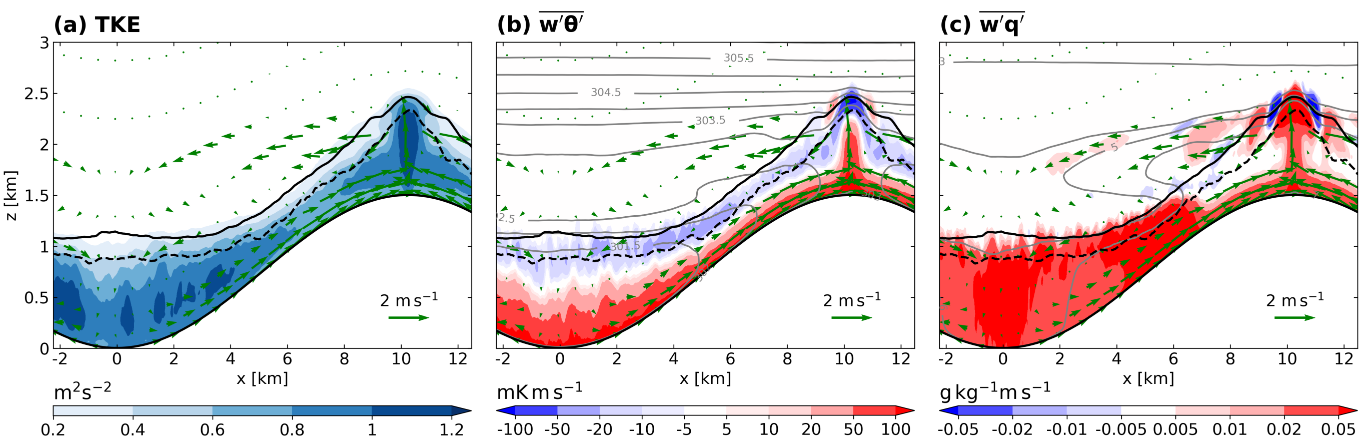

Figure 1: Valley cross sections showing the cross-valley wind vectors as well as (a) the TKE, (b) the turbulent sensible heat flux, and (c) the turbulent moisture flux (shading) at t = 4h for the reference case. Also showing in (b) the isolines of the potential temperature in K and in (c) the specific moisture in g/kg. The dashed line marks the diagnosed mixed layer height and the solid line the diagnosed boundary layer height.

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

Idealized numerical simulations of flow in the stably-stratified atmosphere have been performed using ICON-LES (Dipankar et al., 2015). Parameters such as the vertical coordinate, upper sponge layer, horizontal grid spacing and domain size have been tuned to properly reproduce the generation of orographically induced gravity waves. Simulations of flow over a shallow bell-shaped mountain are simulated and evaluated with results reported in the literature (Xue et al., 2000). ICON-LES properly reproduced the orographically induced gravity waves. However, noise in the base of the vertical profiles of horizontal momentum flux is detected coming from the boundaries, due to the periodic boundary conditions inherent to the ICON torus grid used in the present study. The latter needs to be handled before performing further numerical simulations.

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

The Alpine Foehn forecast with COSMO-1, with a setup close to the operational setup of MeteoSwiss, was evaluated on selected cases. The model shows a cold and moist bias during Foehn hours despite the diversity of the selected cases. Overestimation of the Foehn extent is present in most cases simulated with COSMO-1, except for one case, where the Foehn front stays stagnant in the middle Rhine Valley longer than it was observed.

Three sensitivity tests on the land-atmosphere interaction were conducted: sensitivity to an extra skin layer, sensitivity to employing a new implementation of bare soil evaporation, and sensitivity to increasing the resistance for heat transfer in the viscous sub-layer. All experiments show no or limited improvements of the simulated Foehn event. Simulations with a higher resolution (COSMO-500m) were carried out for the same cases. In these simulations, the forecast of wind, temperature and moisture is improved locally for Foehn events. For some cases, the timing and the extent of the Foehn are also improved.

An example from case 2016nov is shown in figure 1. The Foehn extent is overestimated in COSMO-1, causing large warm biases at the two northern-most stations. In COSMO-500m, the too far extent and the warm bias are reduced.

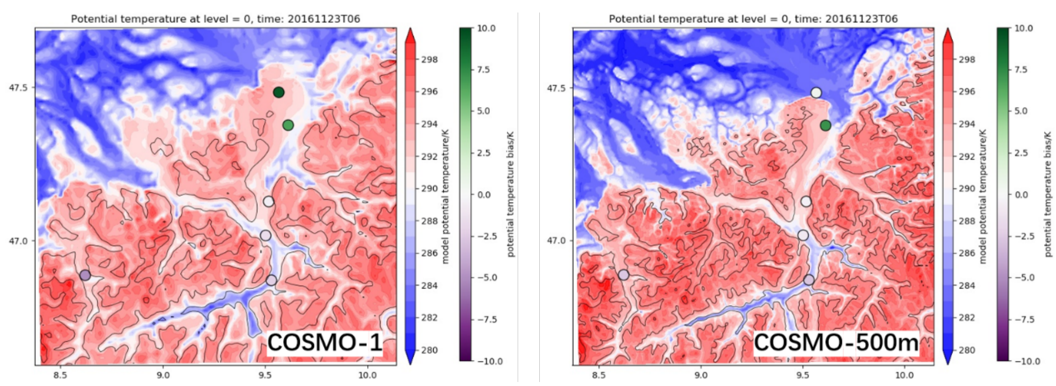

Figure 2: Horizontal cross section of the potential temperature on the lowest model level (shading, unit: K). The circles denote the potential temperature biases at each stations (model-observation). The topography height is represented by contour lines.

References

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