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The daytime boundary layer in the Inn Valley – A model evaluation study with high-quality turbulence measurements

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Atmospheric processes associated with complex terrain include various phenomena on the meso- and microscale, which contribute significantly to the local weather in mountainous areas of the Earth.
One of the most prominent and well-known boundary-layer phenomena in mountainous terrain is the daytime valley wind circulation, which is very pronounced on clear-sky days with weak synoptic forcing. We use several chosen “valley wind days” in the Inn Valley, Austria, as case studies for the evaluation of the performance of the NWP model COSMO on a horizontal resolution of 1.1 km with a focus on boundary-layer processes and turbulent exchange. The overall goal is to evaluate the model setup and to investigate whether the model’s physics schemes (initially developed for horizontally homogeneous and flat surroundings) are suitable for truly complex terrain.
We evaluate the model by using measurements from the so-called “i-Box” located in the Inn Valley. The i-Box consists of six core sites that are located at representative locations in the Inn Valley, and two remote sensing systems (wind Lidar and HATPRO passive T/RH profiler) in the city of Innsbruck. The long-term data set provides a data pool of high-resolution velocity variances, turbulence variables, radiation, soil moisture, and vertical profiles of temperature, humidity, and wind in the lower troposphere, which allows a process-oriented analysis.
A special focus is laid on the daytime valley boundary layer and its interaction with the developing up-valley wind. Vertical cross-sections show that the valley wind has an asymmetric structure, hence, the i-Box stations show a high spatial variability. While the station on the valley bottom and on the south-facing slope are clearly under the strong influence of the valley wind, the two stations on the north-facing slope are rather dominated by slope flows. We find that the valley wind has a strong (indirect) influence on the development of the local turbulence kinetic energy (TKE) structure. The generation of TKE is clearly dominated by buoyancy after sunrise and before noon. This changes when the valley wind is arriving, leading to a shear-dominated TKE generation. Further, both the TKE and the valley wind have an afternoon maximum around 15 UTC in coincidence. Overall, the TKE is underestimated by the model, especially during and after the evening transition: In the model, TKE is almost non-existent, while the observations suggest otherwise.
We find that the three evaluated days exhibit similar structures in the development of the valley boundary layer, but also common model deficiencies which helps us to suggest possible improvements.