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The effect of steep and complex topography on net vertical export of moisture into the free atmosphere

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The turbulent transport of momentum, heat and moisture between the planetary surface and the free atmosphere is a key aspect in the context of land-atmosphere coupling. In typical numerical climate prediction models, these exchange processes are accounted for by subgrid-scale parameterizations at various levels of sophistication. To a large degree, the underlying assumptions are based on empirical knowledge obtained from measurements in the atmospheric boundary layer over flat and homogeneous topography. Yet, it is still unclear what happens if topography is complex and steep. Not only is the applicability of classical turbulence schemes questionable in principle over such terrain. Mountains additionally induce fluxes on the meso-gamma-scale, such as thermally or mechanically driven valley winds, which are neither resolved nor parameterized by climate models but nevertheless contribute to vertical exchange. Attempts to quantify these processes and to evaluate their impact on climate simulations have so far been scarce, and experimental evidence is very limited.

Here we do a step toward filling this gap of knowledge and present results from a comprehensive case study in the Riviera Valley in southern Switzerland, combining experimental and numerical methods. Measurement data (radiosondes, surface towers, airborne data) from the MAP-Riviera field campaign are used to configure a high-resolution large-eddy simulation code (ARPS) for application over steep terrain and to evaluate its performance. The model is then used with horizontal grid spacings as fine as 150 m to detect and quantify the relevant exchange processes between the valley and the free atmosphere. As an example, vertical export of moisture is evaluated for three fair-weather summer days. The simulations show that the moisture fluxes into the free atmosphere are indeed no longer governed by turbulent motions alone. Other mechanisms become important, such as mass export due to topographic narrowing or the interaction of thermally driven cross-valley circulations. Under certain atmospheric conditions, these topography-related mechanisms exceed the "classical" turbulent contributions a coarse model would see by a factor of up to four.

Although these results are based on only a few cases, they demonstrate that over mountainous topography subgrid-scale exchange processes assumed by typical climate models can be highly unrealistic, and that parameterizations are required to also account for the effect of orographically induced interactions.