BAMS
Essay

A Collaborative Effort to Better Understand, Measure, and Model Atmospheric Exchange Processes over Mountains

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ABSTRACT: In this essay, we highlight some challenges the atmospheric community is facing concerning adequate treatment of flows over mountains and their implications for numerical weather prediction (NWP), climate simulations, and impact modeling. With recent increases in computing power (and hence model resolution) numerical models start to face new limitations (such as numerical instability over steep terrain). At the same time there is a growing need for sufficiently reliable NWP model output to drive various impact models (for hydrology, air pollution, agriculture, etc.). The input information for these impact models is largely produced by the boundary layer (BL) parameterizations of NWP models. All known BL parameterizations assume flat and horizontally homogeneous surface conditions, and their performance and interaction with resolved flows is massively understudied over mountains—hence their output may be accidentally acceptable at best. We therefore advocate the systematic investigation of the so-called "mountain boundary layer" (MoBL), introduced to emphasize its many differences to the BL over flat and horizontally homogeneous terrain.

An international consortium of scientists has launched a research program, TEAMx (Multi-Scale Transport and Exchange Processes in the Atmosphere over Mountains–Program and Experiment), to address some of the most pressing scientific challenges. TEAMx is endorsed by World Weather Research Programme (WWRP) and the Global Energy and Water Exchanges (GEWEX) project as a "cross-cutting project." A program coordination office was established at the University of Innsbruck (Austria). This essay introduces the background to and content of a recently published white paper outlining the key research questions of TEAMx.

KEYWORDS: Mass fluxes/transport; Mesoscale processes; Orographic effects; Topographic effects; Turbulence; Climate prediction

https://doi.org/10.1175/BAMS-D-21-0232.1
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In final form 13 February 2022

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The atmospheric boundary layer (ABL) couples the Earth's surface and atmosphere, maintaining the exchange of energy, mass, and momentum between these two systems. On a global scale, processes in the ABL determine the efficiency of the water cycle, the global energy balance, and the carbon and momentum budgets. At regional scale, the relative efficiency of individual exchange processes contributing to the total exchange at different locations (see Fig. 1), together with the availability of the exchanged properties (e.g., latent heat exchange over the ocean versus that over land), lead to spatial differences in the energy, mass, and momentum distribution and hence affect atmospheric dynamics and composition.

Areas characterized by complex terrain cover up to 50% of the Earth's land surface, depending on how complexity is defined (Rotach et al. 2014), and they are unevenly distributed. Therefore, if mountainous terrain (which certainly *is* complex) should alter the exchange efficiency, this would impact not only our understanding of mountain weather and climate itself, but also the state of the atmosphere. In this contribution we argue that *we cannot a priori assume that the exchange over mountainous terrain is governed by the same processes as that over flat and homogeneous terrain*. In other words, if our current understanding of the exchange processes for energy, mass, and momentum is not appropriate (e.g., Rotach et al. 2015), or they are not resolved in numerical models, substantial errors can result—not only locally, but even on a regional to global scale. Even when compared to flat but inhomogeneous terrain, mountains add complexity to the processes by which exchange occurs. For example, gravitational flows require specific treatment, the radiation receipt varies depending on slope aspects, thermally driven flows with strong daily and seasonal cycles also generate 3D spatial variability, airflow is deflected around orography of a range of scales resulting in a variety of phenomena (e.g., rotors, gravity waves)—and there are interactions between these processes. Hence, we make a case for increased research efforts dedicated to improved observations, weather

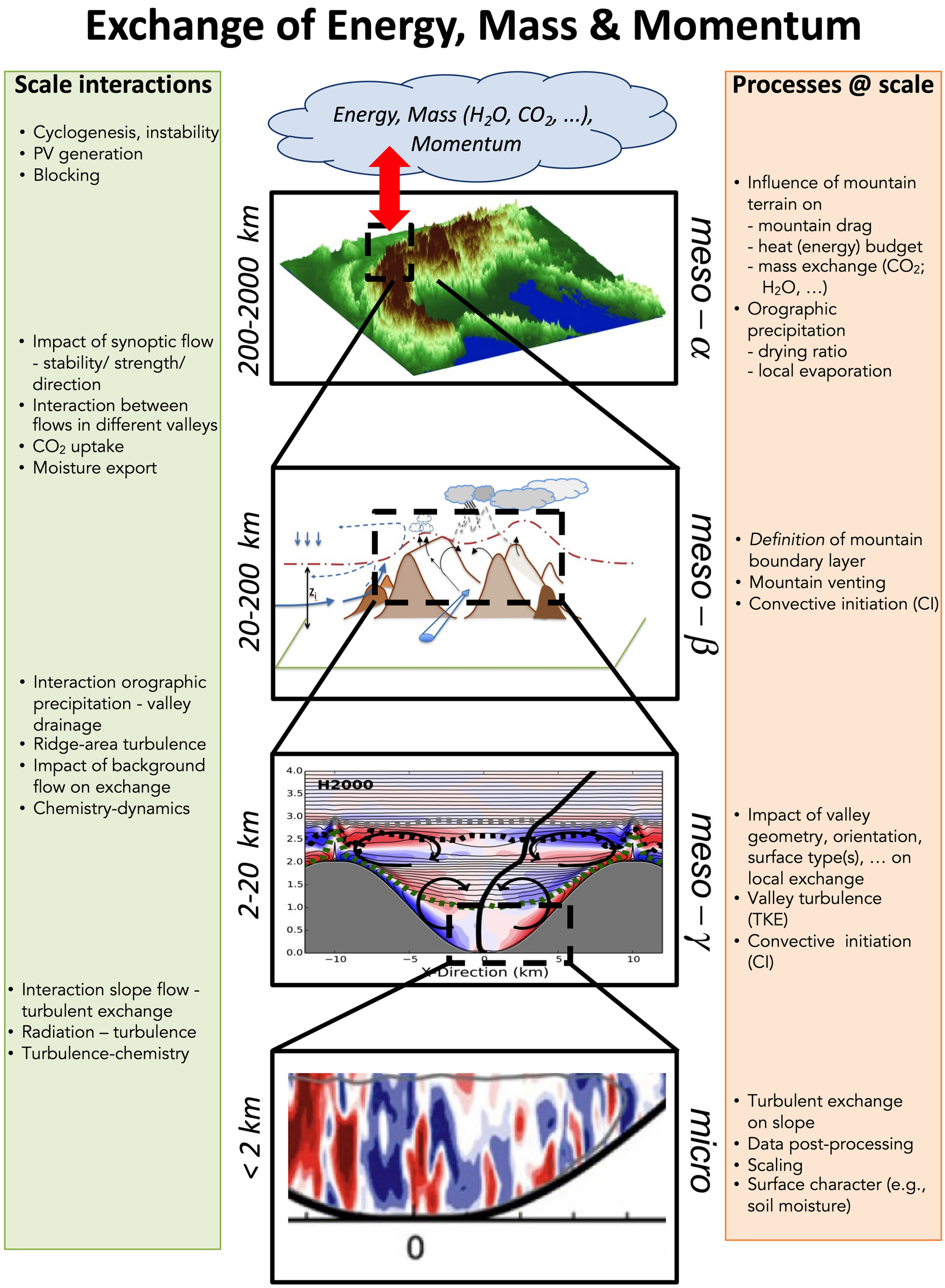

Fig. 1. Different scales in mountainous terrain, corresponding atmospheric processes at these scales (right bar), and scale interactions and multiscale processes (left bar). The top panel in the middle column shows the Alps at 1-km horizontal grid spacing in the WRF Model. Adapted from Lehner and Rotach (2018).

and climate modeling, and understanding of transport and exchange processes over mountainous terrain.

Our understanding of exchange processes in the ABL is to a large degree dependent on a theoretical framework (similarity theory) that assumes horizontally homogeneous (explicitly) and flat (implicitly) conditions (hereafter HHF). Similarity theory reasonably successfully