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Editorial

Transport and Exchange Processes in the Atmosphere over Mountainous Terrain: Perspectives and Challenges for Observational and Modelling Systems, from Local to Climate Scales

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Abstract: This Editorial offers an overview of the results presented in the series of coordinated articles included in the *Atmosphere* special issue on *Atmospheric Processes over Complex Terrain.* In particular, the variety of approaches and methods, as well as the main outcomes of recent progress in the field, are outlined, along with open questions and challenges for future developments. The possible outreach of future research in the field is also pointed out, especially in connection with the ongoing international cooperation initiative *Multi-scale transport and exchange processes in the atmosphere over mountains programme and experiment (TEAMx).*

Keywords: transport; exchange; mountain; atmosphere; climate; turbulence; observations; numerical modelling; forecast

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Mountainous terrain affects the interaction of the atmosphere with the Earth' surface in many ways, as well as on a variety of different scales, in space and time, ranging from near-surface layer processes to planetary circulation patterns, from the hourly evolution of the atmospheric boundary layer and atmospheric convection, to the long-term trends of climate variables (Chow et al. 2019), [1].

Among the key factors controlling these interactions, transport and exchange processes occurring in the atmospheric boundary layer play a major role. Also known as the Planetary Boundary Layer, this relatively shallow region of the atmosphere controls surface–atmosphere exchanges over the whole planet. Therefore, processes occurring therein affect, on the long term, even many forcing factors of larger scale processes, including climate change, such as surface exchange of greenhouse gases, water vapor, and heat. Similarly, many impacts of climate change occur through the boundary layer processes (Serafin et al. 2018) [2].

Mountainous terrain shapes the dynamics of the atmospheric boundary layer, including turbulence, in such peculiar ways that a specific notion of a Mountain Boundary Layer (MoBL) needs to be appropriately identified for the case (Lehner and Rotach, 2018, [3]). Nevertheless, the intricate combination of complex terrain effects, with the inherent complexity of boundary–layer turbulence, makes the goals of understanding these processes further challenging. As opposed to flat horizontally homogeneous terrain, where the main variability occurs over the vertical direction and corrections might allow to account for horizontal heterogeneity, the variety of landforms, land cover, and situations that can be found in the many and diverse mountainous regions worldwide make it very difficult to identify generally valid concepts and schemes (Rotach and Zardi 2007, [4]). As a consequence, the search for a thorough theoretical framework to treat these processes is still widely open on different fronts, as is well summarized in the comprehensive paper by Serafin et al. (2018) [2]. The impact of the mountain-related phenomena is not limited to boundary layer processes, of course, but extends to the meso-scale, thus triggering processes such as orographic convection (Kirshbaum et al. 2018, [5]) or downslope windstorms (such as Föhn), and with the generation of orographic waves (Vosper et al. 2018, [6]) these might affect even larger scale motions.

Challenges arising from many open questions, and opportunities increasingly offered by emerging measurement systems and innovative methods, both for direct and remote sensing techniques, stimulate the development of new observational approaches (Emeis et al. 2018 [7]).

Additionally, advances in the computational power offered by new generation computers allow for higher spatial resolution and hence a more realistic representation of orography. However, to be fully exploited, this progress needs to be accompanied by appropriate numerical schemes and parameterizations for unresolved processes (Chow et al. 2019 [1]), as well as data assimilation procedures (Hacker et al. 2018, [8]). Therefore, suitably refined, or even substantially new schemes, need to be implemented in new numerical modelling tools, not only for weather and climate prediction (Chow et al. 2019, [1]), but also for many other applications, thoroughly reviewed in De Wekker et al. (2018) [9], and in particular for pollutant transport simulations (Giovannini et al. 2020, [10]).

Indeed, a variety of applications in impact modeling might benefit from improved observational systems as well as from new generation modeling suites, specifically designed for mountain environments, as clearly demonstrated by De Wekker et al. (2018), [2].

The need for such a comprehensive progress in our understanding and modeling capabilities motivated the intense cooperative effort behind the international program TEAMx *Multi-scale transport and exchange processes in the atmosphere over mountains programme and experiment*. The review papers as cited above served as extremely valuable sources, on the basis of which the TEAMx White Paper (Serafin et al. 2020, [11]) was worked out. Its introduction summarized: "TEAMx is an international research programme that aims at improving the understanding of exchange processes in the atmosphere over mountains at multiple scales and at advancing the parameterizations of these processes in numerical models for weather and climate prediction". Following the examples, and pursuing the legacy, of many previous similar efforts performed in the past such as ALPEX, PYREX, MAP, VERTIKATOR, and COPS (see Serafin et al. 2018 [2] for reference) TEAMx motivated a broad international community of institutions and scientists to focus on unresolved issues connected to atmospheric transport and exchange processes over mountainous terrain. The effort will culminate in the preparation and execution of a large-scale field experiment at selected target areas representing characteristic orographic features and associated exchange processes over a multitude of scales in the Alps. It is associated with efforts in numerical experimentation, ranging from short (weather) to long (climate) time scales.

Results from these efforts are expected to provide significant improvements through the implementation of more appropriate schemes in operational weather prediction and regional climate models, consistent with the increasingly higher resolutions allowed by continuous progress in computational resources.

Apart from the review papers as summarized above, the special issue on Atmospheric Processes over Complex Terrain contains a number of research papers demonstrating recent progress in the various areas of relevance for transport and exchange processes over complex, mountainous terrain.

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