Multi-Scale **T**ransport and **E**xchange Processes in the **A**tmosphere over **M**ountains E**x**periment (TEAMx)

Executive summary

Mountainous areas contribute in major ways to synoptic-scale and meso-scale atmospheric flows (e.g., orographic precipitation; gravity wave drag; thermally driven flows). Both weather and climate models need to get these processes right. Indeed, interaction with mountainous terrain constitutes one of the major uncertainties in Earth-system modelling. Important internationally coordinated activities in the past (such as ALPEX, PYREX, MAP) have addressed these issues and have substantially advanced our knowledge with respect to the impact of mountainous terrain on the atmosphere.

Due to technological and scientific progress, physical scales (time and space) that can, in principle, be treated are getting smaller (better numerical resolution, surface based remote sensing, more satellite programs at better spatial resolution). Hence, we begin to be able to model in a physically consistent manner what traditionally is called 'earth-atmosphere exchange', i.e., the coupling between the surface and the atmosphere – *even over complex mountainous terrain.* While this task over flat terrain essentially corresponds to using concepts of boundary layer meteorology, it *includes processes at distinctly different scales* (from synoptic and meso-scale to the local boundary layer and near-surface micro-scales), as well as *their interactions* over mountainous terrain.

Output of numerical models ('Numerical Weather Prediction', NWP) is nowadays used to provide point-specific weather information (weather apps) - what is extremely challenging in mountainous terrain. Increasingly, it is *also* used as input for applied models[1] for, e.g., hydrology (flood warning, hydro power), health-related forecasts (heat stress, air pollution), energy smart-net regulations and potential assessment (solar, wind, hydro), economic decision models (airport management systems, agricultural models) or ecological budgeting (CO_2 source/sink appointment, anthropogenic/biogenic aerosol sources). sAll these have in common, that not only the 'bulk impact of the surface' onto the atmosphere needs to be modelled appropriately – but also the state of the atmosphere and surface) at any potential location of application. Thus, the extension of NWP models from pure weather prediction applications to, *additionally,* Earth System services calls for adding another dimension, i.e. extending our attention from surface → atmosphere only, to ***surface ↔ atmosphere exchange***. This again is a particular challenge over mountainous terrain.

In parallel with these scientific/technological advancements, the on-going *climate change* due to anthropogenic modification of the atmosphere's composition calls for our ability to correctly model scenarios for future climate states. Mountainous areas not only seem to exhibit a stronger climate sensitivity (e.g., stronger presently observed temperature increase over mountains than in the global average) and are thought to be particularly vulnerable, but also pose a particularly challenging task to the climate modelling community due to unresolved processes, terrain representation and scale interactions. Due to longer integration times, possible errors in surface ⟷ atmosphere exchange will likely have even stronger impact for the assessment of input data for climate services modelling (again, the entire range of energy, agriculture, health, hydrology applications) than for Earth System services.

Atmospheric composition is not only relevant with respect to climate forcing, but also – on shorter time scales – in view of air pollution. Mountainous terrain does not only trigger its characteristic pollution threats (such as smog episodes in a stably stratified valley) with their feedbacks to Earth-System Services, but also largely increases the complexity by introducing air chemistry as another process that needs to be taken into account. The interactions between chemical transformations and

[1] Sometimes, the processes and activities handled by these models and for which some examples are given in the text, are called *Earth-System Services*. According to the WMO definition, *Climate Services* on the other hand, provide climate information in a way that assists decision-making by individuals and organizations. The processes and human activities, for which this information and data is provided, are again those covered by the Earth-System Services.

turbulence diffusion (which are complicated enough) are thereby augmented by additional length and timescales related to meso-scale processes in complex terrain.

All these developments make it highly timely to plan and execute – some twenty years after the last major international project on mountain meteorology, MAP[2] - a new internationally coordinated project focusing on the investigation, experimental assessment and numerical modelling of the *exchange of energy, mass, and momentum between 'mountainous terrain' and the free atmosphere at all scales and especially their interactions.* Figure 1 below graphically summarizes the endeavour.

It is expected that TEAMx largely contributes to

- increasing the quality and reliability of meteorological point forecasts and climate diagnostics in complex mountainous terrain;
- improving parameterizations both in weather and climate models and Earth-System Service models in complex terrain;
- assessing the uncertainty of the involved processes and hence addressing questions of predictability
- adding to the quality and reliability of Climate Services for areas dominated by topography
- substantiating the scientific basis for air quality abatement strategies and assessment practices.

[2] The Mesoscale Alpine Programme, MAP, was one of the first Research and Development projects of the World Weather Research Programme, WWRP, of WMO)

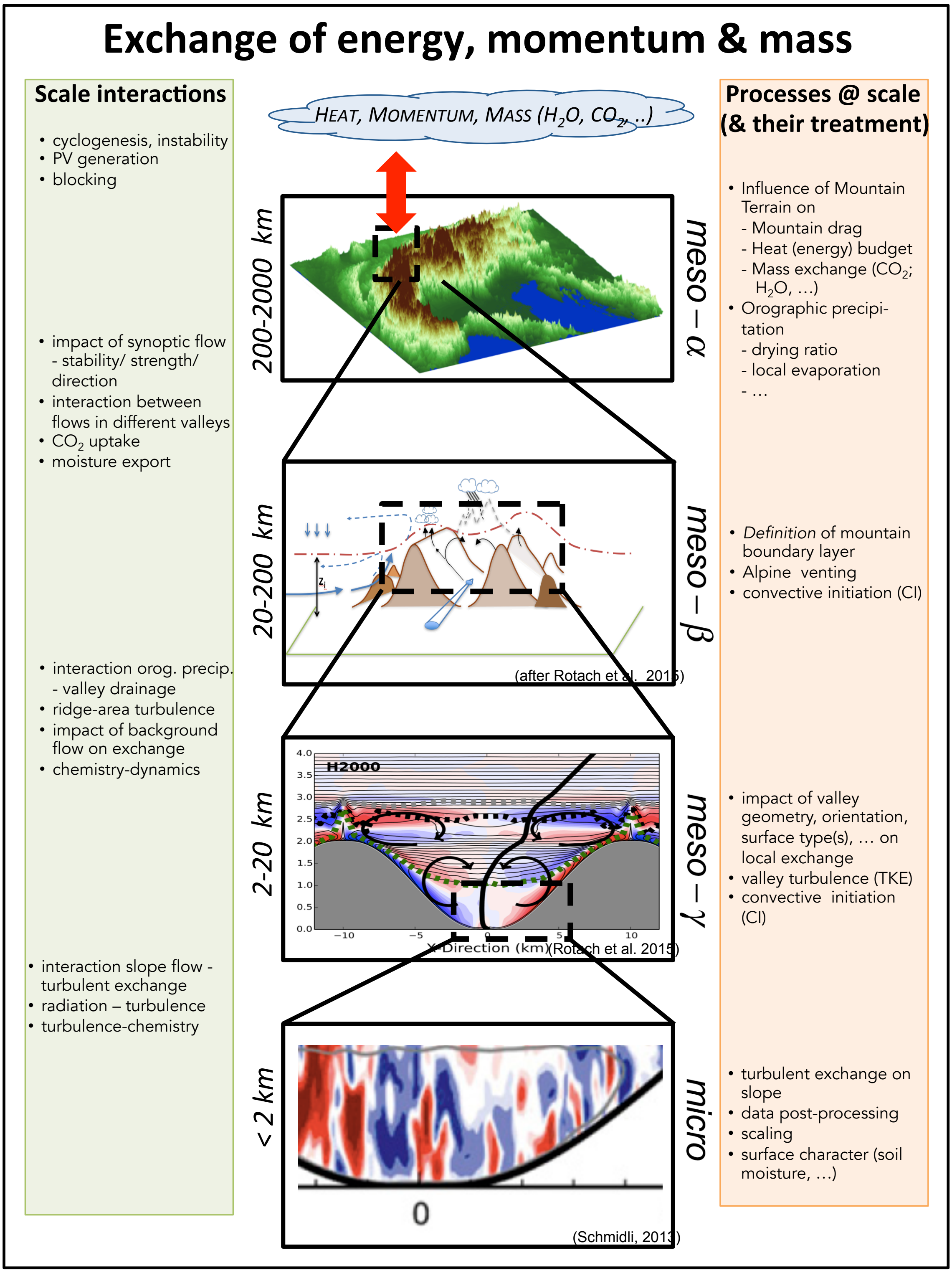

Figure 1 *Different scales in mountainous terrain, atmospheric processes on these scales (right bar) and scale interactions (left bar). The top panel in the middle column shows the Alps at 1 km horizontal grid spacing in the WRF model.*