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Data-driven exploration of orographic enhancement of precipitation

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Orographic enhancement of precipitation is a complex phenomenon met at various spatial and temporal scales. Particularly, a close association between orography and precipitation patterns can be observed at spatial scales of a few kilometres. A broad range of physical mechanisms of orographic enhancement is known, however, issues still remain in mesoscale numerical modelling as orographic effects provoke strong systematic errors on both the windward and the lee sides of terrain features.

A useful insight into the nature of phenomenon can be provided by statistical methods. Many studies in the recent decades aimed to investigate the relations between a variety of topographic indices and the long term average precipitation observed at rain gauge networks. While statistically significant influence of topography on precipitation amounts is often observed, no single topographic index can provide a sufficient description due to the extreme variability and complexity of the phenomenon.

Remote sensing instruments such as Doppler radars provide better spatial and temporal resolution in precipitation observations. Radars, however, require complicated post processing and correction schemes to account for ground clutter, earth curvature, beam oscillation, etc. Particularly, proper correction schemes to account for orographic enhancement effects are essential for quantitative precipitation assessment in the regions of complex topographies. In the context of hydrologic modelling radar imagery can be used to generate precipitation ensembles to estimate the uncertainty in hydrological risk assessment. Covariance models and pattern generation schemes used in multi-point statistics for ensemble generation still need to be improved with respect to orographic enhancement effects.

This study investigates the phenomenon using novel techniques of exploratory data analysis with machine learning methods. The major 5-day precipitation event in Switzerland in August 2005 is used for the analysis. Precipitation fields with a spatial resolution of 1x1 sq. km and a temporal resolution of 5 minutes are observed and aggregated from Doppler radars. Image processing algorithms were applied to estimate the air mass flow from radar imagery and to identify and to track precipitation cells. A variety of topographic descriptors including the terrain slope, curvatures, and directional derivatives relative to flow direction were computed at different spatial scales using the digital elevation model.

A novel clustering method was applied to the dataset to identify typical flow and topographic conditions leading to the formation of precipitation cells. Clusters of typical orographic enhancement effects were observed. As a second step, we applied recent non-parametric kernel techniques to: (1) delineate the most consistent and frequently observed combinations of conditioning factors leading to orographic enhancement; (2) estimate the support of the probability density function of these events in the high-dimensional space of topographic conditioning factors. This work presents the main finding of this analysis and discusses the implications it brings to quantitative modelling of precipitation fields in mountainous regions.