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Multiscaling properties of embedded convective structures in orographic precipitation: toward subgrid-scale predictability

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Along mountain ranges, it is often observed a situation where a stratiform orographic cloud develops shallow embedded convective structures, which change the rainfall pattern and amount considerably and can lead to localized extreme values of rainfall. These localized extremes present a great challenge for forecasters and are responsible for mountain hazards including landslides, debris flows and flashfloods.

Precipitation processes have previously been shown to follow multifractal structure predicted by multiplicative cascade models. This implies that the scaling is determined not by one, but by an infinity of scaling exponents, which can be specified by the scaling exponent function, K(q). This function can be determined using the universal multifractal model (UMM). However, there is no consensus on how to estimate a priori the UMM statistical parameters for a particular rain event. Additionally, the precipitation processes should also be anisotropic, with different scaling exponents in the horizontal and vertical directions, meaning that the atmosphere stratification is scaling. In the present study, these properties are explored by performing a spatial scaling analysis of the statistical moments and using the UMM to empirically quantify the scaling behavior of cloud embedded convective structures, for both 2-dimensional (surface accumulated precipitation) and 3-dimensional (cloud liquid water and vertical velocity) fields. The simulated fields resulting from these highly idealized simulations show the same type of spatial multiscaling that has been reported in the literature for observations of rain, even though the initial conditions fields are not scaling and the underlying terrain is very simple. These results are used to investigate possible relationships between the statistical universal multifractal parameters and the small scale terrain features, terrain-slope (i.e. upwind or downwind), dynamical regimes (described by moist stability, advective time scale, mean wind intensity and mean wind shear) and the different levels of convective organization (more stratiform, cellular or organized bands). Here, we argue that spatial scaling is a characteristic of the solutions of Navier-Stokes equations, at least for these convective rain cases, which are a particular class of turbulent flow. We propose that the introduction of transient multifractal diagnostics in numerical models could provide a pathway to extend the range of resolved scales below the grid resolution, and thus address the question of subgrid-scale parameterization.

A population of idealized 3D cloud resolving high resolution simulations performed with the Weather Research and Forecasting (WRF) model, for various configurations of small scale terrain and upstream profiles are used to analyze the spatial multiscaling properties of embedded convective structures in orographic precipitation.