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Elements of a stochastic precipitation model: from drop to planetary scales

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Technological advances have now permitted observations of precipitation over wide ranges of scales including the extreme small drop scales (using stereophotography to determine the liquid water density) and the extreme large planetary scales (using satellite borne radar to measure reflectivities). Statistical analyses show that at small scales (less than roughly 30 - 50 cm depending on the rate) rain is organized into “patches” at scales such that the Stokes number (St) >1; the implied decoupling of the rain with the turbulence leads to high wavenumber white noise spectrum so that the patches are statistically homogeneous. At larger scales, where St <1 the precipitation is strongly coupled with the turbulence and on the contrary, the liquid water statistics are very nearly those of passive scalars. In terms of scaling exponents, it is characterized by a non (scale by scale conservation) exponent H = 1/3 and (mean) intermittency exponent C1 = 0.1. In comparison, recent analyses of the TRMM satellite radar data show that from 20,000 km down to 4.3 km, the radar reflectivity is very close to that predicted by pure cascade models i.e. with H = 0 but with very high (mean) intermittency exponent C1 = 0.63.

In this talk, we outline a stochastic model which explains this small scale/large scale change in the scaling exponents in a straightforward way. First, we show how coupled multiplicative cascade processes involving energy and liquid water variance fluxes can subordinate a compound Poisson process yielding a model in which the drop positions and sizes are specified in a way that is compatible with turbulence theory and the observations: the key is the scaling of the rain drop number density. When the number density is low the discrete nature of the particles acts as a rain/no rain threshold. Complete theoretical analysis of this compound Poisson - multifractal model is difficult: it imples that the thresholding is both stochastic and coupled with the turbulence. However, we show by a simple approximation that the model does yield the observed change in exponents. We further argue that it can potentially explain both observations of precipitation scaling as well as those finding breaks in the scaling: the latter being fundamentally consequences of rain – no rain transitions.