The wide range space-time scaling of precipitation: from stereophotography to gages, radars, satellites, and numerical models

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Abstract. Precipitation is a key input in hydrological systems and models; it displays extreme variability with complex structures embedded within structures, from drop to planetary scales in space and from milliseconds to millennia in time. The only hope for taming such variability is the existence of some scale by scale regularity, the existence of regimes which are in some sense scale invariant over wide ranges of space-time scales. Over the past thirty years it has become clear that scale invariance is a symmetry principle of great generality; a system can scale invariant even when it is highly anisotropic so that small and large structure are statistically related by "zooms" followed by the squashing and rotation of structures. It is also known that multiplicative cascades are typically associated with nonlinear scale invariant dynamics.

Today, technological advances have permitted observations of precipitation over wide ranges of scales including the extreme small drop scales (using stereophotography) and the extreme large planetary scales (using satellite borne radar) as well as meteorological reanalyses. Below scales of roughly 30 - 50 cm (depending on the rate) the rain decouples from the turbulence forming statistically homogeneous "patches". At larger scales, on the contrary, precipitation is strongly coupled with the turbulence so that the liquid water statistics are very nearly those of passive scalars. Using in situ rain gage networks, ground and satellite radar data and meteorological reanalyses, we show that precipitation has a multiplicative cascade structure up to planetary scales in space and up to 30-50 days in time.

But precipitation is strongly nonlinearly coupled to the other atmospheric fields. To be credible, this scale invariant cascade dynamic must apply to the other fields as well. We outline such a paradigm based on a) advances in the last 25 years in nonlinear dynamics, b) a critical reanalysis of empirical aircraft and vertical sonde data, c) the systematic scale by scale space-time exploitation of high resolution remotely sensed data (TRMM radar and radiances, MTSAT radiances) d) the systematic reanalysis of the outputs of numerical models of the atmosphere including GFS, GEM models and the ERA40, and the NOAA 20th Century reanalyses) and e) a new turbulent model for the emergence of the climate from "weather" and climate variability.

We conclude that Richardson's old idea of scale by scale simplicity - today embodied in multiplicative cascades – can accurately explain the statistical properties of the atmosphere - including precipitation - and its models up to nearly planetary scales in space and over most of the meteorologically significant range of scales in time.