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The stochastic multiplicative cascade structure of determinstic numerical weather models and re-analyses

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By direct statistical analysis of model output we show that over almost all their range of scales and to within better than $\pm 1\%$, that analyses and short range numerical integrations of nonlinear PDE atmospheric models have the statistical structure predicted by multiplicative cascade models. For a midrange forecast (6 days), this agreement with multiplicative cascade models stays within $\pm 2\%$. We quantify this for the horizontal wind, temperature, and humidity fields at 5 different pressure levels for the ERA40 reanalysis the Canadian Meteorological Centre Global Environmental Multiscale (CMC GEM) model, and the NOAA Global Forecasting System (GFS). We discuss how this multiplicative cascade structure can be exploited in improving forecasts through theoretically-motivated stochastic sub-grid parameterizations, checking the stochastic coherence of the models and the assimilation system, and their use in ensemble forecasts.

Multiplicative cascade models came into existence in the 1960's and were developed in parallel to numerical weather prediction models. By the 1980's, these were established as being equivalent to multifractals. Multiplicative cascade models can be of interest to atmospheric scientists because the basic system of equations of the atmosphere allow for cascade behaviour via the lack of existence of a characteristic scale in the equations in between the planetary scale and viscous scale. Furthermore, recent analyses of TRMM satellite observations determined that the radiances observed in VIRS and TMI channels respected scaling behaviour to within $\pm 1\%$. It is believed that there are many cascades determining the underlying scaling behaviour of the various atmospheric fields, which are all coupled. Because of this, scaling behaviour in one field suggests scaling behaviour in other fields. As well, the empirical establishment of cascade behaviour requires that model products also have this underlying behaviour.