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Comparing and contrasting the large scale stochastic cascade structure of atmospheric radiances, numerical models, and reanalyses: implications for model dynamics and errors

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Since the 1960's, stochastic cascade models have been developed as phenomenological models of fluids whose structures span wide ranges of scales. By respecting the basic symmetries of the fluid equations (especially their scaling and conservation properties) they can be considered to be models of models. In the 1980's, it was discovered that cascades are very general; they are the generic multifractal process. Up until now, in the atmosphere, the predictions of cascade models have been repeatedly confirmed empirically over small scales, but numerical weather models have not had sufficient ranges of scale to warrant their application.

However, with the development of modern global scale satellite data and new generations of numerical models, all this has changed. In this presentation, we discuss systematic global scale space-time analyses of radiances (visible, infra red, microwave, passive and active from TRMM and MTSAT satellites) over the range 20,000 km down to 4 km, showing that the predictions of cascade models are respected to within roughly 1% (depending somewhat on the wavelength). Since the radiances, clouds and dynamics are strongly nonlinearly coupled we conclude that the atmosphere also respects cascade dynamics over this range.

We also present the first cascade analyses of numerical weather models and analyses (those with a large enough range of scales) and show that they exhibit this behaviour

as well. In particular, we have found that both the ERA40 reanalysis and CMC GEMS operational models display cascade statistics over virtually their entire ranges of scales (until cut-off by hyperviscosity at scales of a couple of pixels). These discoveries support the use of cascade process models and multifractals in describing the behaviour of the models and analyses.

We conclude that although the models involve complex interacting processes, there is an underlying scale-by-scale simplicity. We describe several ways in which this can be exploited. First, since the cascades determine all the scale-by-scale statistical properties, their characterization allows us to stochastically evaluate the model output: a necessary (although not sufficient) condition for the model to be accurate is that it displays realistic scale-by-scale statistical properties. Indeed, since the model involves a series of steps (assimilation, initialization, integration), the "stochastic coherence" of the steps must be studied. In this way systematic model errors can be statistically identified. Knowledge of the cascade structure can also be exploited in sub-grid parameterizations: one need only assume that the observed large scale cascade structure continues down to sub-grid scales: the cascades thus provide a solid basis for existing ad hoc ideas of "stochastic parameterization".