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Single and Multiple Scattering in Optically Thick Multifractal Clouds

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Satellite studies have shown that cloud radiances (at both visible and infra red wavelengths) are scale invariant over scales spanning much of the meteorologically significant range, and airborne lidar data have shown that vertical cross sections of passive scalar clouds are also scaling but with quite different exponents in the horizontal and vertical directions (quantified by an “elliptical dimension” = Del-23/9 close to the empirical value 2.55ś0.02). This multifractality is the result of huge cloud variability spanning vast scale ranges; over the last twenty years, many studies have been made of radiative transfer in scaling cloud fields, the vast majority of which have been limited to numerical studies in relatively optically thin clouds. An exception to this was the development of a formalism for treating single scattering in optically thick but special (“conservative”) multifractal clouds. In this presentation we show how these results can be extended to nonconservative general “universal” multifractal clouds, and how the analytic single scattering results can be generalized to multiple scattering - at least for optical thickness below a “super thick” limit (?>>100). The theoretical analytic results thus give accurate predictions for the mean cloud optical properties of clouds with realistic multifractal parameters and cloud thicknesses; for example using the observed multifractal cloud characteristics, we predict that the mean cloud transmission decreases with the 0.88 power of the optical thickness (the homogeneous exponent is unity). For clouds with mean optical thickness of 100 (with 1-g=0.15); this is a 38% effect with respect to homogeneity. These theoretical multiple scattering predictions are numerically tested using the discrete angle radiative transfer (DART) approach in which the radiances decouple into non-interacting families with only four (for 2-D clouds) radiance directions each. Since in thick clouds the phase function is of secondary importance (it doesn't affect the scaling exponents), this approach is justified in optically thick clouds where photons undergo many scatterings; sparse matrix techniques allow for rapid and extremely accurate solutions for the transfer. By varying the extinction coefficient, we were able to study the effect of increasing cloud thickness, for typical cloud mean optical thickness in the range 8-200. In this paper we present new results on the transmission statistics in general 2-D universal multifractal clouds (for various Hurst exponents and levels of intermittency). By "renormalizing" the radiation, we relate the mean transmission statistics to those of a homogeneous cloud. Preliminary results concerning the effects of stratification and more generally of anisotropy (associated with different cloud types) are also presented.