Reply to "A Brief Comment about Ergodicity and Rosenfeld-Lensky Method"

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The Method of Rosenfeld and Lensky (1998), hereafter RL, indeed utilizes the ergodicity of specific key properties of clouds at the scales that can be encompassed by a satellite snap shot. In order to avoid the pitfalls that were specified by A. Ruiz based on general theoretical considerations, it is indeed important to specify more clearly than has been made by RL the cloud properties that do show ergodicity.

The effective radius (Re) is obtained only for the cloud tops, and not for the interior of the clouds. The ergodicity argument of RL exactly states that the effective radius at the top of a ***growing*** convective element during its growth undergoes the same evolution as a function of cloud top temperature (T) (and hence as a function of cloud top height and as a function of height and time) as the top properties of ensemble of ***growing*** convective elements at a given time, for a given convective regime.

The cloud microstructure below the top and the precipitation forming processes are then inferred from the evolution of the effective radius with cloud top temperature. The qualification of RL that the inner cloud composition at a given temperature is reflected by the cloud top composition when it was at that temperature, only as long as precipitation does not fall through that height, is not really a limitation in the methodology of RL. It is just part of the inference procedure from the T-Re dependence to the microphysical and precipitation processes.

A. Ruiz suspects that clouds evolve in ways that compromise the ergodicity assumption, in two ways:

First is the concern about different growth modes in clouds when they grow and merge into convective complexes.

This is indeed a theoretically valid concern. However, reality shows that the growing convective elements in a given convective regime, as defined by specific thermodynamic and aerosols conditions, have remarkably similar T-Re relations.

Proper representation of the growing convective elements is simply done by taking care that the snap shot will include growing cloud elements at all top temperatures of interest. This is usually easily obtained at scales of 100X100 km. This has been documented as the smallest scale that represents in a snap shot the equivalent of a precipitating cloud cluster throughout its life cycle (Rosenfeld et al., 1990).

A convective cloud at a given height usually remains nearly at the same effective radius even as it matures, as long as it is not developing ice phase. This has been shown to be the case by aircraft measurements (see RL in their Fig. 10). Clouds above the freezing level develop ice with time, and hence increase the indicated Re as they mature. Therefore, the spread of the Re is typically quite tight until the 0^oC isotherm, and can spread considerably (not always) at colder temperatures (RL; Rosenfeld, 2000; Rosenfeld et al., 2001 and 2002; Rosenfeld and Woodley, 2003). The youngest cloud elements are those with the smallest Re for a given T. This property is used for selecting the young growing convective elements in the determination of the microphysical zones.

The second concern of A. Ruiz for violation of the ergodicity assumption is the concern of inhomogeneous field, mixing different modes of convection. This concern becomes more valid when the scale of the composed snap shot increases. For a 100X100 km the likelihood to mix convection modes due to different aerosols and thermodynamic situation is not very large in an area such as Texas. A more informed selection of areas can take into account air mass (e.g., fronts) and geographic (e.g., land-sea) boundaries. Again, the space scale also translates to time scale. Recent measurements of the same areas by late morning and afternoon satellite overpasses (MODIS on Terra and Aqua) show that the T-Re relations are usually conserved for convective cloud systems. This is supported by aircraft measurements. These findings are now being processed into a full article. These observations are in the directions suggested by A. Ruiz, and therefore, should go a long way to alleviate his theoretical concerns.

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