A Brief Comment about Ergodicity and Rosenfeld-Lensky Method

Arquimedes Ruiz-Columbié
8696 Hangar Rd.
San Angelo, Texas 76901

Abstract

The Rosenfeld-Lensky method to infer cloud microstructure from satellite information is analyzed under the ergodic hypothesis that states at its basis. However, processes of merging and clustering might undermine this assumption. Considerations about quasi-ergodicity are done to validate conclusions about the possible application of this method in the evaluation of operational cloud seeding programs.

Introduction

The use of satellite information to study weather phenomena is today a large and rapidly developing subject. In the particular case of Cloud Physics, Rosenfeld and Lensky (1998) designed a method to infer cloud microstructure using NOAA-14, multi-spectral, **AVHRR** (**A**dvanced **V**ery **H**igh **R**esolution **R**adiometer), which uses the visible band (0.65 μm) to select points with bright clouds whereas the thermal infrared (10.8 and 12.0 μm) is used to determine cloud-top temperature and the solar radiation component of 3.7 μm wave band to calculate cloud-top particle size. The quantity used to characterize cloud microphysical structure is the effective radius (**r_{eff}**), whose dependence as a function of cloud-top temperature can show very important aspects of the microphysical evolution of clouds. The main problem that this methodology faces is the feature that satellites carrying **AVHRR** sensors provide only twice-daily snapshot image of a ground target (only one shot in the afternoon for Texas) and a single cloud cannot be followed continuously in its evolution; its temporal evolution cannot be observed. To overcome this handicap, the methodology utilizes the results for all the growing convective clouds in a specific cluster and composes a function, **cloud-top temperature vs. r_{eff}**, considering each cloud as a representative of a particular stage of 'a typical cloud'. This latter theoretical-basis consideration (the construction of a typical cloud, which exhibits the essential characteristic of a group) is known as the ergodic hypothesis, and was introduced by Boltzman and Gibbs in their works on statistical physics and thermodynamics two centuries ago.

Ergodicity

Historically, the pristine idea came from Boltzmann's ergodic hypothesis (Petersen, 1983). Boltzmann in his works stated that **the long-term time average along a single history of an ensemble should equal the average at any other single moment over all possible histories (all possible ensembles**). The former average would represent the 'typical history' and the latter average would take into account all histories at a given time. In fact, there are now at least two ways of averaging, one taking one ensemble and observing it for a long time (this is the climatologic style), and the other taking many systems and observing them all in one time. The ergodic hypothesis postulates that time average is equal to ensemble average. In order to obtain this conclusion Boltzmann, and Gibbs later, hypothesized that each history filled out all of the phase space (their case was a surface of constant energy in a phase space), which means that in equilibrium the ensemble can visit every state with equal probability. Is this ergodic hypothesis always correct? Gibbs answered positively, but certainly there are many assumptions involved. First it all, how large should be the time of average, because for gases (the main Boltzmann's subject) this time is very small to obtain the equilibrium (ergodicity works), whereas in the case of clouds this time can be very large, and besides, clouds are open system, importing energy and mass from the environment, and also are not actually in equilibrium, they are complex structures in the edge of atmospheric chaos, far from equilibrium, whereas equilibrium means for them death (Ruiz et al, 2002).

It appears that ergodicity will rigorously work only in dead clouds, a stage without interest to Weather Modification. However not all is lost, and its range could be extended, if the clouds are considered living in a stationary regime, far away of transient features, in a dynamical environment that permits an evolution where past, present and future statistics of the cloud system are approximately the same. Then, we would be speaking of **quasi-ergodicity** (or **weak ergodicity**). It is important to point out that two timescales have been found in the evolution of the convective clouds, one scale of growing, the other of stationary behavior and later decay (quasi-ergodic). Measurements should be carefully analyzed to be certain that they belong to the ergodic timescale. Moreover, the aforementioned consideration about the environment is not always true, and therefore, the system has to be followed in detail to determine under the perception of the observers whether or not there is repetition of observed states, or drastic changes, or violation of the quasi-ergodic condition.

Violations of quasi-ergodicity are usually present in the evolution of complex systems with many interacting components: these systems present path dependence and face bifurcation points in their evolution. The fact that clouds are complex, open, and ordered non-equilibrium structures -despite the second law of Thermodynamics- indicates the presence of a broken ergodicity and the formation of cloud patterns with self-organization. Nevertheless, it is also possible sometimes to identify 'ergodic components' of behavior, which means that between knots of transience a system might behave quasi-ergodically.

Some necessary (not sufficient) conditions for **quasi-ergodicity** must be observed:

- Conservation of **dimensionality**: The system under observation must maintain a similar structure and function during all its life. Structural and functional changes are (or may be) inherently non-ergodic, which means that the system is too unique. **Clustering** is a phenomenon that can change dimensionality.
- Presence of almost every stage of development at any time.
- Approximately the same percent for the occurrence of a stage in the ensemble at a given time that the percent of time in this stage for any single history.
- Similarity between earliest and recent observations.

Rosenfeld-Lensky Method Afresh

In the case of Rosenfeld-Lensky method, the actual average is the ensemble average over all the **growing** convective clouds present in a specific cluster. The method then uses a quasi-ergodic treatment to obtain the function **cloud-top temperature vs. r_{eff}**. The shape of this function has plenty of information on the microphysical processes in the observed clouds. The information allows identifying maritime and continental clouds (large droplets in the formers, large concentrations of many small droplets in the latter), but also, the microphysical processes present in those clouds. Five microphysical zones have been identified. An important note has been made then: the aforementioned function is a description of the time evolution of a growing convective cloud top (ergodic hypothesis), and it can be considered a description of the vertical composition of a convective cloud at a given time throughout its depth only as long as no precipitation is falling through the cloud from higher levels. It is clear from this statement that precipitation is a factor that breaks ergodicity. However, we also know that the growing time-scale of convective clouds is essentially not ergodic. How to avoid the contradiction?

Probably the unique alternative is to use the actual measurements of r_{eff} to determine the characteristics of the convective clouds in their early stages, and later follow each one of the cells to figure out the temporal evolution of this variable for each particular type of evolution (let's say single-cell, multi-cell, or super-cell types). Then, in each one of these types the new calculations will offer "the typical case" based on the quasi-ergodic assumption.

The actual method is successful in those aforementioned identifications at a given time (the time of the satellite shot), and it has been used for the identification of seeding signatures (Woodley et al, 2000). Albeit, in this case, and its extension for evaluation purposes, it is very important to be sure that quasi-ergodicity is maintained during all the period of analysis, because changes in the system, especially merging and clustering, can induce variations in microphysics that can be erroneously associated with seeding operations. The analysis of the microphysical processes must be accompanied with thermodynamic and dynamic considerations on the formation and evolution of the observed clouds, the appropriate tracking of the systems, and the detailed description of the actual histories. These tasks are only possible if the satellite information (only one shot from **AVHRR**) is complemented with other satellite images, radar tracking, ground and upper air stations. Additional calculations of the effective radius using other remote sensors and the correlations with the measurements from **AVHRR** might show the evolution of this variable in time, and important feature for evaluation purposes. The principal condition to follow is that quasi-ergodicity must be fulfilled.

Conclusions

- Assumption of ergodicity is present in Rosenfeld-Lensky method of multispectral analyses of satellite image to infer cloud microstructure using AVHRR. This assumption allows the construction of 'a typical cloud' from many actual clouds in a specific target area using only one snapshot.
- Clouds are not really in a state of equilibrium, in fact they are open complex processes with a behavior

in the opposite way of entropy (exporting entropy), although there is a timescale where they can be modeled in a stationary regime and in the absence of drastic changes the quasi-ergodic approximation may be valid.

- Phenomena of merging and/or clustering (non-stationary) might destroy quasi-ergodicity through structural and functional changes.
- Appropriate tracking of observed clouds should be done to guarantee the fulfillment of quasi-ergodicity. Additional calculations should be done to figure out the temporal evolution of the effective radius.

References

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