Breakup of Stratus Cloud Structure Predicted from Non-Brownian Motion Liquid Water Fluctuations

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Introduction

The Detrended Fluctuation Analysis (DFA) statistical method is applied to observed microwave radiometer time series to identify signatures associated with the formation and breakup of stratus cloud in the atmospheric boundary layer. The existence of long-range power-law correlations in stratus cloud liquid water and infrared radiance fluctuations is demonstrated over about a two-hour period. Moreover, use of a finite-size (time) interval window in the DFA clearly allows one to associate the cloud structure changes with transitions from non-Brownian to Brownian-type fluctuations. Such findings are similar to those found in DNA and financial data sequences when mosaics of persistent and antipersistent patches are present. The occurrence of these statistics in stratus cloud water content gives some insight about the underlying (nonlinear) dynamics and suggests the utility of similar studies of the cloud structure given by stratocumulus-topped boundary layer models.

Data

The data used in this study includes the vertical column amounts of cloud liquid water retrieved from microwave radiometer (Radiometrics, Model WVR-1100) measurements. The instrument is located at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program's Southern Great Plains (SGP) central facility. The microwave radiometer measures the downwelling atmospheric radiance in two spectral intervals, one centered at 23.8 GHz and the second at 31.4 GHz. The microwave radiometer records the data as a brightness temperature at 20-s intervals. The field of view of the microwave radiometer is 5.7° at 23.8 GHz and 4.6° at 31.4 GHz. These two frequencies can be used to retrieve the total column amounts of water vapor and cloud liquid water. The column amounts of cloud liquid water are used in this study.

Method

The DFA technique consists in dividing a random variable sequence $y(n)$ of length N into N/t non-overlapping boxes, each containing t points. Then, the local trend (assumed to be linear in this investigation) $z(n) = an + b$ in each box is computed using a linear least-square fit to the data points in that box. The detrended fluctuation function $F(t)$ is then calculated following

$$F^2(t) = 1 / t \, \Sigma_{n=kt+1}^{(k+1)t} [y(n) - z(n)]^2 , \qquad k=0,1,2, \ldots, (N / t - 1).$$

Averaging $F^2(t)$ over the N/t intervals gives the fluctuations $< F^2(t) >$ as a function of t. The procedure is repeated for almost all realistic t interval sizes. If the $y(n)$ data are random uncorrelated variables or short-range correlated variables, the behavior is expected to be a power law

$$< F^2(t) > \sim t^{2\alpha}$$

with an exponent $2\alpha = 1$ (Peng et al. 1994). An exponent α not equal to 0.5 in a certain range of t values implies the existence of long-range correlations in that time interval as, for example, in fractional Brownian motion (Addison 1997). By analogy with DNA sequences, an α exponent drop below 0.5 indicates so-called non-coding regions. A small value of α indicates antipersistence (Addison 1997) of correlations.

Results and Discussion

We have considered the liquid water content in stratus clouds as retrieved from microwave radiometer measurements obtained in Oklahoma between 1996 and 1999. We have chosen two cases for illustration, each of several days duration, as most representative of thick stratus cloud formation and evolution from thick stratus cloud through broken clouds to clear sky. The first case represents a long and uniform stratus cloud from January 9 to 14, 1998, i.e., 144 h.

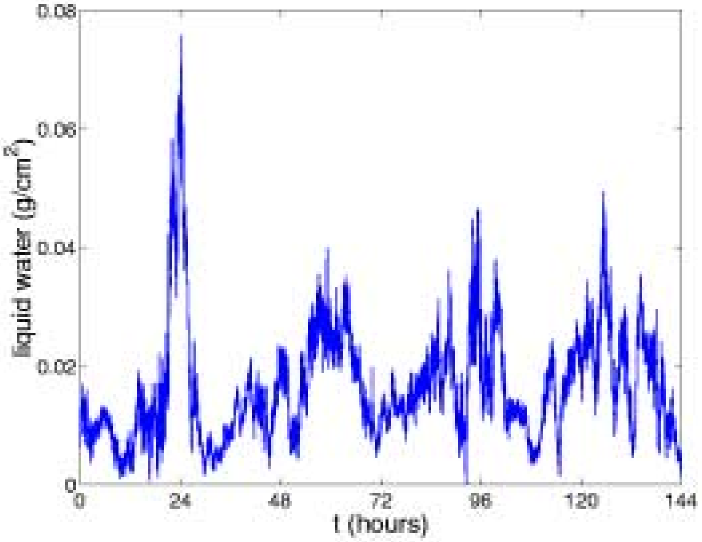

Figure 1. The evolution of a stratus cloud liquid water path (LWP) measured in Oklahoma for the January 9-14, 1998, period. The data series consists of 25,772 data points measured with a time resolution of 20 s.

In Figure 2, a log-log plot of the function $(< F^2(t) >)^{1/2}$ is shown for the data in Figure 1. This function is close to a power law with an $\alpha \sim 0.35$ holding over about two decades in time, i.e., from about 6 to 100 minutes (about 2 hours). This power law is interpreted as a signature of a propagation of some information across the cloud system up to about 100 minutes. These results clearly support the existence/hypothesis of long-range power-law correlations in the cloud liquid water path whatever the trend (see Figures 1 and 3).

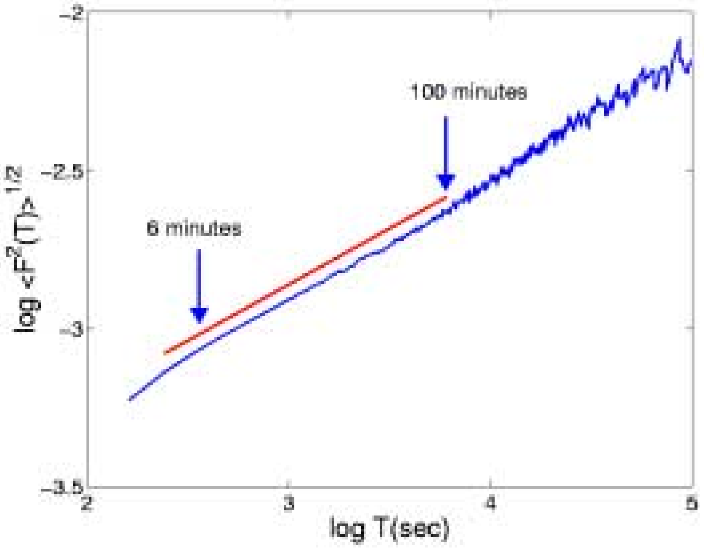

Figure 2. The log-log plot of the α exponent obtained with the DFA method for the liquid water path data of January 9-14, 1998. The scaling properties hold from 6 to 100 minutes; $\alpha \sim 0.35$.

To search for the existence of locally correlated sequences, we constructed a so-called observation box (a window) of “length” w placed at the beginning of the data; then calculate α for the data in that box, and move the box by m+ minutes toward the right along the signal sequence (Figure 4). By iterating this procedure for the data sequence, a “local measurement” is obtained for the degree of local long-range correlations.

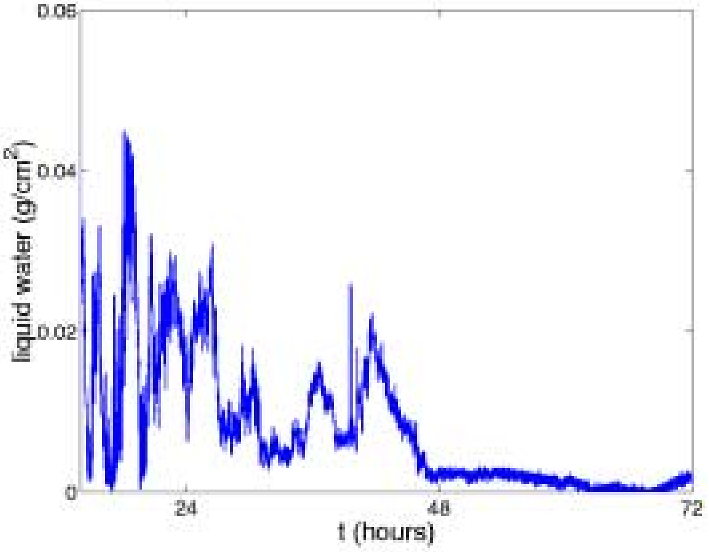

Figure 3. The evolution of stratus cloud liquid water path measured in Oklahoma for the period April 3-5, 1998. The data series consists of 10,381 data points.

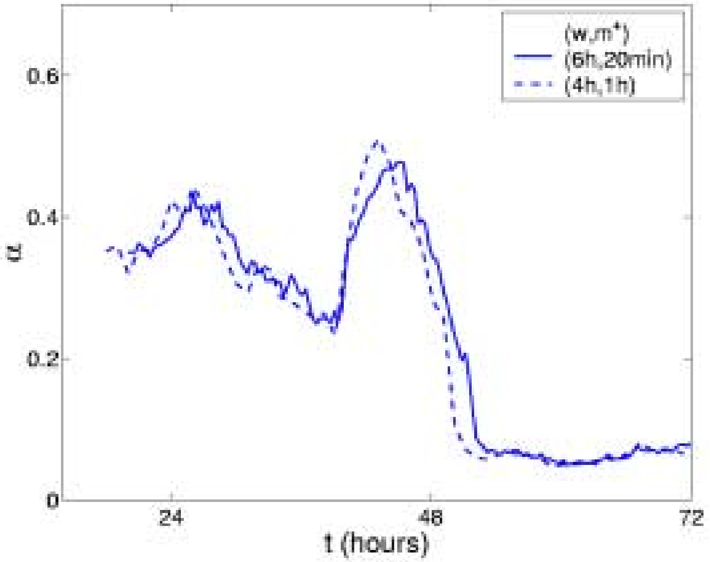

Figure 4. The evolution of the local value of α estimated with the DFA technique for boxes of different size, which slide to the right with m+ minutes; $\alpha \sim 0.34$ for the cloud period and $\alpha \sim 0.06$ for the clear sky. Several robustness tests have been made varying the observation window size w and the number of minutes m+ shift.

The main advantages of the DFA method over techniques like a Fourier transform are that 1) local and large-scale trends are avoided, and 2) local correlations can be easily probed. Moreover, the local value of the α exponent indicates what type of physics underlies the phenomenon.

Conclusions

The liquid water path clearly contains information about the structure of the cloud; the very well defined increase to $\alpha \sim 0.5$ is to be interpreted as the existence of a driving ingredient toward more stochasticity and less predictability. In summary, long-range power-law correlations have been shown to occur in stratus cloud systems. Moreover, we have quantified that specific sequences appear when the cloud system starts to break apart and undergoes a transition to clear sky.

References

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Peng, C.-K., et al., 1994: *Phys. Rev. E*, **49**, 1685.