Internal Variability and Pattern Identification in Cirrus Cloud Structure within the Fokker-Planck Equation Framework

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Abstract

Investigating the internal variability of clouds is of paramount importance to understand, describe, and parameterize the sub-grid processes in large-scale models. In this paper, we focus on the methodology used to study the internal variability of cirrus clouds within the Fokker-Planck equation framework.

Introduction

Because of their vertical extent, cirrus clouds present a suitable experimental setup to study the internal variability in clouds. Given the complexity and difficulty inherent in understanding dynamics in cirrus clouds, a number of studies focus on description and investigation (Quante and Starr 2002 and references therein). In a review article, recent achievements in the analysis of spectral characteristics and scaling of cirrus clouds' behavior dynamics are summarized (Quante and Starr 2002). Various methods of analysis, such as power-spectral analysis (Sassen et al. 1989), cross-spectral analysis (Gultepe and Starr 1995) and wavelet analysis (Demoz et al. 1998) are used to study the dynamical processes in cirrus clouds, including gravity waves. We recently studied the scaling behavior of the internal variability in dynamics of cirrus clouds, employing a detrended fluctuation analysis method at the bulk and at various levels within the cloud. We found that the long-range correlations are different at the top and the bottom layers than those at the bulk of the cloud (Ivanova et al. 2003, 2004). Most recently, adapting a different approach using the Fokker-Planck equation method, we reported on the internal variability of cirrus clouds (Ivanova et al. 2006).

Data and Defining the Stratification

We analyzed observations collected with a 35-GHz millimeter wave cloud radar. The radar produces measurements in four modes (Clothiaux et al. 2000) that are used to obtain a best estimate of the cloud signal following an interpolation procedure described in Clothiaux et al. (2000). The radar measures the backscattering cross section of the emitted wave per unit volume of cloud particles. The logarithm of the backscattering cross section per unit volume η is called the radar reflectivity ($Z_e = 10 \log_{10}\eta$) and is the quantity typically used in the field. Because we are studying the fluctuations, however, we prefer to use the backscattering cross section signal itself. The radar reflectivity is used only at the initial processing to distinguish regions in the cloud having radar reflectivity within certain ranges. In this study, we consider observations collected from 18:00 Universal Time Coordinates (UTC) on January 26, 1997, to 06:00 UTC on January 27, 1997, where the cloud is taken to exist when the signal level is above Z_e = - 45 dB. In our previous study (Ivanova et al. 2004), based on merged sounding data of mixing ratio, temperature, and pressure from four radiosondes launched on January 27, 1997, we calculated the value of both the potential temperature θ and the equivalent potential temperature θ_e (Figure 4 in Ivanova et al. 2004). We found that in different regions of the cloud the signs of the derivatives of both θ and θ_e with respect to height are different. To define the stratification, we compared the sign of the derivatives of θ and θ_e at different heights in the cloud. We found that the upper layer (A) of the cloud, extending between 10 and 12 km, is characterized by neutral stratification. The middle layer (B), extending between 8.2 and 10 km, is characterized by unstable stratification. Finally, the lower layer (C) of the cloud, extending between 5 and 8.2 km, is characterized by stable stratification. The extent of each of the layers is then transformed to radar reflectivity limits. The neutral layer (A) extends within the (-45, -13.5) dB range. The unstable layer (B) corresponds to the radar reflectivity Z_e values within the (-13.5, -7.9) dB range. The stable layer (C) corresponds to Z_e within the (-7.9, +10) dB range. To investigate the bulk of the cloud we defined sub layers within each of the layers. For the neutrally stratified upper layer the sub layers are defined in steps of the radar reflectivity $\Delta\eta$ (shown in Figure 1).

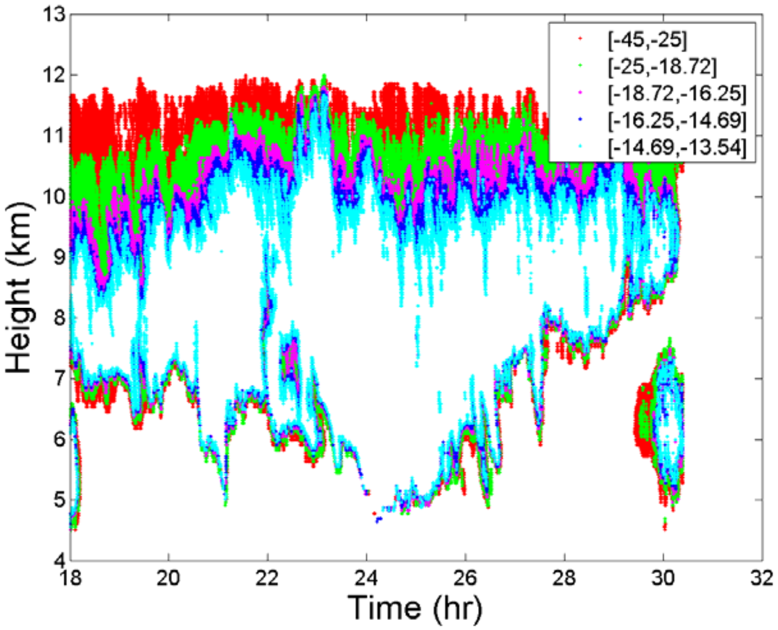

Figure 1. Sub layers within the neutrally stratified upper layer of the cloud (above ~8 km). The range of the radar reflectivity values for each sub layer is shown in the legend. Data were measured at the ARM Climate Research Facility (ACRF) Southern Great Plains (SGP) site on January 26 and 27, 1997. The time is the number of hours after 0 UTC on January 26, 1997.

The unstable layer (B), extending for the radar reflectivity Z_e values within the (-13.5,-7.9) dB range, is divided into sub layers (shown in Figure 2).

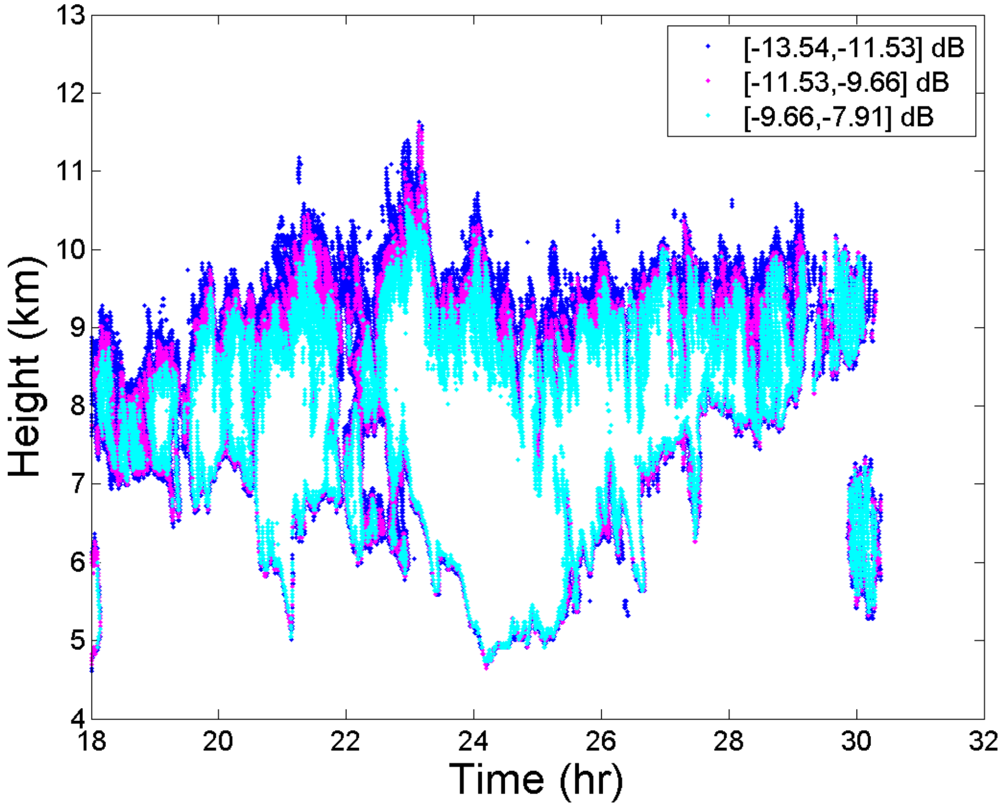

Figure 2. Sub layers within the unstable middle layer of the cloud (above ~7.3 km). The range of the radar reflectivity values for each sub layer is shown in the legend. Data were measured at the ACRF SGP site on January 26 and 27, 1997. The time is the number of hours after 0 UTC on January 26, 1997.

Furthermore, in order to extract the maximum amount of information from the observations, we defined time series within each of the sub layers. We considered the time series of the backscattering cross section at the maximum height within each of the sub layers. In Figure 3, the time series of the backscattering cross section at the maximum height within (-13.54, -11.53) dB is shown as a function of time. This is the uppermost sub layer in the unstable layer (B). Following this rule, time series of the backscattering cross section were defined within each of the eight sub layers.

Method of Analysis

Previous studies (Ivanova et al. 2003, 2004) have shown that the backscattering cross section signal is non-stationary, with long-range correlations between the fluctuations of the signal. As seen in Figure 3, the backscattering cross section signal is characterized by highly irregular and clustered fluctuations

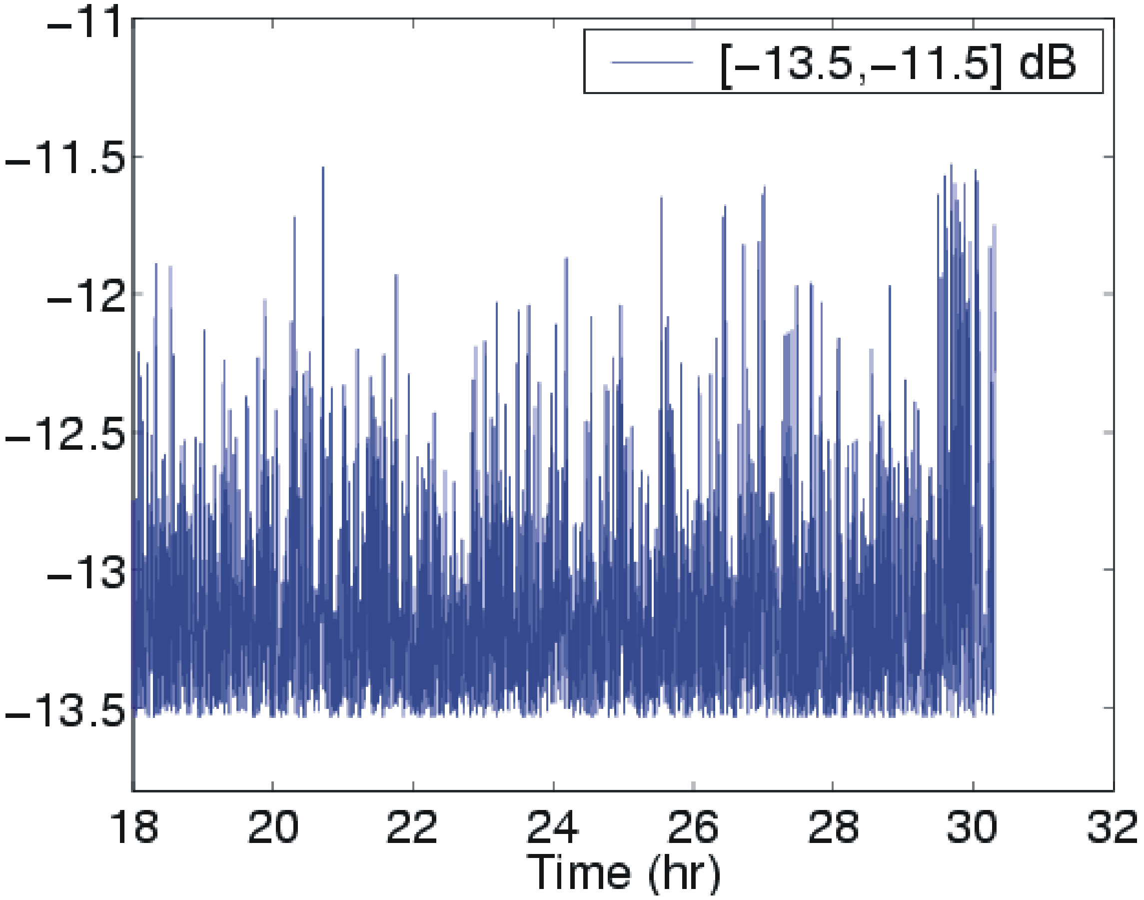

Figure 3. The backscattering cross section signal η measured at the maximum height within the (-13.54, -11.53) dB range as a function of time; the uppermost sub layer in the unstable layer (B).

owing to a set of various influences governing the particle motions at different temporal and spatial scales. Thus, it is of interest to distinguish and quantify from first principles the deterministic and stochastic influences on the backscattering cross section signal in cirrus clouds as described by the drift and diffusion coefficients. These coefficients characterize the dynamics of the processes in the layers having different stratification. It is known that two equivalent master equations govern the dynamics of a system, i.e., the Fokker-Planck equation and the Langevin equation, the former for the probability distribution function of temporal and spatial signal increments and the latter for the increments themselves. The application of the Fokker-Planck equation method to describe and quantify the deterministic and stochastic influences on atmospheric signals is presented in detail elsewhere (Ivanova and Ausloos 2002; Ivanova 2004; Ivanova et al. 2006). The main result obtained from applying this approach to time series of atmospheric quantity is the values of the drift γ and diffusion β coefficients that describe the deterministic and stochastic influences on the dynamics of the signal. We applied the Fokker-Planck equation approach to each of the eight backscattering cross section signals that we defined for each sub layer in the cloud. From the observational data we directly obtained the values of γ

and β for each signal. Based on the requirements of the Kolmogorov -4/5 law for fully developed turbulence (Frisch 1995; Tatarskii 2005), we obtained a relationship between the drift and diffusion coefficients and then found that this relationship holds true for the well-mixed upper layer of the cloud.

Conclusion

In conclusion, we presented a methodology for studying the dynamics of vertical layers in cirrus clouds having different stratification. The method of the Fokker-Planck equation allows us to distinguish and quantify, from first principles, the deterministic and stochastic influences on the backscattering cross section signal in cirrus clouds. From the observational data of the backscattering cross section we directly obtained the values of the drift and diffusion coefficients for vertical sub layers in the cloud. The relationship between the drift and diffusion coefficients that we obtained, based on the requirements of the Kolmogorov -4/5 law, holds true for the well-mixed upper layer of the cloud. These findings will facilitate parameterization of sub grid processes in large-scale models.

Acknowledgments

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