P3.3 OBSERVATIONS OF DROPLET CONCENTRATION AND SPECTRUM SHAPE VARIABILITY IN AMAZON CLOUDS.

Antônio Carlos Santana dos Santos*
Fundação Cearense de Meteorologia e Recursos Hídricos, Fortaleza, Brazil
Universidade Federal do Ceará, Fortaleza, Brazil

Alexandre Araújo Costa
Universidade Estadual do Ceará, Fortaleza, Brazil

José Carlos Parente de Oliveira
Universidade Federal do Ceará, Fortaleza, Brazil

1. INTRODUCTION

Microphysical variables such as droplet concentration and size distribution have great importance in atmospheric studies because they influence precipitation formation and cloud radiative properties (Twomey, 1977a, b). Therefore, improving our knowledge in cloud microstructure is essential in order to understand possible feedbacks in global climate changes (Arking, 1991)

Several previous works were dedicated to the subject of cloud microphysics, in which droplet concentration and/or size variability was analyzed from observations (Hill and Choularton, 1985; Austin et al., 1985; Brenguier, 1993; Twohy and Hudson, 1995; Oliveira, 1998; Costa et al, 2000a, etc.) and modeling data (Brenguier and Grabowski 1993; Costa et al., 2000b, etc.). A common behavior in clouds studied is that the microphysical variability depends upon the air mass and the altitude.

In particular, cumulus clouds usually show significant microphysical variability in space and time. Measurements of vertical velocity, temperature and liquid water content tend to be well correlated, indicating the intrinsic relationship between dynamics, thermodynamics and microphysics within such clouds (Paluch 1979).

This paper presents a study of the variability of microphysical parameters in Amazon convective clouds. Data were collected during a research flight over Rondônia, Brazil (10.3−11.3 S, 60.7−62.0 W) on 23 January 1999, as part of the Tropical Rainfall Measuring Mission / Large Scale Biosphere−Atmosphere Experiment in Amazonia (TRMM/LBA).

2. TRMM/LBA INSTRUMENTATION

One of TRMM/LBA's objective was to study the physical characteristics of Amazon convection. The field campaign comprised a variety of surface instruments: two meteorological radars (S−POL, S band, polarimetric, and TOGA, C band), wind profiler, tethered balloons, radiosonde stations and a raingauge network, as shown in Figure 1.

In addition to the surface−based instrumentation, two research aircrafts were operational on January and February 1999: NASA's ER−2 and North Dakota's Citation II. The former carried a set of instruments similar to the ones found in the TRMM satellite. The latter was equiped with microphysical probes: a Forward Scattering Spectrometer Probe (FSSP−100), a Two−Dimensional Cloud Probe (2DC), a One−dimensional Precipitation Probe (1DP) and a High−Volume Particle Spectrometer (HVPS). In this paper, emphasis is given to the FSSP, which detects cloud particles in the 4.2 − 52.4 um diameter range.

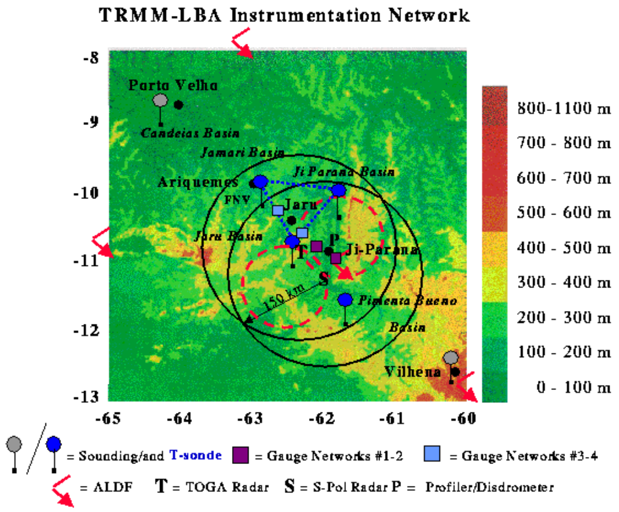

Figure 1 − The TRMM/LBA network.

3. CASE STUDY: 23 JANUARY 1999

3.1. *Environmental conditions*

On that date, the convective available potential energy at 1800 UTC was 1296 J/kg, while the convective inhibition was 29 J/kg. Weak winds prevailed, with little direction change up to the 450 mb level. The lifting condensation level was approximately at 900 mb and the equilibrium level was about 140 mb, as shown in Figure 2 (skew−T / log−p diagram).

---

* *Corresponding author address*: Mr. Antônio Carlos Santana dos Santos. Departamento de Meteorologia. Fundação Cearense de Meteorologia e Recursos Hídricos. Av. Rui Barbosa, 1246. Fortaleza−CE 60115−221. E−mail: acs@fisica.ufc.br

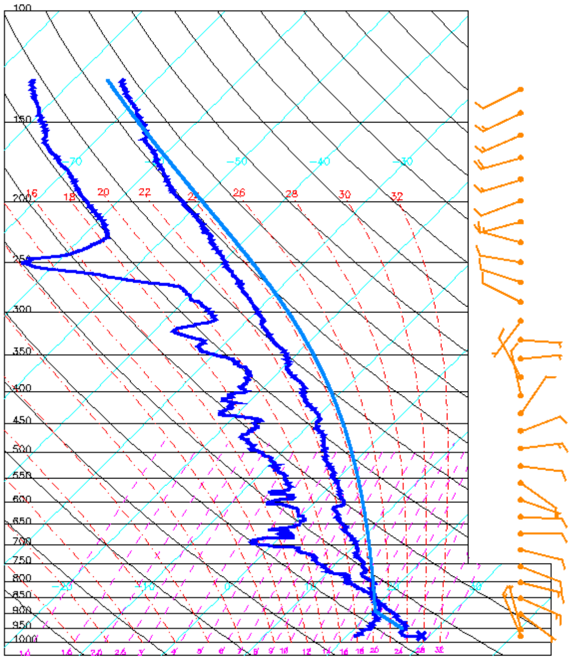

Figure 2 − Skew−T / log−p, 1800 UTC, 23 January 1999

3.2. *Flight Description*

The Citation II took off at 1752 UTC and landed at 2125 UTC. Initially, the aircraft moved to the stratiform region of a cloud system to the East−Northeast of the S−Pol radar, approximately at 10º59’ S, 60º49’ W. The aircraft sampled that region three times, at different levels, before making six passes at the convective part of the system. Finally, the aircraft performed an ascending spiral inside an isolated convective cell. The aircraft trajectory is shown in Figure 3.

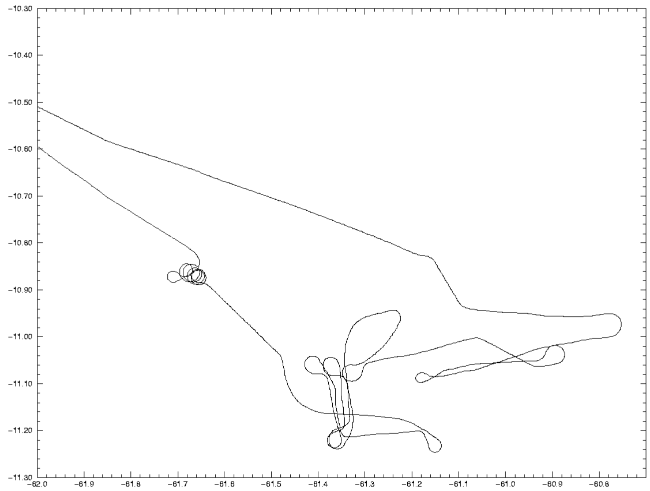

Figure 3 − Citation II trajectory, 23 January 1999 flight

The cloud system exhibited continuous radar echos corresponding to precipitation rates above 10 mm.h^{-1} with a linear dimension of approximately 80 km in the Northwest−Southeast direction (Figure 4a). It moved nearly westward at about 7 m.s^{-1}. The isolated cell studied by the Citation II was developing to the Northwest of the position were it made the first passages in the cloud system. The ascending spiral within the cell was made from an altitude of 1900 m (at 2021 UTC) up to 5500 m (2035 UTC), corresponding to a temperature range of +17 to −2 ºC. Each two−minute interval in the spiral will be treated, in our analysis, as a “pass” inside the cell.

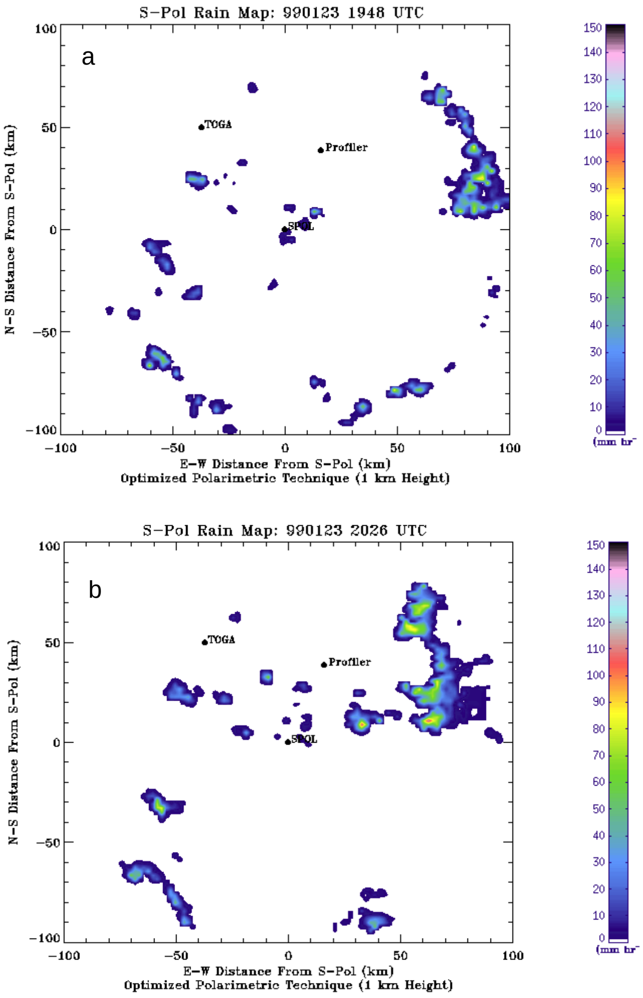

Figure 4 − S−Pol images at (a) 1948 and (b) 2026 UTC.

4. DATA ANALYSIS

The definition of variability coefficient, proposed by Rodi (1978) was used. Let *N* the droplet number concentration, the variability coefficient is defined as the ratio of the number concentration standard deviation and to the average number concentration, both calculated at a given cloud region, or as in equation (1).

$$C_N = \frac{\sigma_N}{\bar{N}} \qquad (1)$$

In this study, the averages and standard deviations are calculates for 5s of contiguous FSSP data. As discussed by other authors (e.g., Austin et al. 1985), if the variations in the observed concentration are due solely to random fluctuations in the sampling process, the cloud region is assumed as “stable” or “homogeneous”. The multiple concentration values must follow approximately a Poisson distribution in that region.

In the opposite case, if the observed variability is much greater than the one expected due to sampling errors, mixing and entrainment are probably affecting the behavior of the cloud region. The region is hence assumed as “variable” and, greater values of the variability coefficient must be found.

With the purpose of characterizing different regions within a cloud, Austin et al., (1985) introduced the normalized variability coefficient, as in equation (2), i.e., the ratio of the actual variability coefficient, given by equation (1) and the one expected for a stable region:

$$R_N = \frac{C_N}{C_{N,\,stable}} \qquad (2)$$

In this paper, both C_N and R_N were generalized in order to take into account not only the concentration variability, but also the spectrum shape variability. With this purpose, two new coefficients (C_S and R_S) were defined as weighted averages of $C_{N,i}$ and $R_{N,i}$, i.e., the concentration variability coefficients for individual FSSP−100 bins. Hence, a high droplet spectrum variability can now be found, even if the total concentration is fairly uniform.

In the present study, cloud regions are considered stable with respect to the number concentration if $R_N < 2$ (arbitrary threshold). Otherwise, the cloud region is assumed as variable, with similar definitions regarding the droplet spectrum. As a consequence, four types of regions can be found in a cloud: type 1 (stable with respect to both total number concentration and spectrum shape), in which $R_N < 2$ and $R_S < 2$; type 2 (variable regarding the total number concentration, but showing nearly uniform spectrum shape), in which $R_N > 2$ and $R_S < 2$; type 3 (stable total number concentration and variable shape), in which $R_N > 2$ and $R_S < 2$; and type 4 (variable with respect to both total number concentration and spectrum shape), in which $R_N > 2$ and $R_S > 2$.

5. RESULTS

Examples of occurrences of type 1−4 regions, as defined in the previous section, are shown in Figure 5. Panel 5a shows droplet spectra with similar modal diameter, width and maximum distribution−function values. Hence, the corresponding cloud region is uniform with respect to both shape and concentration (i.e., type 1). In panel 5b, spectra exhibit similar modal diameter, but the total number concentration (integral over the distribution−function) is clearly variable. The region is hence classified as type 2. In panel 5c, the total number concentration is approximately the same, but the spectrum shape changes (for instance, the first and ninth distributions are quite narrow, while the seventh is broader), which characterizes a type 3 region. Finally, in panel 5d, in a few hundreds of meters inside the cloud, there are both narrow and broad spectra, small and large number concentrations, as expected for a type 4 region.

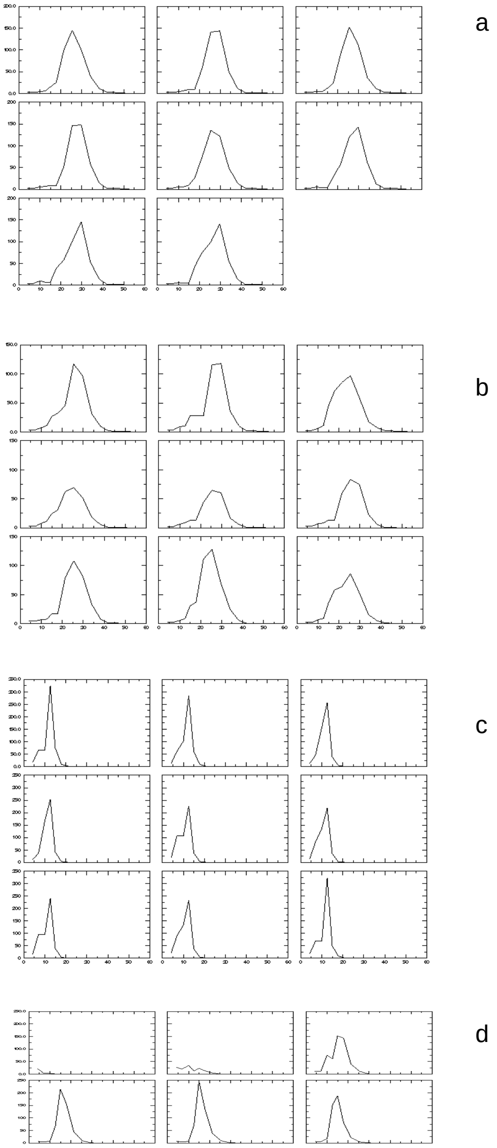

Figure 5 − Sequences of observed cloud droplet distribution functions (FSSP−100 spectra) during the 23 January 1999 TRMM/LBA Citation flight: (a) from 19:36:55 to 19:37:02; (b) from 19:36:39 to 19:37:47; (c) from 19:57:05 to 19:57:14; (d) from 20:24:16 to 20:24:21 UTC. Each spectrum, from the upper left to the bottom right, represents 1s observations. Horizontal axes represent droplet diameters and vertical axes, the distribution−function.

In the cloud system, greater variability in microphysical parameters was found in the last 6 passes, corresponding to its convective part. While type 1 (i.e., uniform) regions represented between 34 % (third pass) and 77 % (second pass) of the rear stratiform part, in the frontal convective portion they were only 0 % (seventh pass) to 25 % (forth pass). Oppositely, type 3 regions, extremely rare in the stratiform part of the cloud system, represented 41 % of the regions sampled during the 8th pass, at the 1600 m level. Type 4 regions, in which both droplet number concentration and spectrum shape are highly variable, dominated the last three passes (38 % to 39 % of the total). As expected, greater convective activity and turbulence led to intense entrainment and mixture in the convective portion of the cloud system, as opposed to its stratiform counterpart.

In the isolated cell, type 2 regions were more frequent, while type 1 regions represented only 8 % of the total, suggesting a highly variable environment. The percentage of each type of region the isolated cell and each pass inside the cloud system is shown in Table 1.

Table 1 − Percentage distribution of different types of regions for each pass in the cloud system and in the isolated cell studied on 23 January 1999.

Pass		***Type 1 (%)***	***Type 2 (%)***	***Type 3 (%)***	***Type 4 (%)***
Stratiform part of the cloud system	1st	52	47	0	1
	2nd	77	22	1	0
	3rd	34	56	0	10
Convective part of the cloud system	4th	25	47	10	18
	5th	6	94	0	0
	6th	20	38	4	38
	7th	0	62	0	38
	8th	13	7	41	39
	9th	Only raindrops, no cloud droplets			
Isolated cell		8	46	4	42

6. SUMMARY AND DISCUSSION

In this paper, as opposed to previous works, in which the microphysical variability was analyzed regarding only the total number concentration of cloud droplets, it was shown that quantifying the variability with respect to both the concentration and the spectrum shape is important in order to describe the microphysical behavior of clouds. A 4−type cloud region classification was then achieved: Type 1 (uniform concentration and spectrum shape), type 2 (uniform shape and variable concentration), type 3 (uniform concentration and variable shape) and type 4 (variable concentration and shape).

Probably, physical processes such as entrainment, discrete and occurring mainly in certain regions of stronger convective activity, were responsible for the variability found in the clouds studied in this paper.

Significant differences were found between the stratiform and the convective portions of a cloud system. While the former was dominated by uniform regions, the later showed a significant number of variable regions of type 2 (4th, 5th, 6th and 7th passes), 3 (8th pass) or 4 (6th, 7th and 8th passes). The isolated cell also exhibited a majority of variable regions.

ACKNOWLEDGEMENTS

The authors thankfully acknowledge the North Dakota University for the data collected by the Citation II during the TRMM/LBA campaign and the National Space Development Aeronautics and Space Administration (NASA) for data, information and figures available in its website. Dr. Murilo Pereira de Almeida, from the Physics Departament of the Federal University of Ceará provided indispensable computational support. José Carlos Parente de Oliveira received support from the Instituto Nacional de Pesquisas Espaciais (INPE) to participate in the field campaign. Antônio Carlos Santana dos Santos was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

REFERENCES

Arking, A., 1991: The radiative effects of clouds and their impact on climate. *Bull. Amer. Meteor. Soc.*, **72**, 795 − 813.

Austin, P. H., Baker, A. M. Blyth, J. B. Jensen, 1985: Small−Scale Variability in Warm Continental Cumulus Clouds. *J. Atmos. Sci.* **42**, 1123−1138

Costa, A. A, C. J. de Oliveira, J. C. P. de Oliveira, A. J. C. Sampaio, 2000a: Microphysical observations of warm cumulus clouds in Ceará, Brazil, *Atmos. Res.*, **54**, 167−199.

Costa, A. A., G. P. Almeida., A. J. C. Sampaio, 2000b: A bin−microphysics cloud with high−order, positive−definitive advection, *Atmos. Res*., **55**, 225−255.

Brenguier, J. L, 1993: Observations of cloud microstructure at the centimeter scale. *J. Appl.Meteor.*, **32**, 783−793.

Brenguier, J. L. And W. W. Grabowski, 1993: Cumulus entrainment and cloud droplet spectra: A numerical model within a two−dimensional dynamical framework. *J. Atmos. Sci.*, **50**, 120−136.

Hill, T. A. and T. W. Choularton., 1985: An airborne study of the microphysical structure of cumulus clouds., *Quart. J. R. Met. Soc.*, **111**, 517−544.

Oliveira, C. J., 1998: Um Estudo das Propriedades Microfísicas de Pequena Escala em Nuvens Tipo Cumulus do Estado do Ceará. Ph.D. Dissertation, Physics Department, Universidade Federal do Ceará − UFC, 230 pp.

Paluch, I. R, 1979: The entrainment mechanism in Colorado cumuli. *J. Atmos. Sci*. **36**, 2467−2478.

Rodi, A. R., 1978: The small scale variability of the cloud droplet spectrum in cumulus clouds. Proceedings of the International Conference on Clouds and Precipitation and Atmospheric Electricity, 88−91.

Twohy, C. H., and J. G. Hudson, 1995: Measurements of clouds condensation Nuclei Spectra within maritime cumulus cloud droplets: implications for mixing processos. *J. Appl. Meteor.*, **34**, 815−833

Twomey, S., 1977a: The influence of pollution on the shortwave albedo of clouds. *J. Atmos. Sci.*, **34**, 149−152.

Twomey, S., 1977b: *Atmospheric Aerosols*. Elsevier, 302 pp.