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TEMPORAL EVOLUTION OF RAINDROP SIZE DISTRIBUTIONS FROM MIXED CLOUDS IN MEXICO CITY

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1. INTRODUCTION*

Warm rain processes play an important role not only in tropical regions, but also in mid-latitude summer precipitation, where collision-coalescence mechanisms may take place in lower atmospheric layers. This is the case of Mexico City, that is located in the southwest area of the Mexico Basin at an altitude of about 2,250 masl, with its rainy season occurring over the summer and autumn. This geographical location, along with the typical meteorological characteristics during the rainy season, allow for the development of convective clouds with warm bases, although cloud-tops show the presence of ice particles that formed and developed during the early stages of precipitation. Furthermore, the location of the 0°C isotherm, typically at a height of about 1,500 meters above cloud-base, allows for small ice particles to melt during their fall. Thus, it is not surprising for the climatology of the region to show that the number of hail events in the Mexico Basin is negligible as compared to the number of rainy days (Jáuregui 2000). This indicates that, although the clouds over the Basin are mixed, cloud and precipitation ice particles have enough time to at least partially melt and interact with other liquid drops before reaching the ground.

The importance of the observation and study of raindrop spectra arises from the fact that they contain basic information regarding cloud and precipitation microphysical processes and their interactions with dynamical aspects of their development. On one hand, numerical modeling studies for warm-rain predict fixed shapes for equilibrium raindrop size distributions (DSD). Generally, equilibrium DSD show a multimodal behavior (i.e., with several peaks) and are only dependent on rainfall rate. According to these models, the shape of a DSD remains the same independently of the initial drop spectra, given that a long enough period of time is allowed for microphysical processes to reach steady-state conditions. In 1982, Low and List predicted peaks in warm-rain spectra by using numerical and laboratory work that simulated natural events. Numerical models of steady (Valdez and Young, 1985; List *et al.*, 1987) and non-steady (McFarquhar and List, 1991) rain predicted three-peak distributions (3PD) with similar, fixed diameter ranges between 0.22-0.27, 0.7-0.93 and 1.3-2.0 mm (List and McFarquhar, 1990). Further simulations with an improved collision-coalescence-breakup kernel predicted spectra with only two peaks at 0.26 and 2.3 mm (McFarquhar, 2004). It is important to note that these results were obtained assuming events with large, constant rain rates sustained over periods of time longer than about twenty minutes. On the other hand, clustered rain (referred to as zones with different raindrop concentrations falling through an area) can be observed by noticing that rain intensity changes in time over a single precipitación event. However, when rainfall intensity measurements are made with a proper time resolution (for example, with a raingauge), it is possible to detect short periods over which rain intensity remains almost constant.

With the purpose to studying the evolution of clustered rain originating from mixed clouds, simultaneous observations of rainfall rate and microphysical parameters were made at ground level in a site located in the southwest area of Mexico City. Data were obtained with a rain gauge and two 2-D optical array spectrometer probes, and stratified in terms of time periods with similar values of rain intensity. Also, in order to support the hypothesis on the microphysical processes for the development of warm rain in the region, a cloud and precipitation climatology for the Mexico Basin was developed using available data from the TRMM satellite, atmospheric soundings and a raingauge network. The results are presented in what follows.

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2. CLOUD AND PRECIPITATION CLIMATOLOGY

Available TRMM satellite data for the Mexico Basin were acquired from NASA's Earth-Sun System Division, comprising the 15 May to 15 November (rainy season) periods between 2000 and 2005. During this six-year period, about two hundred and seventy satellite passes over the area were found. Given that rainfall in the region typically occurs during the afternoons and evenings, only data between LST 1500 and 2100 hours were kept, thus reducing to about seventy the number of satellite passes available. Out of this sample, cloud and precipitation "cells" were detected only in about fifty passes, in most of which only one "cell" was observed in each case. The TRMM data (*2A12*, *2A23* and *2B31*) files were analyzed using the *Orbit Viewer 1.3.5 for Windows XP* software (also provided by NASA's Earth-Sun System Division), and used to discriminate between cloud and precipitation, liquid water and ice particles at different atmospheric height levels. For surface precipitation the satellite images were compared to the automatic raingauge network data provided by the Mexico City Water System (Sistema de Aguas de la Ciudad de Mexico, SACM). To do so, the rain accumulated over 1-hour and 15-minute periods around the time of the corresponding satellite pass at each station was integrated and then interpolated over the region. An example is shown in Figure 1, demonstrating good agreement between both data sources.

Since one of the main goals of this study was to observe the behavior of the ice particles while precipitating, comparative analyses of the TRMM data with atmospheric soundings were made to locate the melting band and the average height at which ice completely melts. Data from soundings, regularly launched at 1800 LST from Mexico City's International Airport, were used to locate the average height of the 0℃-isotherm during the rainy months over the Basin. On the average, the 0℃-isotherm was found at 4,800 masl (i.e., 2500 m above the ground), whereas cloud bases were usually estimated to occur about 1 km above the surface (i.e., 3,755 masl). From TRMM Microwave Imager (TMI) and Precipitation Radar (PR) data during precipitating events, the height of bright band was found between 4 and 5 km above sea level, having an average width of less than 1km. Thus, a good correspondence between radar and sounding data was found. Furthermore, for the whole data set, no cases of hail at the surface were reported nor ice particles observed below the 1,500-m level (from the ground), even for high, larger than 20 mm hr^{-1} rainfall rates (Figure 2).

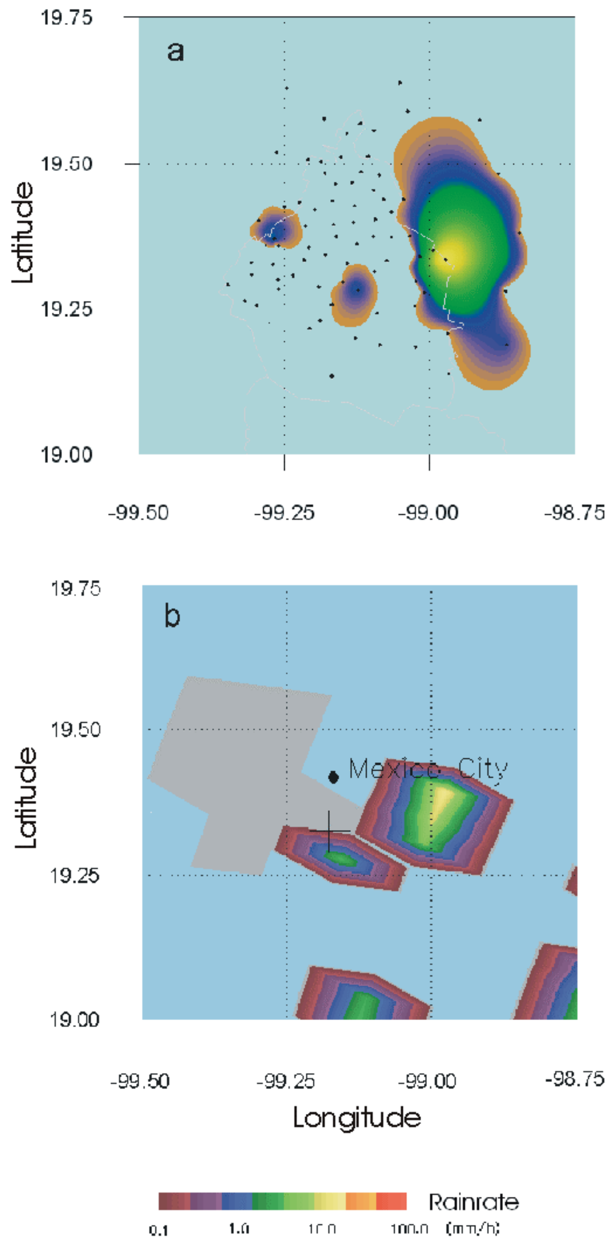

Figure 1. Rainfall rate estimation at the surface, on 18 October 2001 at 1700 LST: (a) from the SACM network, and (b) from the corresponding TRMM *2A12* file. Rain intensity interpolations in (a) for the network data from individual raingage stations (dots) were made with the *Surfer V 8.01* software, using a Kriging-type algorithm.

From the previous discussion it can be argued that, even though precipitation events over the Mexico Basin originate from mixed clouds, the rain they produce at the surface may well be the result of warm-rain processes developing towards the mature and final cloud and precipitation stages.

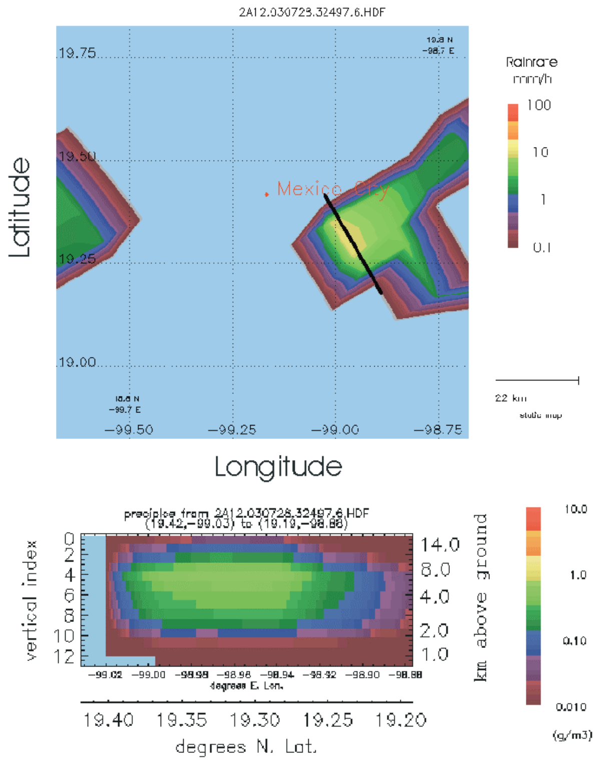

Figure 2. Ice particle content (g m-^{3}) vertical profile inside a precipitating cloud (bottom) on 28th July 2003. The solid line in the top, TMI image indicates the location of the cross-section.

This is plausible considering that there is enough time for ice to melt and water drops to interact during their fall through the melting layer, so the collision-coalescence-breakup mechanisms can take over before precipitation reaches the ground (about 2,500 m below). Depending on the characteristics of each particular event (such as its duration and intensity, temperature and humidity profiles below cloud-base, etc.), rainfall may even evolve towards equilibrium, as described by some of the numerical models mentioned above. It should be noted, however, that most observed events do not generally attain long constant-rainrate periods, exception made of some short-lived (a few minutes), high rain intensity episodes.

3. MICROPHYSICAL CHARACTERISTICS

Raindrop spectra near the surface were measured in the southern end of Mexico City during the 2002 and 2004 rainy seasons. The data were obtained with two airborne optical array spectrometer probes [(OAP): a 2D-C and a 2D-P, 32-photodiode array versions, manufactured by Particle Measuring Systems (PMS - Knollenberg, 1976)] adapted for a fixed, vertical orientation operation at the ground. An OAP uses a photodiode array and associated photodetection electronics to achieve two-dimensional information from particles passing through a laser beam at the sampling region. This type of probe employs a linear array of photodiode elements and takes image slices of the shadow cast by a particle as it progresses through the sampling volume, at a rate given by a clock. By relating it to the number of image slices, the clock frequency also serves to keep track of both the time a particle takes to cross the array (particle transit time) and of particles inter-arrival times. Thus, the size of the particle is determined from the maximum width (number of shadowed diodes times the resolution of the probe) across the array; and its velocity derived by dividing the size by the transit time. It should be noted that PMS two-dimensional optical array probes were originally designed for airborne use, so a clock frequency of 4 MHz was chosen such that, for a sampling speed of 100 m s^{-1}, shadow images of spherical particles would attain circular shapes. In order to operate the probe at lower, constant sampling speeds without loosing the “roundness” of the images, the reference oscillation frequency can be varied “at will” via the electronic circuitry. For two probes operating simultaneously, as in the present case, the second spectrometer frequency is “slaved” to that of the first one by a factor of eight. Thus, for two-dimensional OAPs operated in a stationary mode, the resulting images will always appear elongated in either direction, exception made of those corresponding to spherical particle sizes whose fall speeds match the constant sampling frequency used. In this way, the sampling volume is indirectly measured for each drop image given the sampling frequency of the probe used (for further details see García and Montero, 2004). The 2D-image data were analyzed with a software routine specifically developed for the particular sampling conditions (Álvarez and Torreblanca 1992). The reconstruction algorithm uses a center-in technique and is capable of taking into account the slanting of the images. Probe resolutions were 25 and 200 µm for 2DC and 2DP, respectively. The maximum detection size for the 2D-C was 762 µm, and the minimum for the 2D-P was 538 µm. In addition, arrival times for each drop were obtained from with the software by extracting the image-data analyses from PACS, the default data-acquisition software.

Environmental conditions during sampling were monitored and recorded with a weather station located next to the OAPs. Temperatures recorded during the field observations ranged from 15 to 25°C under calm wind conditions (maximum wind speed drafts of 2 m s^{-1}). One-minute periods of rainfall rate, as detected by the raingauge, were compared to those derived from the precipitation water content of the measured 2D-P spectra. These comparisons showed a small, systematic overestimation of rain intensity as calculated with the OAP data, thus requiring further instrumental analyses.

It was found that comparisons of the number of raindrop counts detected by the two 2D-probes and the rainrate calculated from the raingauge serve to qualitatively correlate the behavior of the precipitation event as it evolves in time. An example is shown in Figure 3, where it can be appreciated that periods of constant rain intensity can be considered good candidates to establish the presence of drop clusters, provided that further testing for particle interarrival times is performed. An example of the latter is presented in Figure 4, where one-minute averages of raindrop interarrival time (RIT) calculated from the 2D-P image data for drops with D_e~630 µm are shown as a function of time. In this figure, and for the first part of the episode (before 1544 LST), it is observed that the RIT averages variation is larger than in the last part, without any noticeable correlation between periods of different rain intensity. In the second part (after 1544 LST) the RIT average values are significantly smaller, even for periods with rainfall rates similar to those observed at the beginning of the rainshower event. However, the differences between RIT average values increase again at the final part, when rainfall rate begins to diminish.

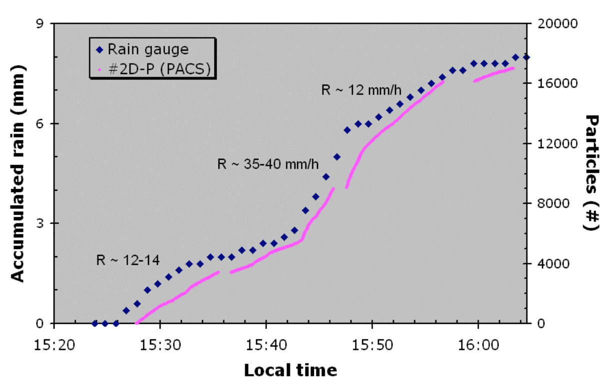

Figure 3. Time evolution of one-minute, accumulated rain from the raingauge data and of the corresponding cumulative raindrop number of counts detected by the 2D-P for a rainshower on 22 July 2002. Periods of constant rainfall rates (*R*) larger than 10 mm hr^{-1} over a few minutes are also shown.

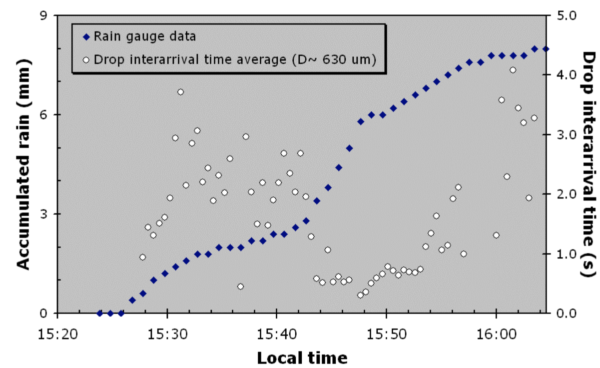

Figure 4. Time evolution of one-minute averages of raindrop interarrival time for raindrops with D_e~630 µm, calculated from the 2D-P data for the same rainshower presented in *Figure 3*.

The raindrop size distributions at diverse stages of the event allow one to observe the evolution of the rain episode. Figure 5 shows two series of spectra, in terms of the natural logarithm of drop diameter, *D* [$N = a(l)\,dl$, where $l = \ln D$], based on one-minute sampling of the 2D-P probe data for two periods with similar *R* values. In this case, differences between drop size distributions are noticeable: there is a lack of drops smaller than 1-mm in diameter (Figure 5a) during the early stages of the rainshower in comparison to those in the spectra corresponding to the mid- and final stages (Figure 5b). This behavior is reflected also in the larger, more variable RIT values for the first part of the rainshower event (Figure 4), that may be also an indication of evaporation and other processes affecting raindrops during their fall below cloud-base.

4. CONCLUDING REMARKS

TRMM satellite data were used to characterize precipitation over Mexico Basin during the rainy season. Estimations of precipitation from the TRMM data were found to agree well with data reported by the SACM surface raingauge network and the occurrence number of hail events at the ground in the region. Results from the TMI and PR analyses were also found in good agreement with sounding data in regards to the height of the melting band during the rainy season. These results indicate that, although most of the precipitation that occurs in the region originates from mixed clouds, the rain they produce at the surface may well be the result of warm-rain processes developing towards the mature and final cloud and precipitation stages, considering that there is enough time for ice to melt and water drops to interact during their fall through the melting layer, so the collision-coalescence-breakup mechanisms can take over before precipitation reaches the ground.

The OAP-2D data were used to study the drop interarrival times at different stages during rainshowers. The results show that, for periods of heavy rain, there is a trend for similar drop counts and interarrival time values when the observational time period lasts for more than three minutes. This may be interpreted as an indication of spatial homogeneity of rain inside a cluster and give information regarding the drop interaction processes occurring during different precipitation stages. The study also indicates that changes in environmental conditions of the lower atmospheric layers and the raindrop interactions that occur there play an important role in the evolution of raindrop interarrival times and the shape of the spectra.

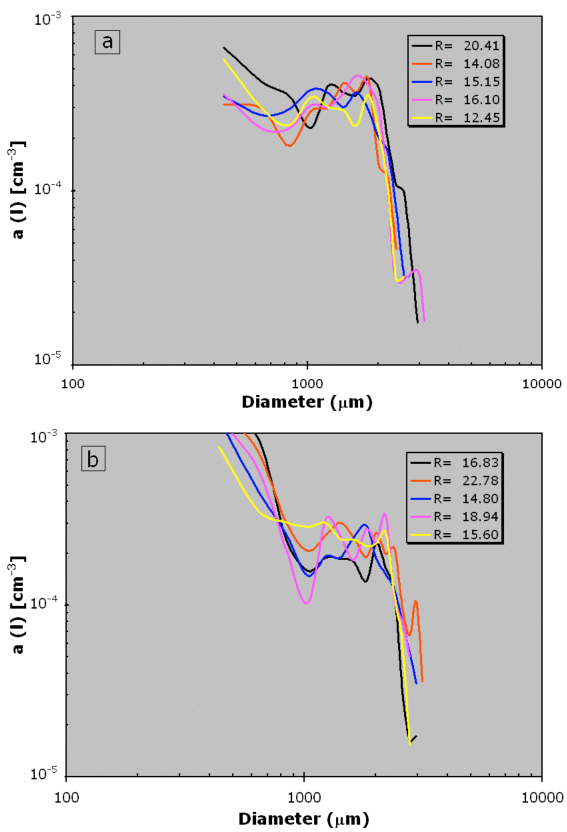

Figure 5. Raindrop size distributions obtained for the same event presented in *Figure 3*, for periods with similar *R* value: (a) spectra corresponding to the period 1529 to 1534 LST, and (b) spectra corresponding to the 1552 to 1557 LST interval.

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REFERENCES

Álvarez-P., J.M.,. Torreblanca-B., J., 1992: *Desarrollo de un Sistema de Software para Interpretación y Análisis de Datos de Espectrómetros de Gotas*. Tesis de Licenciatura, UNAM, 150 pp. [Available from UNAM, Library Code 001-01132-A6-1992-1]

García-García, F., Montero-Martínez, G., 2004: On the measurement of raindrops fall speeds at the ground using optical array probes. *Proc. 14th Int. Conf. Clouds Precip*. IAMAP/ICCP. Bologna, Italy, **2**, 1085-1088.

Jáuregui, E., 2000: *El Clima de la Ciudad de México*. Plaza y Valdez Eds. 131 pp.

Knollenberg, R.G., 1976: Three new instruments for cloud physics measurements: The 2-D Spectrometer, the Forward Scattering Spectrometer Probe, and the Active Scattering Aerosol Spectrometer. *Prepr. Int. Cloud Phys. Conf*. Boulder, CO. Amer. Meteor. Soc., 554-561.

List R., McFarquhar, G. M., 1990: The evolution of three-peak raindrop size distributions in one-dimensional shaft models. Part I: Single-pulse rain. *J. Atmos. Sci*., **47**, 2997-3006.

List, R., Donaldson, N. R., Stewart R. E., 1987: Temporal evolution of drop spectra to collisional equilibrium in steady and pulsating rain. *J. Atmos. Sci*., **44**, 362-372.

Low, T. B., List, R., 1982: Collision, coalescence and breakup of raindrops. Part II: Parameterization of fragment size distribution. *J. Atmos. Sci*., **39**, 1607-1618.

McFarquhar G., 2004: A new representation of collision-induced breakup of raindrops and its implications for the shapes of raindrop size distributions. *J. Atmos. Sci*., **61**, 777-794.

McFarquhar, G. M., List, R., 1991: The evolution of three-peak raindrop size distributions in one-dimensional shaft models. Part II: Multiple pulse rain. *J. Atmos. Sci*., **48**, 1587-1595.

Valdez, M. P., Young, K. C., 1985: Number fluxes in equilibrium raindrop populations. A Markov chain analysis. *J. Atmos. Sci*., **41**, 1024-1036.