# PHASE COMPOSITION OF CUMULUS CLOUDS IN THE CAMAGUEY METEOROLOGICAL SITE

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## ABSTRACT

This paper presents the time evolution of phase composition and other main characteristics of tropical cumulus clouds measured as part of the Cuban Weather Modification Program in the Camagüey Meteorological Site. Measurements were made from an AN-26 instrumented aircraft at a flight level of nearly 6 km, it air temperature ranging from -7 to -10 ºC. Cloud top heights ranged from 6 to 8 km. Ice concentration obtained for particles greater than 120 microns, was less than 2 - 3 $\ell^{-1}$ for young developing cumuli. The ratio of solid to total water for these clouds was less than 0.1- 0.2. Moderate increase of ice was detected 12 – 15 min. after first echo in an x – band radar.


Fig.1: Aircraft AN-26 used to data collection.

Fig. 2: Microphysical measurement complex IVO-1 and IVO-2.

## INTRODUCTION

Microphysical characteristics of clouds and the time evolution of phase composition are of great importance for finding the possibility of adequate response to the seeding with a freezing reagent and to define the seeding hypothesis and methods.
Particular attention has receive in the last years the so called time seeding window, or the time interval for which the LWC is enough and the processes of secondary ice production are not yet valuable. Only if the dynamic seeding is made within this interval of the cloud lifetime, it may be successful.

The purpose of this paper is to present an analysis of the time evolution of phase composition (liquid - solid) to find the seeding window and the seedability of clouds of the Cuban Weather Modification Program (in Spanish, Projector Cubano de Modificcaci'on Artificial del Tiempo, PCMAT) in the Camagüey Meteorological Site (CMS). Equipment, Measurements and data
The measurements were made during the rainy season in Cuba, in the months of July and August The CMS is located on the central eastern part of Cuba and is limited by a circumference of 80 km radius, centered at the Camagüey Meteorological Center, in the Camagüey City.

An Instrumented, twin-engine AN-26 aircraft was used to collect the data, with a service ceiling of about 6 km and a cruising true airspeed of about 100 $ms^{-1}$. The aircraft was instrumented with the following set of equipment: Instruments for measurements thermodynamic parameters such as temperature, pressure, and humidity; mean temperature and temperature fluctuation thermometer (Dimitriev and Strunin, 1985), with a range from -70 to 50 ºCfor mean values and ± 2 ºC for fluctuation and errors of ± 0.4 ºC and ± 2.4% respectively; the LWC prove IVO-1 (Nevsorov, 1983) with a range of 0.003 – 4.5 $gm^{-3}$ and an error of ± 5%. The radius range that can be measured by the Nevsorov probe is of 2 – 150 µm. The total water content (TWC) Nevsorov probe IVO-2, similar to IVO-1 but capable to measure both, droplets and ice crystals. Concentration of ice particles with radius greater than 120 µm was measured with the Mee – 120 (WMO, Report # 7, 1977).

The values of ice water content (IWC) were calculated from the results of simultaneous measurements of IVO-1 and IVO-2. Vertical air velocity was measured by the aircraft load complex AVPK (Dimitriev and Strunin, 1983). Vertical air motions are obtained by electronically solving the Duvob equation, using the vertical acceleration, and pitch angle signals. This system works best when the aircraft flies straight and leveled. Taking into account the flight condition in convective clouds, the errors is estimated to be less than ± 0.5 $ms^{-1}$ for vertical velocities less than 10 $ms^{-1}$, but my be greater for stronger drafts.

For the control and track of clouds was used the dual MRL-5 radar, equipped with digitizer. The characteristics of the CMS radar are the following; wavelength, 3.2 and 10.15 cm; peak power, 125 and 500 kw; minimum detectable signal -134 and 136 db; frequency, 9.59 and 2.95 $GH_z$. Pulse duration 1.0 µs; bean 0.5º and 1.5º. The antenna was operated in a step – scan mode with 1.5º steps from 1.5º to 18º elevation angle.

In this work was used data from 58 clouds penetrated at the levels of 5600 – 6000 m (-7 to -10 ºC in most cases). The measurements were made in the period of stronger convective activity, between the 13:00 and 19:00 LST, all clouds sample were well developed cumulus congestus with base heights between 1000 and 1200 m. Cloud selection was made by the chief scientist in agreement with the pilot, according to visual criteria of PCMAT field operations. Selected clouds top heights ranged from 6000 to 8000 m at the time of penetration (corresponding to average temperature from -8 to -20 ºC). Clouds were to show and appearance corresponding with early growth stages, a sharply defined outline, like that of cauliflower, cloud diameter greater than 2 km and limited vertical slope, if any. The 58 clouds presented in this paper met all these criteria.
Operational procedure specified to make nearly direct central penetration whenever safety permitted; this is the case for the date presented herein. Thus, cloud horizontal sizes are estimated by the product of the mean true aircraft speed and the time spent in cloud.
Only no seeded clouds or the first penetration of seeded clouds (at the instant of seeding) were included in the data set. Sampling frequency was 1 $H_z$ . Table 1 summarized the general characteristics of the sample.

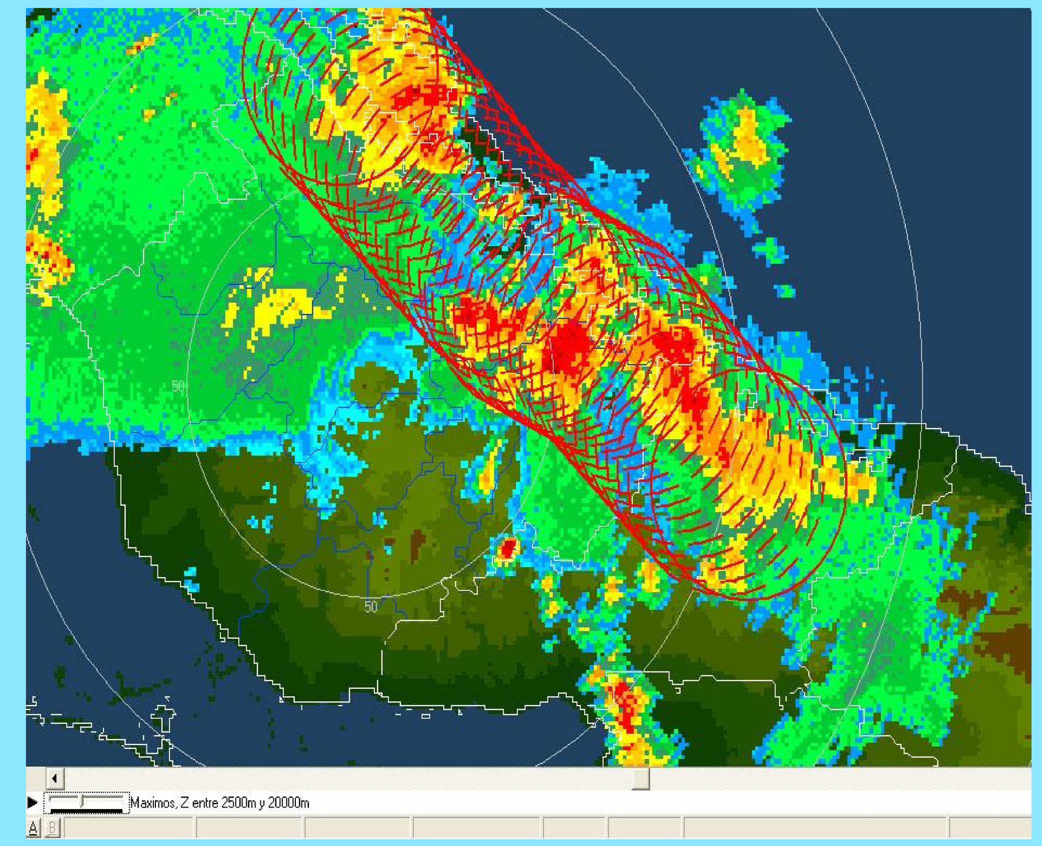

Fig 3: Radar system for control and track of clouds

Table 1. General characteristics and number of penetrations for each cloud's parameters used for the phase composition study.

| Top height (m) | Diameter (m) | penetrations for parameter | | | | |
|---|---|---|---|---|---|---|
| | | N | LWC | IWC | W | T |
| 6000 -8000 | 1000 – 7000 | 48 | 42 | 29 | 57 | 58 |

N: Crystal concentration ($\ell^{-1}$); T: Temperature (ºC); W: Vertical velocity ($ms^{-1}$); LWC: Liquid Water Content ($gm^{-3}$ ); IWC: Ice Water Content ($gm^{-3}$).

## Phase composition

To study the phase composition, the freezing coefficient k was defined as:

$$K = [IWC/ (IWC + LWC)] * 100$$

This coefficient represents the fraction of frozen water and may be used to describe its evolution.
Table 2 shows the sample mean an maximum values of clouds averages and maxima of some cloud physics parameters. As can be appreciated, tºC the values of LWC are greater enough than IWC values, even for the average of extreme values, and ice particle concentration (r > 120 µm) is generally small, showing that in most cases, the condition are suitable for glaciogenic seeding.
The average values of LWC for updraft regions ($LWC_{w>0}$) are greater than average for the whole clouds and conversely for the freezing coefficient values for updraft regions ($k_{w>0}$).
Ice crystal concentration several orders of magnitude higher than ice nucleus concentration were reported by koening (1963), in continental cumulus clouds, and by Mossop et al. (1968) for maritime cumulus. Hobbs (1969) reported that ice particle to ice nucleus concentration ratio appears to decrease with decrease cloud top temperature. These results, confirmed by later evidence, allowed to consider the ice multiplication effect as an important one in certain conditions, especially for maritime clouds with warm bases, (Hallet and Mossop, 1974; Mossop and Hallet, 1974; Mossop 1976) Therefore, this effect might be present in CMS clouds. Yet, the IWC and Ice crystal concentration data do not give any reason to consider it. CMS clouds have been considered as intermediate between maritime and continental, according to microestructural characterization (Valdés and Levkov, 1980; Beliaev et al., 1987; Pérez et al., 1992).
To investigate the time evolution of solid phase, we used simultaneous measurements of radar and aircraft. Cloud Lifetime was defined as the time elapse from first echo to cloud dissipation, using 3 cm band. To describe the stage of cloud development at the time of penetration, a time scale normalized to the lifetime was defines as $t/t_0$, where t is the time elapse from the first echo to penetration and $t_0$ is the cloud lifetime.
Time evolution of ice crystal concentration n ($\ell^{-1}$) and the freezing coefficient (k), average over all clouds investigated are shown in Fig. 4. As can be appreciated, both parameters increase with time, but in the first third of cloud lifetime N = 2-6 $\ell^{-1}$ and K = 10-20% are small enough and began to increase in the second third , but not dramatically, reaching the maximum in the last third. According to PCMAT selection criteria, most measurements were made in young clouds, thus in the first third of clouds lifetime were measured the 49% of cases, in the second 34% and 17% in the third. The data of the later thirds, were obtained by successive penetration of control clouds.
In the qualitative picture of the time evolution of solid phase and phase composition (liquid – solid), we can see that in the first third of cloud lifetime, the LWC budget is greater enough with respect to ice IWC and the onset of ice is not so rapid. Thus, the supercooled liquid water content in this stage in cloud lifetime in CMS, is still enough to allow the possibility of alteration of cloud dynamics by glaciogenic seeding. According to these criteria, the seeding window (Issac, 1986) for CMS clouds is given by the first third lifetime. It is, in average, an interval of 20 minutes after first echo.
Fig. 5 and 6 show the frequency distribution for K and N. As can be appreciated the greater occurrence is concentrated around small values, suggesting that for most cases, the phase composition was dominated by liquid phased. The important matter of whether or not a Hallet-Mossop process is present in the CMS clouds is impossible to solve with the instrument set used in this study and further research is necessary in this direction.

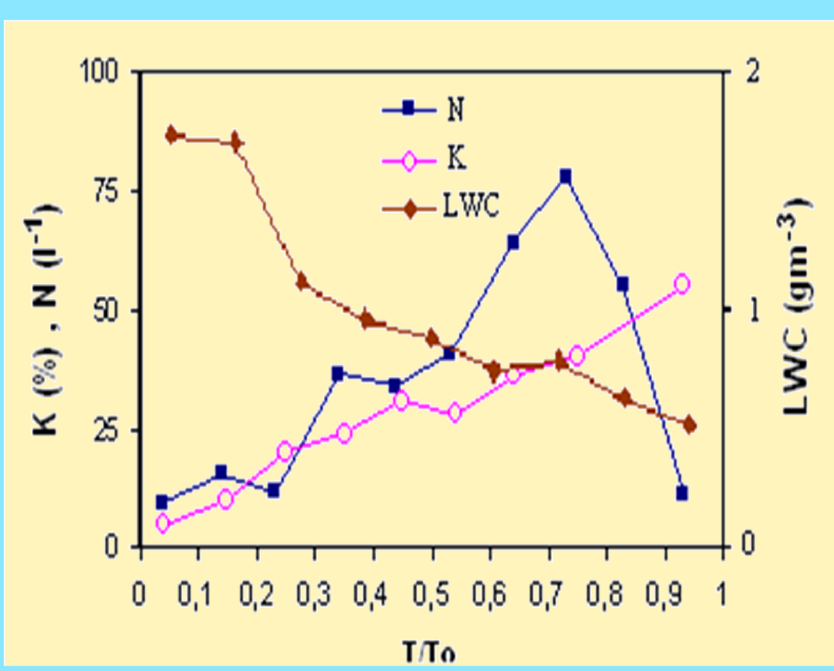



FIG.4: Time evolution of average crystal concentration ($\ell^{-1}$), freezing coefficient (K%) and LWC ($gm^{-3}$), The time of penetration is relative to first echo time , and normalized to cloud lifetime

Table 2. Mean and Maximum microphysical parameters.

| Parameters | Mean | Maximum |
|---|---|---|
| LWC | 0.51 | 1.59 |
| $LWC_{max}$ | 1.04 | 2.30 |
| IWC | 0.10 | 0.45 |
| $IWC_{max}$ | 0.30 | 0.85 |
| K | 31.60 | 88.00 |
| $K_{max}$ | 84.70 | 90.00 |
| N | 6.20 | 8.60 |
| $N_{max}$ | 16.90 | 52.00 |
| W | 1.4 | 11.10 |
| $W_{max}$ | 8.6 | 24.70 |

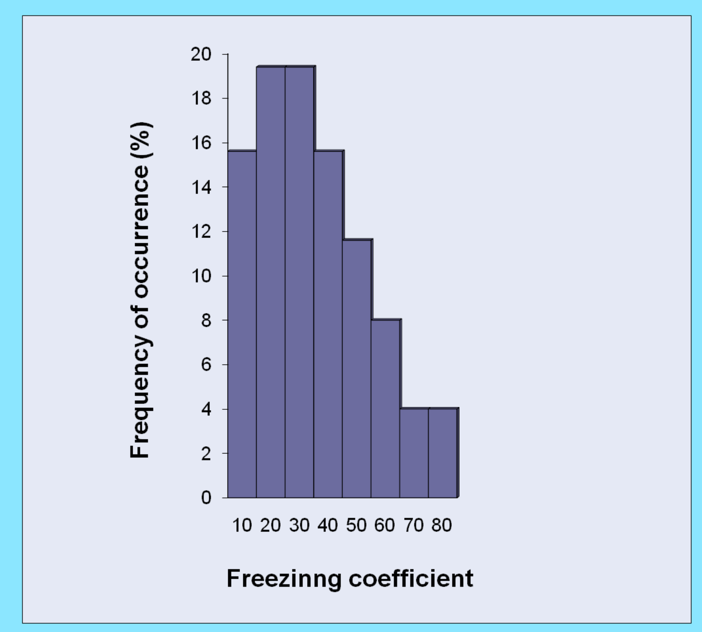



Fig. 5: Frequency histogram of the freezing coefficient (K%)

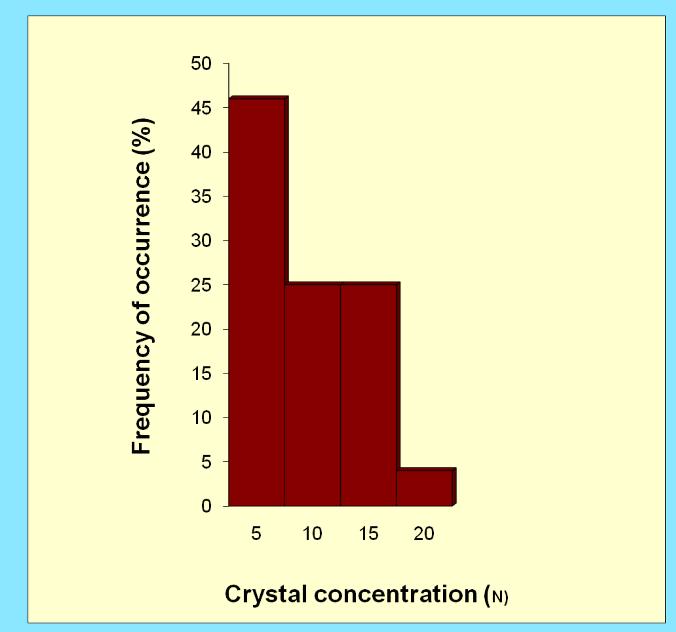



Fig. 6: Frequency histogram of the crystal Concentration (N $\ell^{-1}$)

## Case study

To discuss the time evolution of seedability in PCMAT clouds, a case study of a typical experimental cloud is presented.
Fig. 4 shows time series of LWC, IWC, crystal concentration and vertical velocity for tree successive passes to the control cloud, measured the 3 August of 1990. The first penetration (Fig. 4a) was at 16:30 LST at the level of 5970 m (T = -7.3 ºC) in upwind direction. The cloud top height was 6500 m. Within the cloud is possible to select two zones, zone I for downdraft region (0-27 s) and zone II for updraft region. In zone I, it was detected high crystal concentration (r > 120 µm), up to 22 $\ell^{-1}$, and IWC is greater than LWC (K = 68%). In zone II the crystal concentration decrease to zero (W = 14 m $s^{-1}$) and LWC is very much greater than IWC (K = 10.5%). In the second pas, with heading downwind (Fig. 4b), at 16:15 LST, the crystal concentration increase slighted to 25 $\ell^{-1}$ and k = 75% for zone I and for zone II again crystal were not detected (W = 10.5 m $s^{-1}$, and K = 15%). For the third pass, made at 16:25 LST with heading upwind as the first penetration (Fig 4c), the top height reported by radar was 8000 m and new cell emerged at the upwind side of cloud (zone III). In zone I, crystal concentration increase to 38 $\ell^{-1}$ and in zone II, updraft changed in most part to downdraft, affecting the behavior of LWC that decrease to 1 $gm^3$. Crystals were detected, with the peak in concentration on the boundary between zone I and II (N = 10 $\ell^{-1}$). Zone II had a very strong updraft region (W = 17.8 $ms^{-1}$), was free of crystal and IWC was very small (K = 5%). The analysis of the case study shows that during the three cloud passes, the requirements for dynamic seeding (Kraus et al., 1987) were always met in some part of the measured region of the cloud.

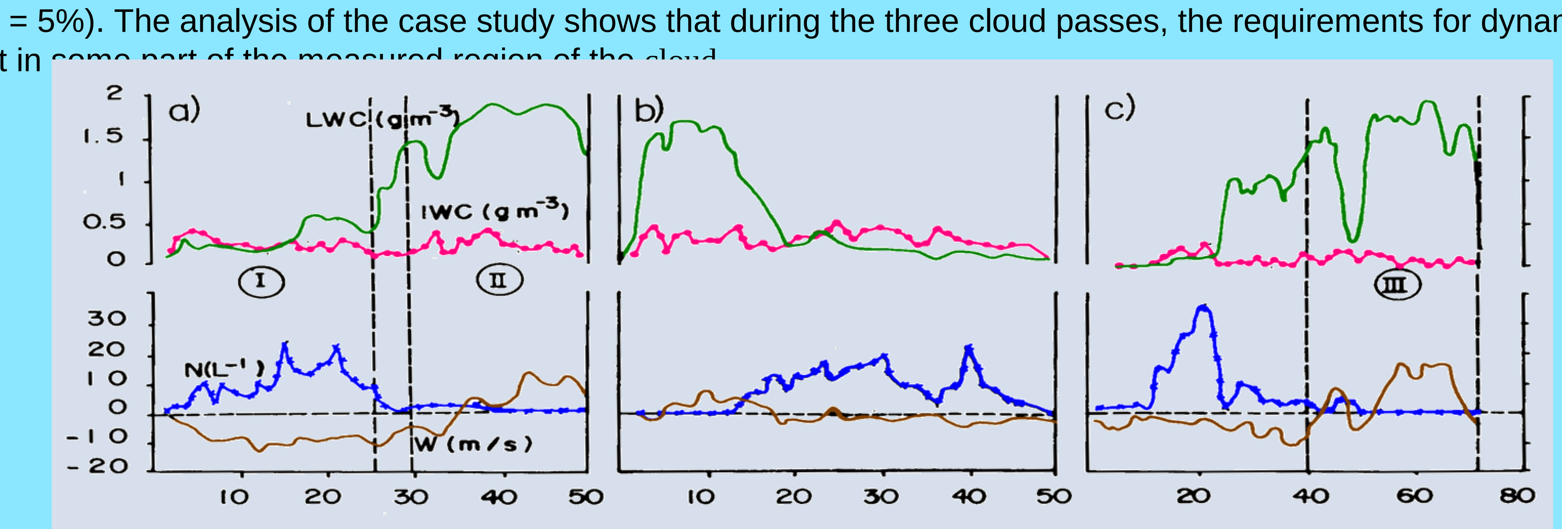



Fig.4: Time series of liquid water content, ice water content, crystal concentration and vertical velocity for three successive passes. The first pass (a) was to 16:08 LST, second pass (b) 16:15 LST, third pass (c) 16:26 LST.