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 been in the last years to 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 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, Proyecto Cubano de Modificacion del Tiempo, PCMAT) in the Camaguey Meteorological Site (CMS). Equipment, Measurements and data The measurements were made during the rainy season in Cuba, in the months of June through August. The CMS is located on the central eastern part of the island, centered at the Camaguey Meteorological Center, in the Camaguey City.

An instrument, 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 m s\(^{-1}\). The aircraft was instrumented with the following set of equipment: Instruments for measurements thermodynamic parameters such as temperature, pressure, and humidity; mean temperature and maximum temperature fluctuation thermometer (Dimitriev and Strunin, 1980); special instrument for LWC; LWC probe IVO-1 and IVO-2 (Nevsorov, 1983) with a range of 0.003 – 4.5 gm\(^{-1}\) and an error of ±5%. The radius range that can be measured by the Nevsorov probe is 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 Mill–Por (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 Dubovick equation, using the vertical acceleration, and pitch angle system. This works best when the aircraft flies straight and level. 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 m s\(^{-1}\), but my be greater for the control and track of clouds was used the usual 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 GHz. Pulse duration 1.0 μs; beam 0.5° and 1°. The antenna was operated in a scan mode with 1.5° steps from 1.5° to 18° elevation angle.

In this work was used data of 58 clouds penetrated at the levels of 5600 – 6000 m (7 to 10°C in most cases). The measurements were made in the period of stronger convective activity, between the 13.00 and 19.00 LST; all cloud samples were well developed cumulus congestus with base heights between 1000 and 1500 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°C). Clouds were to show and appearance corresponding with early growth stages, a sharply defined outline, 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 data 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 Hz , Table 1 summarized the general characteristics of the sample.

Phase composition

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

\[
K = \frac{\text{IWC}}{\text{IWC} + \text{LWC}} \times 100
\]

This coefficient represents the fraction of frozen water and may be used to describe its evolution. Table 2 shows the sample mean and standard deviation values of maximum and minimum values of IWC and LWC for the CMS cloud. The freezing coefficient can be calculated as an average over all clouds investigated. In Fig. 5 are shown the freezing coefficient (K%) for all clouds and the freezing coefficient (K%) for all clouds and the freezing coefficient (K%) for all 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) | N | LWC | IWC | T°C | F
|---------------|--------------|---|-----|-----|-----|---|
| 4000 – 6000 | 1000 – 2000 | 48 | 40 | 5 | 7 | 12

Table 2. Mean and Maximum microphysical parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
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<tbody>
<tr>
<td>LWC</td>
<td>0.51</td>
<td>1.59</td>
</tr>
<tr>
<td>IWC</td>
<td>0.10</td>
<td>0.45</td>
</tr>
<tr>
<td>Crystal concentration</td>
<td>3.60</td>
<td>88.00</td>
</tr>
<tr>
<td>K</td>
<td>52.00</td>
<td>100.00</td>
</tr>
<tr>
<td>N</td>
<td>20</td>
<td>50.00</td>
</tr>
<tr>
<td>W</td>
<td>2.4</td>
<td>12.10</td>
</tr>
<tr>
<td>T°C</td>
<td>8.6</td>
<td>24.70</td>
</tr>
</tbody>
</table>

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 cloud top temperature. The data are available from the flight logbook of the aircraft. The aircraft flies straight and leveled. The errors in the cloud top temperature is estimated by the product of the mean true aircraft speed and the time spent in cloud.

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 cloud top temperature. The data are available from the flight logbook of the aircraft. The aircraft flies straight and leveled. The errors in the cloud top temperature is estimated by the product of the mean true aircraft speed and the time spent in cloud.

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

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

Fig. 3: Radar system for control and track of clouds.

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 at 16:08 LST, second pass (b) at 16:15 LST, third pass (c) at 16:25 LST.