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Precipitation development in some cumulus congestus as a function of the environmental conditions in CCOPE*

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RESUMEN

Datos de radar y de un avión instrumentado fueron usados para caracterizar el desarrollo de la precipitación, hasta la madurez, en los niveles altos de algunos cumulus congestus de larga duración, y para estimar la eficiencia de precipitación en la base de las nubes. Las observaciones, cerca del nivel de los -12°C, son analizadas en función del medio donde crecen las partículas y de las condiciones atmosféricas. Los resultados indican que la concentración de las partículas de hielo, o alternativamente la máxima reflectividad, depende sensiblemente de la vida media de las nubes y está correlacionada positivamente con la energía estática de la atmósfera. La Eficiencia de Precipitación para estas nubes se estimó entre 0 y 30% y, contrario a los resultados obtenidos para tormentas grandes, no se encontró dependencia aparente alguna con el cizallamiento del viento.

ABSTRACT

Radar and direct aircraft measurements are used to characterize the precipitation development up to the mature stage at the high levels of some long-lived cumulus congestus and to estimate the precipitation efficiency at their cloud base. The observations at about the -12°C level are studied as a function of the overall particle growth environment and of the atmospheric conditions. The results indicated that the concentration of ice particles or alternatively the maximum attained reflectivity are sensitive functions of the cloud lifetime and correlate positively with the atmospheric static energy. Precipitation efficiency was estimated from 0 to 30% for these clouds. Contrary to the well known findings for large storms the clouds studied have no apparent influence from the vertical wind structure.

1. Introduction

Observations have shown the important role exerted by the environment on the evolution of hailstorms in the middle latitudes. Longlived storms are favored by strong vertical wind shear usually veering with height (Fankhauser and Mohr, 1977). According to Marwitz (1972) the efficiency for the conversion of water vapor into precipitation is an inverse function of the vertical wind shear. Recent work by Trudeau and Zawadzki (1983) gives no support to Marwitz's findings suggesting that a more basic correlation exists between the precipitation and thermodynamic parameters of the environment.

Little is known about the extent of the validity of these findings for the case of smaller storms. Progress along these lines would broaden our understanding of the environment-storm interaction, which is crucial for the rationale of precipitation enhancement and could shed some light on the transition from small to large convection.

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Towards this end the present work studies the development of ice particles at about the -12°C level and the water budget at the cloud base of 13 cumulus congestus, relating them to relevant dynamic and thermodynamic parameters of the environment.

2. Data processing

Basic data were obtained from the so called "Early Storms" observed during the Cooperative Convective Precipitation Experiment (Knight, 1982). The 13 clouds were selected for having the longest lifetime and a complete data set from two instrumented aircrafts, one measuring cloud base conditions (NCAR Queen Air, H-6) and the other measuring at about the -12°C level (Wyoming King Air, H-2). In addition radar coverage was obtained from the 10 cm CP-2 radar located at Miles City, Montana.

Lifetime for the clouds ranged from 7 to 50 min, taken from the time of the appearance of the first 0 dBZ echo until the time of highest ice particle concentration achieved before decay. The long life of the clouds foresees some higher stability of the draft structure when compared with the rest of the shorter lived Early Storms. The clouds were observed during 7 aircraft missions referred here by letters A to G followed by a sequence number for each cloud studied. For cross reference, the cloud code of the present work and CCOPE cloud number follow: (A1,61703), (A2,61704), (B1, 61804), (B2,61805), (C1,62001), (D1,62401), (E1,64501), (E2,64502), (F1,65001), (F1,65005), (G1,66702), (G2,66703), (G3,66704). A description of observations and a general analysis of the characteristics of the Early Storms is given by Fankhauser *et al.* (1983).

CP-2 radar data is very reliable and posed no problems in characterizing effective reflectivity (dBZe) features on the 0 dBZ level. At the range of 100 km reflectivity of the smallest clouds in the present work may be at the limits of the radar resolution. Atmospheric conditions are derived from rawinsonde data complemented in the lower levels with aircraft soundings taken closer to the clouds in space and time.

Much effort has been undertaken to calibrate and reprocess H-6 data using the techniques described by Fankhauser *et al.* (1985). Radar skin paints and aircraft location by Multiple Aircraft Positioning system were used as true aircarft position to correct the Schuler oscillation of the Inertial Navigation System. From this a new set of horizontal winds was rederived. State parameters were corrected based on intercomparison flights in clear air and some tower fly-by comparisons. Similar instrument response in terms of bias was found even though variations in one of the most sensitive parameters, the vertical velocity, were as large as 6 ms^{-1}. Precipitation size particles at cloud base were measured by a Particle Measuring System (PMS) 1DP probe. Aircraft H-2 particle spectra used in the present work include data with no special corrections from PMS 2DC and 2DP probes. Due to frequent turns, wind derived H-2 data was found generally unreliable except in some selected portions of the track.

Water vapor and precipitation flux at cloud base were estimated by a 2-Dimensional approach assuming mirror characteristics of the measured parameters on the horizontal plane around the aircraft pass. A 2-Dimensional approach was also used assuming quasi-stable conditions during about ±4 min from a reference pass and extrapolating measurements from consecutive passes in a manner prescribed by Fankhauser *et al.* (1985). It should be noted that all the clouds studied have at least one double cross track of the H-6 aircraft sampling along the main axis of transport and perpendicular to it. Main patterns in the x-y plane with about 1 km resolution were consistently reproduced by consecutive passes in most cases. In particular, this was the case for the sensitive updraft cores during the growth stage and for the precipitation distribution during the decaying stage of most of the clouds.

3. Results

3.1. Clouds characteristics

All the clouds were isolated Cumulus Congestus with effective circular diameter at base from 1.4 to 9.6 km and with cloud depths of 3. to 5 km. Radar scans showed that some of the clouds (D1, G1, G2, G3) grew close to large convective systems merging their reflectivities at some stage of their life. Cloud base temperature was for most cases between -2 and +5°C except for missions E and F where the clouds had warmer bases with values of +14 and +7°C respectively. Clouds A1, B1, E1, E2, F1, and F2 had none or negligible precipitation at cloud base.

At the -12°C level all the clouds had a maximum 1 km average of liquid water from 0.8 to 1.6 g m^{-3} except for clouds E1 and E2 which had extreme values of 2.3 and 0.3 g m^{-3}. Maximum 1 km ice particles concentration from 2DC probe were for most clouds below 10 l^{-1}, in accordance with their maximum dBZe of less than 10 dBZ. Clouds G2, A2, and D1 showed the highest 1 km ice concentrations having 2DC values of 180 to 650 l^{-1}, 2DP of 30 to 40 l^{-1} and with maximum dBZe of 25 to 45 dBZ. At cloud base extreme 1 sec vertical winds were found to be +10 and -3 ms^{-1} in the 3 clouds and maximum concentration of precipitation particles per pass was 180 to 250 m^{-3}.

3.2. Ice particles and the environment

Maximum 1 km ice concentration measured by the 2DC probe has been plotted in Figure 1 as a function of the lifetime. Due to observational deficiencies no H-2 data is available for clouds

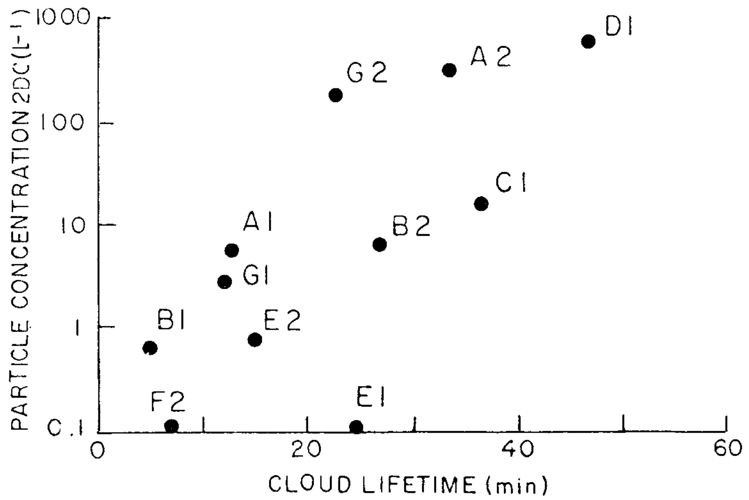

Fig. 1. Maximum 1 km particle concentration (2DC probe) at about the -12°C level as a function of the cloud lifetime. Lifetime is here defined as the lapse between time of the first 0 dBZ and the highest ice concentration before decay. Cloud labels include a letter representing an aircraft mission and a sequence number for each cloud. There is no data available for clouds F1 and G3.

F1 and G3. There is a tendency for the concentration of particles to increase in direct relation with the lifetime of the clouds. The highest values correspond to clouds G2, A2 and D1 having an order of magnitude difference from the rest of the clouds. There is an apparent dependency on the cloud size as clouds A2 and D1 were the largest clouds studied with equivalent diameters of 5.6 and 9.6 km. A more detailed analysis of the radar documentation showed that cloud G2, which is of moderate size with diameter of about 4 km, was most probably naturally seeded by a previously grown cloud in the same location.

Despite the fact that clouds E1 and E2 were longlived no precipitation was detected at cloud base. Atmospheric conditions for groups E and F differ radically from other missions. For the 2 days, average conditions in the lowest 50 mb layer were: mixing ratio >9 g kg^{-1}, equivalent potential temperature >338 K, static potential energy $E+>0.43$ J g^{-1} and wind shear of about 3.5×10^{-3} s^{-1}. These sounding parameters resemble the conditions for hailstorms development given by Fankhauser and Mohr (1977).

As for the rest of the clouds, atmospheric conditions were moderate to marginal for convection development. As shown in Figure 2, particle formation at the -12°C level for some of these clouds seems to be in direct relation with the static potential energy (positive energy area). Due to the completeness of the data, maximum dBZe at about the same level was used in the figure instead of the 2DC concentration but the results are equivalent. The shift in E+ values for groups of clouds A and B, observed during the morning and the afternoon of the same day, is consistently reproduced by the available combined soundings. The fact that cloud A1 departs from the main correlation trend could be related to the smallness of the cloud with a diameter of 2.2 km.

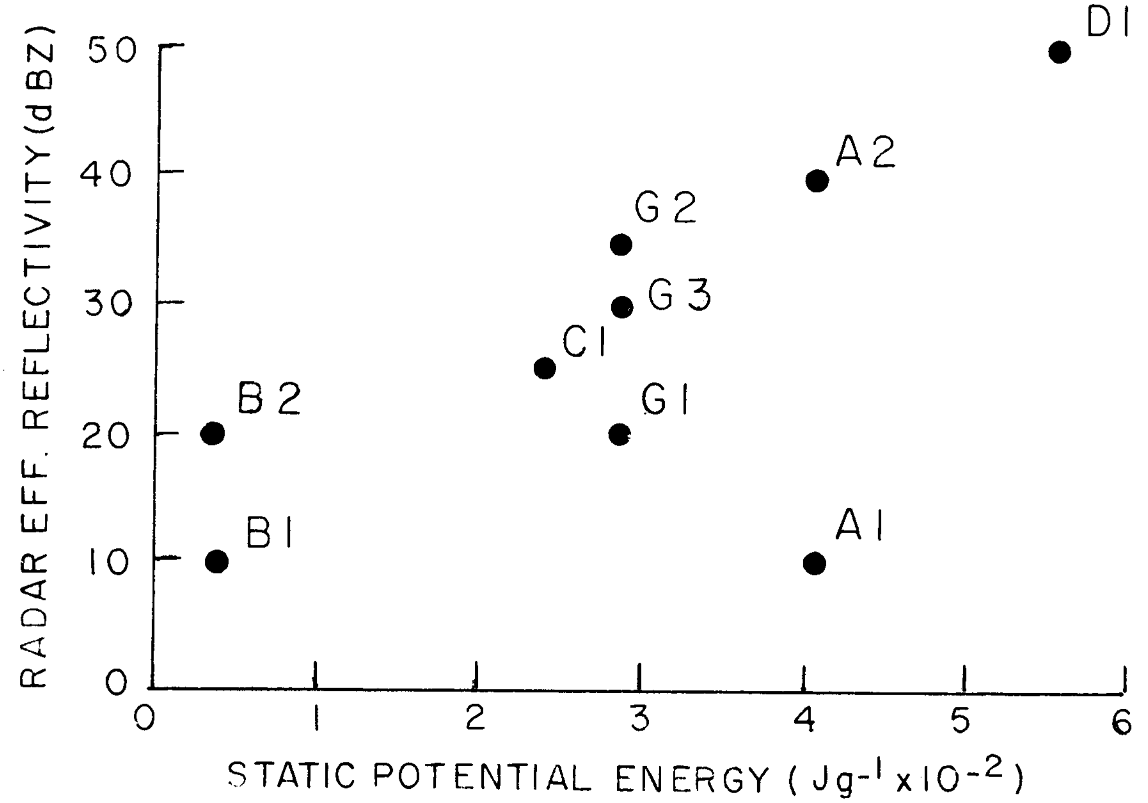

Fig. 2. Maximum radar effective reflectivity as a function of the atmospheric static potential energy (positive energy). Rawinsonde data has been combined with aircraft soundings up to about 5 km.

3.3. Precipitation efficiency

The 1-D and 2-D estimates of the average vapor flux Qv were of the same order of magnitude. In Table 1 the Qv values have been classified by range together with the precipitation flux Qp (2-D). Clouds with no precipitation are found at all ranges of Qv and the larger precipitation flux is associated with the highest Qv values.

Table 1. Matrix classification of the estimated average vapor flux. Qv, and precipitation flux Qp, for the 13 clouds studied. The range of values cover the results of the 1-Dimensional and 2-Dimensional schemes.

VAPOR	PRECIPITATION FLUX		
FLUX	Qp=0	0>Qp<10	10<Qp<100
Qv< 50	B1, F1, F2	B2, C1	–
50<Qv< 100	A1, E2	G1, G2, G3	A2
300<Qv<1000	E1	–	D1

(Flux units: 10^{+6} g s^{-1})

Precipitation efficiency, defined as the ratio of precipitation to water vapor flux, is shown in Figure 3 as a function of the vertical wind shear. The continuous curve represents a segment of the inverse function estimated by Marwitz (1972) for a group of 14 large storms. The vertical lines in the figure connect the calculated efficiencies for the 1-D and 2-D schemes whenever a significant difference exists. The 6 clouds with zero Precipitation Efficiency dominate the trend along the abscissa, with wind shear of 3 to 5 (10^{-3} s $^{-1}$). As a whole, the results show no resemblance to

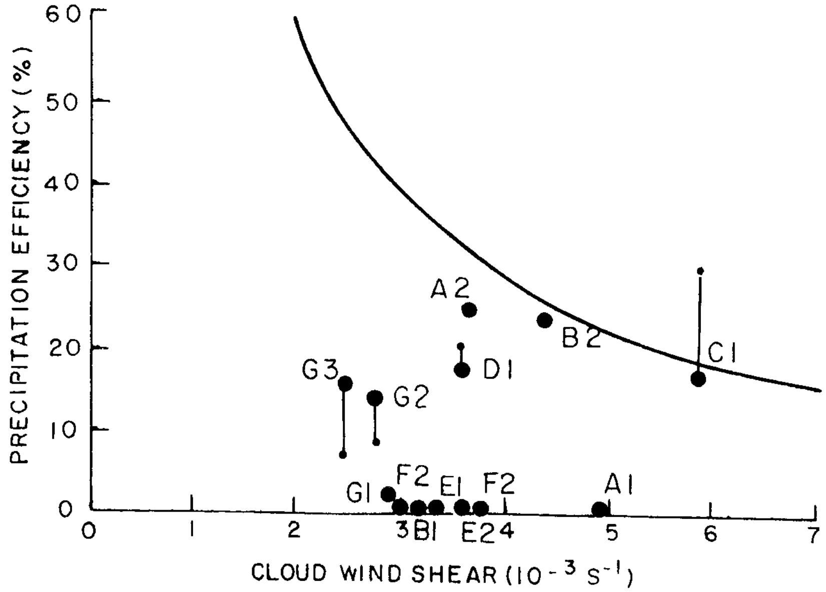

Fig. 3. Precipitation efficiency for the 13 clouds as a function of wind shear at the cloud layer. Non precipitating clouds are shown along the abscissa. A vertical line indicates the difference between the 1-D and 2-D results. The continuous curve represents Marwitz's (1972) precipitation efficiency results for the large storms.

the curve of the large storms. However, regarding only the precipitating clouds, it is group G that mainly departs from Marwitz curve. In order to validate these findings an independent estimate of the precipitation flux is needed.

4. Conclusions

The 13 clouds that are the base of the present study are certainly limited in number for any significant statistical results. However, the analysis relied more on the quality of the data produced by independent sources from which a coherent frame of work has been established for the description of the clouds.

The results indicate that the concentration of precipitation in the higher layers of the clouds for days with moderate to marginal instability could be related to the positive energy of the environment. No clear relationship was found between the Precipitation Efficiency and the vertical wind shear. Both of these results are more in line with the findings of Zawadzki *et al.* (1981), Trudeau and Zawadzki (1983) and more recently by Fankhauser (1988).

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