"REVIEWED"

CLOUD MERGING AND SEEDING EFFICIENCY

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1. INTRODUCTION

The main goal of this pilot project was to begin to identify the principle mechanism for new cell generation in South African clouds which are suitable for cloud seeding activities, as cloud growth patterns may have a major impact on the effective placement of seeding material in all the cells of a storm case (Changnon *et al.*, 1975). Feeder type mergers can be expected to maximise the efficient use of seeding material (as recycling is possible), while in daughter type mergers it is minimised and additional seeding may be necessary to treat all cells of a single dynamic entity. The key feature to be identified is whether the major new cells are essentially separate from the older cells or replace them in the same relative position in the moving storm system.

Radar observations of multicellular storm growth provide the main basis for this discussion, as during the promising Programme for Atmospheric Water Supply (PAWS) this type of storm was found to be suitable for rain stimulation experiments in the eastern part of South Africa, both from the operational and scientific viewpoints. Towers on the edge of relatively isolated multiple cellular storms have been successfully penetrated repeatedly by the sturdy aircraft employed for seeding (a Learjet) with a negligible rate of failure to penetrate due to pilot judgement of overly severe convection. More importantly, early seeding results based on three seasons of data (~85 cases) have been positive, on average, with radar observations indicating both statistically significant <u>and</u> physically logical rain enhancements following randomized seeding of growing turrets at the -10°C level with dry ice (CSIR/CloudQuest, 1990). Although squall lines and similar well organised convective systems clearly will produce more rain on a case by case basis, they are naturally efficient, relatively infrequent (7% of storm days) and dangerous to penetrate as well. Fortunately, multi-cellular storms are the dominate storm type on over half of the storm days over the Witwatersrand region (Carte and Held, 1978).

The most extensive cloud merger studies are all based on radar observations, primarily low elevation angle scans. Westcott (1977), Lopez (1976), and Houze and Cheng (1977) tracked large numbers of echoes using this procedure. Westcott found that merged echoes were 5 (first order mergers) to 30 times (second order - or subsequent - mergers) larger in area than single echoes and produced 10 to 100 times as much rain. However, Lopez found that smaller echoes tended to grow as a result of merger, but that some initially large echo pairs would decrease in size after merging.

New cells of multi-cellular Highveld storms tend to form near expected inflow regions, on the equatorward side (~ 50%) and leading edge (~ 25%) (Carte and Held, 1978). This result compares reasonably well with the results of the American Thunderstorm Project (Byers and Braham, 1949) where the distance dependency of new cell formation was also described (e.g. new cells are very likely to form between cells less than 10 km apart, but 11 times less likely when separated by over 14,5 km).

Examples of storms with more originised inflow regions have been discussed by Dennis *et al.* (1970). Based on 22 Great Plains (USA) severe storms, they found that feeder cells formed close to the main cell (within ~2 km) and rapidly merged. Large and steady severe storms had feeder cells forming in a line along the right rear flank (northern hemisphere). The feeder cell could become the main core of the storm in some cases. A related type of storm in the more humid Midwest (USA) has been described by Grosh (1978) and Grice and Maddox (1984) state that these severe quasi-stationary rain storms occur frequently in other climates as well. In these last cases, the merging cell merges directly with the older core and becomes the dominant tower. These storms have strong similarities with the more steady supercell storms which appear to evolve beyond this stage due to a slightly different environment. Supercell storms occur rarely in the mid latitude climates where they were discovered, and there was only one report of a supercell-like storm in the first seven years of the CSIR radar programme (Carte, 1981). Thus, they will be encountered infrequently and, because of their severity, would be avoided as a seeding target in any case.

On the other hand, Chisholm and Renick (1972) have described the daughter cell type of repeating merger mechanism whereby a new cell appearing to the near right rear (northern hemisphere) grows to become the dominant cell as the older parent cloud fades next to them. This case is thought to minimise the effective spreading of seeding material compared with the feeder case where the new cells actually move into the same region the older parent cell occupies.

2. DATA

CSIR archives of digital data from the S-band Houtkoppen radar covers about 10 years. This data bank served as the primary source of information for the merger study, primarily because of the convenient and relatively advanced in-house data display programs available at CSIR where the study was to be performed. Multiple cellular storm cases were selected from days with relatively isolated convection, as determined from the archive of occasional polaroid scope photographs on storm days as observed by the CSIR radar at Houtkoppen. Following the PAWS procedure, special attention was focused on isolated multi-cellular storms during days with 40 dbZ echoes, and warm cloud bases (CBT > 5°C).

Six storms from three days in 1987 were tracked on the radar imagery for the pilot study. The synoptic pressure patterns giving rise to the multiple cellular storms were rather similar on all three days. A trough was observed over the heart of South Africa, while high pressure dominated the west coast and also north of Maputo on the east coast. Noontime, upper-level winds at nearby Irene were generally from the west-southwest on all three days, with peak winds at 200 mb of 21 to 32 m/s. Thus, single cell storms were not expected on these days, but multicell storms were clearly favored and on the two days with distinct directional shear, the possibility of severe weather needed to be considered as the hodographs approached the supercell profile described Chisholm and Renick (1972). The atmosphere was unstable (Δ at 500 mb = 3 to 6°C) on all three days, and cloud top heights for boundary layer parcels (60 mb averaging depth) could rise to above 200 mb (about 12.4 km). Although the sample of storms used was small, a wide range of cloud conditions were covered, including warm (13°C) and cool (7°c) bases and strong (50 km/h) and weak (15 km/h) translation.

3. SUMMARY

Details of the particular cases are described in Grosh (1991). Based on virtually all the storms studied, it is quite clear that a very common type of echo pattern in multicell storms is for sequential cells to appear near each other but with cores (and towers) which do not merge. Instead, they remain remote at nearly constant spatial separations in various quadrants and echo merging is achieved primarily via the expansion of the weaker echo periphery (23 dbZ contour) of the discrete cells. The observed merged cloud systems had dimensions of about 25 to 50 km (23 dbZ contour). Typical 40 dbZ cells were up to 5 to 15 km long, with 50 dbZ cores being roughly half that size. Thus, these storms are large but still likely treatment candidates. It also seems likely that up to four cells may often be present at about the same time in a multicellular system in the process of developing and more contiguous cells may appear later on during continued propagation.

Furthermore, over 20 years of experience with remote storm observations suggests that the expansion pattern is one of the most, if not the most, frequent types of cloud merging. Nearby cells may exist independently or may be initiated and/or influenced by the downdraughts or pressure pulses from neighbouring cells, but the actual mechanism of the cells linking together is related to the cells proximity rather than some explosive strongly interactive dynamic mechanism and, thus, the merging often occurs in a relatively benign fashion. If isolated multiple cellular storms are to be focused on for rain stimulation research activities, this type of merging will be encountered quite frequently. Expanding systems are probably not as likely to be hazardous for penetrating aircraft as those systems merging via mechanisms involving strong relative cell motions or the rapid systematic self generating propagation and incorporation of new cells. Nevertheless, expanding storm systems will still be relatively difficult to treat for rain stimulation purposes, as the storms may still be quite intense, and each cell must be treated individually.

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