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PROJECTION ONTO GROUND RAINFALL DISTRIBUTIONS OF EFFECTS OF SEEDING CONVECTIVE CLOUDCELLS

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Abstract. Observed changes in the ground distributions of rainfall in the first and Second Israeli cloud seeding experiments are related to observed changes in cloud cell size and rainwater volume, rate and duration. The ground information is recorded by standard stations under static seeding experimentation in Israel, while the cloud information is of a radar records under dynamic seeding experimentation in Florida. The increase in the ground rainfall intensity seems to follow the increase in cloud cell depth. The increase in the ground rainfall duration, frequency and spatial correlation is suggested to be related to the increase in the cloud size and rainwater content, and to the kinematics of its motion. The well known increase in the ground rainfall depth (Gagin and Neumann, 1974)

1. INTRODUCTION

Static cloud seeding experiments in Israel, 1960 to 1967 and 1969 to 1975, apparently caused an average increase of 13 to 15 percent, significant within 5%, in the daily depth of precipitation over the target area (Gagin and Neumann, 1974, 1981). Further analyses of ground data reveal increases in the spatial correlation of daily depth of precipitation (Sharon, 1978; Ben-Zvi, 1988), in the daily duration of the rainfall (Gagin and Gabriel, 1987), in the number of rainfall events per day (Gagin and Gabriel, 1987), and in the rainfall intensity (Ben-Zvi, 1988).

The dynamic cloud seeding experiment brought increases in the precipitation echo for the top height of the convective cells, for the area covered by the cells, and in the radar derived rainfall volume, rate and duration (Gagin et al., 1986). The main results of the two modes of experimentation have been been summarized by Gagin (1986). The present work provides another link between the results of the two modes of seeding.

2. RAINFALL INTENSITY

Based upon vertically pointing radar data of cloud depths, and upon ground data of raindrop characteristics, Gagin (1980) has derived regression formulas relating rainfall intensity to cloud depth. In these formulas, the maximal and the temporally averaged rainfall intensity from a passing raincloud, increase monotonously with the maximal cloud depth.

Having analysed raingage charts, of ten stations for the Second Israeli Rainfall Enhancement Experiment, Gagin and Gabriel (1987) found no apparent effect on the distribution of the daily rainfall intensity. Yet, from their mean daily depth and duration of rainfall, one can compute totals for the entire experiment and obtain the overall mean intensity for the different series in the experiment. These are (in mm/h): 3.99 for the seeded target, 3.32 for the unseeded target, 5.29 for the "seeded" control, and 4.68 for the "unseeded" control. The overall mean intensity for the seeded rainfall at the target is 1.20 times higher than that for the unseeded rainfall. The ratio of the overall mean intensities for the corresponding days at the control is only 1.13. This indicates, although without any computable statistical significance, that the cloud seeding contributes also to the rainfall intensity.

From an independent analysis of charts of four of those raingages, Ben-Zvi (1988) obtained some additional conclusions. A summation of the rainfall depth, according to the instantaneous intensity, reveals that its distribution is changed. The share of the intense rainfall depth (>20 mm/h) increased from 11 to 17 percent, while the share of the depth falling at low intrensity (<5 mm/h) decreased from 63 to 54 percent. At the same time, the distribution of the rainfall depth at the control is the same for the "seeded" and the "unseeded" states.

From an analysis of radar data on clouds in the FACE-2 dynamic seeding experiment, Gagin et al. (1986) concluded that cells exposed to a high dosage of AgI in their early stages, grow larger and yield more rainwater. On the average, these cells are 20 percent taller, and their areas are 50 percent larger, than those of the corresponding sand-treated cells. The average rainwater yield of those cells is 2.6 times higher than that of the corresponding sand-treated cells. On the average, the maximal rainfall rate for the early and high dosage AgI treated cells is 2.0 times higher, and the duration of the rainfall at their bases is 1.8 times longer than those for the corresponding sand-treated cells. These figures are statistically significant within 2%. Cells which are exposed to a lower dosage, or are treated at a later stage of their lives, are considerably less affected.

The data published by Gagin et al. (1986) provide for two estimates of the mean rainfall intensity at the cloud base:

$$R_m = RVR_{max} \ / \ A_{max} \qquad (1)$$

$$R_a = RV \ / \ (DUR \ . \ A_{max}) \qquad (2)$$

in which R_m and R_a are "maximal" and "averaged" intensities at the cloud base, RVR_{max} is the maximal rainfall rate at the cloud base, A_{max} is the maximal cell area, RV is the rain volume which the cell yields, and DUR is the rainfall duration at the cloud base. It should be noted here that since A_{max} does not last for the entire DUR, and as it does not necessarily appear simultaneously with RVR_{max}, both estimates for R_m and R_a are downwardsly biased. We assume that the bias inflicted on the estimates for the AgI treated cells is similar to that for the sand treated cells.

For the early and the high dosage AgI treated cells, R_m is 9.8 mm/h, and R_a is 5.6 mm/h; while for the corresponding sand treated cells they are, respectively, 8.1 and 4.6 mm/h. The estimates for these AgI treated cells are 1.21 times higher than those for the sand treated cells. This ratio is equal to the single ratio of the maximal cloud depths (Gagin, 1986).

The simultaneous increase in the cloud depth and in its rainfall intensity is consistent with the conclusion of Gagin (1980), although the numerical value is different. This difference is attributed to the differences in the observation and the seeding methodologies, and to the differences in the rain processes between the sites.

The seeming inagreement between our positive results, about the rainfall intensity, and the inconclusive results of Gagin and Gabriel (1987), stems from the difference between the definitions of the discussed intensity. Gagin and Gabriel (1987) compared statistics of mean daily intensities, while we compare the distribution of the depth according to the instantaneous intensity. The relation between these two variables is not linear. For example, an addition of a few days of low depth and intensity might affect their statistics, but would contribute little to ours. Therefore, the different conclusions are not necessarily contradictory.

3. FRQUENCY AND DURATION

Gagin and Gabriel (1987) observed that the number of rainfall events on seeded days is larger than that on unseeded days. Gagin et al. (1986) observed that early treatment with a high dosage of AgI causes an extension of the area and the duration of raincells. These two observations are linked here to each other.

The convective raincells are small and short lived. Wind moves them with respect to the ground. The tracks and the birth points of the cells have strong random components with respect to the ground. As a result, the rain traces of cells cover small and randomly located areas. The integrated trace of a large number of individual cells forms a stable pattern, as is shown in rainfall maps.

In considerating an individual cell, the extension of the cell area results in an extension of its trace area. Records of raingages which are located at the extended area include events which reach them only due to the effect of the seeding. Owing to the random locations of the traces, additional events would be recorded by every raingage in the target area. Thus, the extension of the cell areas causes an increase in the number of events detected by the raingages.

In case that two adjacent cells are united by the extension of their areas, their traces are united too. If the individual traces had a certain overlapping area, a raingage located at that particular area would have counted only the united event, rather the two individual ones. We believe that this effect is considerably smaller than the effect of the extension of the cell areas.

We should note here that cell area may be extended by linear extensions in all horizontal directions. Components in the direction of cell motion contribute to the lengthening the ground trace, while components in the perpendicular directions contribute to widening it. Trace lengthening results in an extension of the rainfall duration at the front and the back edges of the trace. By that, the effect of the extension of the cell area is mixed with the effect of the extension of the rainfall duration from the cloud.

The extension of the rainfall at cloud base results in an extension of the duration at ground points which would have recorded the entire duration of the unseeded cloud rainfall. It also results in an additional lengthening of the rainfall trace, and by that to another increase in the number of events recorded by gages located at the extended area.

We conclude that extension of cell area provides an explanation for the increase in the ground rainfall duration as well as for that in the number rain events (Gagin and Gabriel, 1987). Yet, it does not contradict their explanation about initiation of rainfall from clouds which would not have rained otherwise.

A third possible explanation considers the evaporation from the rainshaft on its way from the cloud base to ground. If evaporation rate is higher at the edges of the shaft, the size of the ground trace is reduced with respect to the projection of the moving cloud base, and a number of small and low intensity events do not reach the ground. As the seeding extends the rain volume and intensity (Gagin et al., 1986), it results in a smaller reduction of the trace area and of the number of events which reach the ground. In other words, the increase in the raincell intensity and volume may cause an indirect increase in the ground trace area and in the number of recorded events. This conclusion, and the assumptions leading to it, still need verification.

We conclude that the extension of cell area and its rainfall duration (Gagin et al., 1986) causes an increase in the trace area of the cell. As a result, the probability of simultaneous recording of the same event by different raingages is enhanced, and it causes an increase in the spatial correlation of the rainfall depth, as it is observed by Sharon (1978) and by Ben-Zvi (1988).

4. CONCLUSIONS

A link is provided here between changes observed in dynamically seeded raincells and changes observed in ground traces of statically seeded clouds. The increase in the intensity, duration, frequency and spatial correlation of the ground rainfall seems as being explained by the increase in raincell size, and rainwater volume, rate and duration from the cloud. The quantitative rate of the changes may differ from one experiment to another due to differences in the rain processes, the seeding modes, the measurement methodologies, and the dilution of the intensive effect of the dynamic seeding of suitable clouds by a static seeding of presumably all the clouds which cross a predetermined line. Yet, the trends observed on the ground seem consitent with those observed on the cloud cells.

Changes are observed in the depth, duration, intensity, number of events, depth and duration per event, and the spatial correlation of rainfall depth at the ground level. These variables encompass all the components of the rainfall volume at the target area. They all have positive effects on the generation process of hydrologic water.

5. REFERENCES

Ben-Zvi, A., 1988: Enhancement of runoff from a small watershed by cloud seeding, J. Hydrol. 101, pp. 291-303.

Gagin, A., 1980: The relation between the depth of cumuliform clouds and their raindrop characteristics, J. Rech. Atmos. 14, pp. 409-422.

Gagin, A., 1986: Evaluation of "static" and "dynamic" seeding concepts through analyses of Israel II and FACE-2 experimemnts, in R.R. Braham Jr. (ed): Precipitation Enhancement - A Scientific Challenge, Met. Monograph v. 21, Am. Met. Soc., pp. 63-76.

Gagin, A. and K.R. Gabriel, 1987: Analysis of recording raingage data for the Israeli II experiment; pt. I: effect of cloud seeding on the components of daily rainfall, J. Clim. Appl. Meteo. 26, pp. 913-921.

Gagin, A. and J. Neumann, 1974: Rain stimulation and cloud physics in Israel, in W.N. Hess (ed): Weather And Climate Modification, Willey N.Y., pp. 454-494.

Gagin, A. and J. Neumann, 1981: The second Israeli radomized cloud seeding experiment: evaluation of the results, J. Appl. Meteo. 20, pp. 1301-1311.

Gagin, A., D. Rosenfeld, W.L. Woodley and R.E. Lopez, 1986: Results of seeding for dynamic effects on raincells properties in FACE-2, J. Clim. Appl. Meteo. 25, pp. 3-13.

Sharon, D., 1978: Rainfall fields in Israel and Jordan and the effect of cloud seeding on them, J. Appl. Meteo. 17, pp. 40-48.