# A Biennial Systematic Test of Some Newly-Developed Cloud-Seeding Nucleants, Under Orographic Conditions

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*Summary* – A systematic cloud-seeding experiment was conducted in the Prenestine Hills, east of Rome, during the period of time Jan. 1966 – June 1968. The objective was to determine whether the use of monodisperse, electron-emitting giant condensation nuclei, and of giant $Al_2S_3$ ice-forming nuclei, both recently developed in our laboratories, could increase the precipitation over an area circumjacent to the site of aerosol dispersion. The method of evaluation involved comparisons of precipitation fallen during the week which followed the aerosolization of about 15 kg. of particulate matter, to the precipitation collected during the fortnight aftei that period. The results show that despite a relatively small amount of nuclei used per seeding operation, and notwithstanding an apparently handicapped design of data evaluation, the normalized and cumulated ratios of precipitation events, associated with those periods of time, indicate significant increases during summer and autumn, and significant decreases during winter season, over the area considered.

## *1. Introduction*

A rapid growth in demand for water is known to be associated with the expansion of modern economies. This increasing demand hence also exists in characteristically mountainous countries, despite the fact that some of them are, to all practical effects, surrounded by the sea. Inasmuch the combination of those two factors might often be thought to provide plentiful supplies of rainwater, a substantial part of Southern Italy is frequently refered to as a semi-arid zone. This situation seems to interfere with the development of that area which is now strongly promoted by both Government and private agencies.

We have recently reported on progress, made in this laboratory, towards development and testing of compact, storable and simple generators of monodisperse nuclei of both, condensation and ice-forming types [1–3][2]). Extensive laboratory work on those 'thermit' generators begun in 1961 and was completed a few years thereafter. Since qualitative observations carried out during that preliminary field work [2–3] suggested that precipitation increases occured in the area following tests carried out in conditions which favored the formation of natural updrafts, a larger systematic experiment was programed with the aim of assessing the feasibility of those increases,

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[2]) Numbers in brackets refer to References, page 200.

by the use of this material. It is well-known that hygroscopic particulates of suitable size may enhance the precipitation of various types of clouds [4–9], and several attempts at rainfall stimulation by means of sodium chloride were hence recently described [10–13]. On the other hand, the use of silver and lead iodide ice-forming nuclei in artificial 'seeding' processes seems to be a household word today and needs, therefore, not be quoted in this paper again.

The investigation herein described was conceived as a pilot experiment aimed at testing the effect of short bursts of active nucleating materials; the program was carried out with the primary object of assessing the feasibility of an operation to be carried out subsequently on a larger scale, under local conditions of overall weather.

## 2. *Design of the experiment*

### a. *The operational site*

The site was meant to be always the same, to be situated at a relatively short distance from our laboratories in Rome, and to be easily accessible. The selection of the place also called for a geographic configuration favorable to a creation of natural, orographic updrafts. The semi-barren Guadagnolo ridge, of about 1000 m elevation, was hence chosen for this purpose following an extensive search in the region. During clear days the ridge is well visible from our laboratories and cloud developments there may often be observed directly. Fig. 1 shows the topography of the area around this ridge.

### b. *The raingage network, the raw data, and the terrain selected for analysis*

All pluviometers and pluviographs used for the purpose of data evaluation belonged to the network routinely operated by the 'Hydrographic Service' of the Italian 'Ministry of Public Works' (Servizio Idrografico, Ministero dei Lavori Pubblici). The amounts of daily precipitations collected in these instruments and in the area of interest, are routinely published, annually, by that 'Service' in their 'Annals of Hydrology' (Annali Idrologici), sections of Rome, Naples and Pescara. Since daily precipitation values are taken in the morning and since they are entered in the Annals under the date of that morning, all those raw values were shifted by one day, for the purpose of data evaluation.

We have followed the terminology used by the 'Hydrographic Service' with regard to the definition of 'days of precipitation'. While the collected water is registered in the Annals day by day on the basis of direct readings, the definition of a 'rainy day' calls for a daily total larger than one millimeter. On some infrequent occasions totals for periods of 3–5 days are pooled in those Annals as a result of the inability of a local operator to attend his gage daily. On such occasions those totals

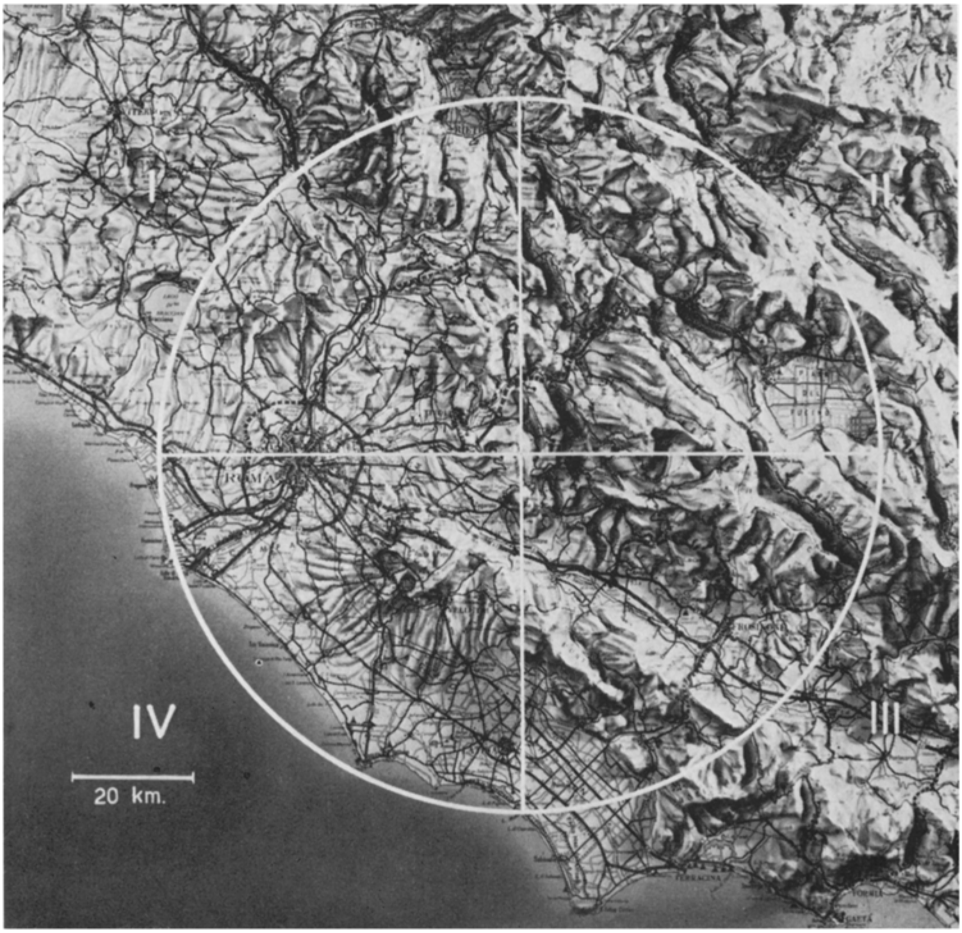


Figure 1
Topography of the area circumjacent the site of aerosolization. Circle contains raingages used for the evaluation of data. Center of circle falls on Guadagnolo ridge

were confronted with the corresponding values from the immediately surrounding gages of this dense network, and the missing daily rainfall data were interpolated linearly.

Fig. 2. shows the dislocation of the 107 gages used for the purpose of this paper. The actual network is somewhat denser in that all gages which lacked, during those two years, data for three trimesters or more, were eliminated from this computation. The lack of operation for more than 1.5. months, of any gage shown in Fig. 2, caused the rejection of that station for purposes of computation on the corresponding *trimestrial* basis. ($3 \pm 2\%$ of stations shown in Fig. 2). Also, data from stations which were inoperative for more than fourteen days during a month (also $3 \pm 2\%$), were

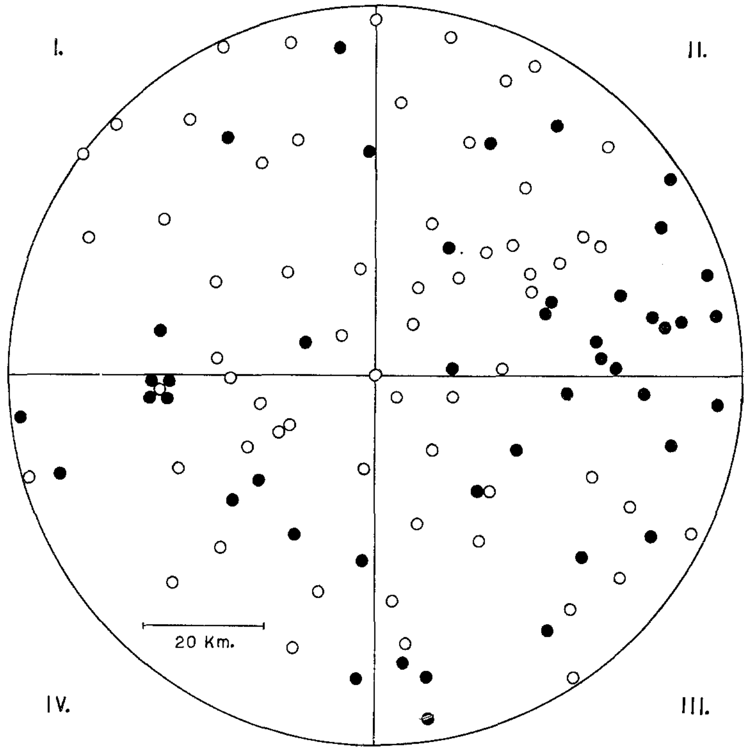


Figure 2
Dislocation of gages used. Empty circles stand for pluviometers, black circles show pluviographs. Average elevations of gages are 307 ± 160, 798 ± 274, 438 ± 291 and 199 ± 275 meters, for the four consecutively numbered quadrants, respectively

rejected for purposes of *monthly* evaluations. The circle drawn in Figures 1 and 2 shows the arbitrary limit of the area used in our calculations. This limit coincides, approximately, with the distance from the Guadagnolo ridge to the sea. The circular area was arbitrarily divided, for purposes of data-processing, into four separate sectors each of which has different conditions of orography and distance from the sea.

c. *The seeding equipment and the days of operation and control*

The combustible aerosolizing compositions used [1, 3] were prepared in our laboratories and were packed and sealed in tubular containers made of extruded anti-corrosive aluminum, 1 meter long and of 5 cm internal diameter. Generators of condensation nuclei [1] were thus substantially of the same type as those used in some of our work on warm fog dissipation [14]; generators of ice-forming particulates were also of the same dimensions, but their content corresponded to the composition given in [3]. The dates of aerosolizations were arbitrarily pre-set for Wednesdays. The following six days were hence also termed 'operative', for the purpose of evaluation of data. The next fourteen days were considered 'non operative' and the pertinent values of precipitation were used for control. This pre-set arrangement was used in order to:

1. allow for the possibility of any widespread effect of seeding: this possibility is suspected since the very early days of experimentation on artificial rain stimulation [15] and appears to be recently under investigation again [16–17];
2. compensate for any bias due to possible annual or quasi-monthly calendricities;
3. avoid references to 'historical periods' [18].

A systematic experimental design was used because of time requirements necessary and left to Nature the randomization of weather conditions propitious for any such seeding endeavours as might be carried out with the object of obtaining sporadic clear-cut successes. Also, it was hoped to obtain, during a comparatively short period of time, data necessary for an approximate evaluation, in terms of broad trends, of precipitation and frequencies of rainy days and changes in precipitation per day of rain. There was obviously more practical interest to obtain evidence of positive effects occuring during the summer season when water is badly needed in some parts of Italy, than during the rest of the year when the supply of water is yet relatively adequate. A further aim consisted, therefore, in confirming the possibility of seasonal effects due to seeding, such as those mentioned by Siliceo, Ahumada and Mosino [19]. It was thought that those effects could also be expected to occur in Italy during summer, because of frequent opposite motions of moist air masses from the sea inland. These well known breezes occur, for obvious reasons, regularly during summer on clear and undisturbed days, contemporaneously from both sides of the peninsula. They evidently may be expected to carry any nuclei dispersed to overland elevations adequate to promote and favor any such activity of said nuclei as, under suitable conditions, may result in an increase of precipitation. Accordingly, in case positive results were obtained during the warm season, an opposite effect could be expected to be detectable during the cold season, due to the rainout of such nuclei over the sea and a consequent depletion of atmospheric water overland. It is clear that Italy possesses an ideal geographic configuration for testing this hypothesis and that, apart of possible local sporadic bursts of stimulated precipitation, the occurrence of small, overall, decreases in winter rainfall over a suitable target area would thus be of no surprise, provided that the condensation nuclei used were efficient, the summer effect clear cut and the proportion of ice-forming nuclei small.

d. *The schedule of operations*

Inasmuch we have sought to adhere rigorously to the predetermined schedule outlined above, a few delays were invariably encountered due to rainfall on the site during the days scheduled for dispersions of nuclei. Since most particulates airborne would have been wasted, under those circumstances, due to washout, aerosolizations were postponed by a full week on these occasions, and the week of delay included among the control data. A few instances which called for a demonstration to a third party, or for a test aimed at streamlining the technology of mass-production of generators used, were also enclosed among the periods of operation. Those few random cases are specifically marked in Table 1 which gives all dates of these aerosolizations.

Table 1

*Dates of aerosolization at Guadagnolo*

| Month | Day and Year | | Month | Day and Year | |
|---|---|---|---|---|---|
| | 1966 | 1967 | | 1967 | 1968 |
| June | 15, | 7, 28, | Jan. | 11, | 3, 24, |
| July | 6,20**, | 19, | Feb. | 1, 22, | 14, |
| Aug. | 3, 24, | 4**, 9, 25**, 30, | March | 15, | 6, 27, |
| Sept. | 14, | 20, | Apr. | 5, 26, | 17, |
| Oct. | 5, | 11, | May | 17, | 8, 29, |
| Nov. | 2*, 30*, | 1, 22, | | | |
| Dec. | 21, | 13, | | | |

*) Postponed due to rain.
**) Demonstration run or technological test.

Each operation consisted of a series of combustions, evenly spaced between 1130–1230 hrs l.s.t., of about 5 and 1–2 charges of compositions which generated condensation and ice-forming nuclei, respectively, with an approximate yield of 80% by weight.

e. *Length of period*

A triennial duration was planned for originally, unless consistent results were obtained during the first biennium. The experiment was discontinued after the first full two years. The rainfall-event data cover period June 8th, 1966–June 11th, 1968 incl.

## 3. *The evaluation of data*

a. *General*

Since neither the operators of gages, nor the Hydrographic Service were informed about the project, it is assumed that any subjective bias of the raw data is to be excluded. It was thought desirable to start the evaluation by pooling the parameters investigated by trimester, per raingage, and by transforming the values obtained into a very simple function which would possess additive properties and be also normally distributed about the mean. This would later enable to carry out summations or averagings of values per circle or quarter of a circle (Figures 1–2), per season, annum or both years. Original raw data on precipitations were thus used without resorting to transformations based on isohyetal interpolations. Generally, the degree of association between rainfall parameters pertinent to 'operative' and 'non operative' days, for the gages considered, was found to be poor, probably due to large diversities of weather regiments occuring during those periods of time. Test plots of pooled seasonal 'operative' vs. 'non operative' values inherent to stations considered, gave either no correlation at all or else yielded, in cases of some seasons, patterns of very approximate direct proportionality without skewness. We have hence tried to keep the statistical analysis as simple as possible and to avoid complicated and time-consuming transformations which sometimes fail to give the expected basis for a final evaluation.

b. *The transformation of raw data*

This transformation is based on the use of $R$, a modified version of the ratio $R'$ of pooled seasonal precipitation events (rainday and rainwater totals, and precipitation per rainday) – which occured per raingage on a daily average basis during the 'operative' periods, – to the events which took place during the 'non operative' intervals of time. If $R'$ is this *true* ratio we put:

$$R = R' - 1, \quad \text{for} \quad R' \geqq 1,$$

and

$$R = 1 - \frac{1}{R'} \quad \text{for} \quad R' \leqq 1.$$

This transformation may readily be obtained from the corresponding sums by means of a conditioned routine, using any small modern desk computer. It subsequently allows a direct processing of data in terms of averages of the $R_i$ ratios, per season and per area. All calculations were made using an Olivetti 'Programma 101' machine. $R_i$ values obtained on a trimestrial basis yielded, when pooled biennially, distributions normal at a level better than 0.05 [20] for the three parameters investigated, i.e. the frequencies of raindays, the precipitation totals and the rainwater fallen per rainy day.

c. *Results per season and discussion*

A straightforward trimonthly period of time is called 'season' for the purpose of this contribution. Thus, for example, 'spring' consists here of the time interval covering March–May incl. Overall precipitation events, pooled per raingage and averaged per quadrant, are given in Table 2.

The results of the experimentation described in this paper are contained in Tables 3–6, and are strongly indicative of non-negligible changes, due to bursts of seeding, in the precipitation pattern of the area which surrounds the operational site. While data

Table 2

*Seasonal precipitation totals per area shown in Fig. 1 and based on readings of gages dislocated according to Fig. 2*

| Quadrant | Rainy days ±SD | Average precipitation (cm.) ±SD | Rainy days ±SD | Average precipitation (cm.) ±SD |
|---|---|---|---|---|
| | Spring | | Summer | |
| 1 | 21.3 ± 6.5 | 19.1 ± 6.1 | 14.0 ± 4.3 | 16.1 ± 7.8 |
| 2 | 23.7 ± 7.3 | 18.2 ± 6.9 | 16.9 ± 5.7 | 15.2 ± 6.7 |
| 3 | 22.6 ± 6.3 | 22.6 ± 7.9 | 12.9 ± 5.7 | 13.4 ± 6.5 |
| 4 | 19.1 ± 5.3 | 15.1 ± 4.8 | 11.3 ± 3.5 | 10.2 ± 3.6 |
| | Fall | | Winter | |
| 1 | 19.8 ± 7.4 | 33.1 ± 8.6 | 27.8 ± 4.7 | 36.1 ± 9. |
| 2 | 19.9 ± 6.9 | 29.9 ± 11.3 | 28.2 ± 5.1 | 35.8 ± 11.7 |
| 3 | 19.6 ± 9.0 | 38.2 ± 17.5 | 27.4 ± 6.7 | 45.9 ± 13.3 |
| 4 | 19.8 ± 9.5 | 29.8 ± 10.6 | 26.9 ± 4.5 | 31.6 ± 5.6 |

associated with *spring* (Table 3) appear to be somewhat erratic, especially in what regards the precipitation frequencies, a marked tendency for a general decrease in rainfall events is clearly detectable over all areas. The largest scatter of values occurs in the quadrants which are near the sea, the smallest in the second quadrant which is most mountainous, possibly indicating the effect of overall surface temperatures and circulation. The results shown in Table 4 represent the *summer* situation and are much more consistent. They indicate substantial increases, over all quadrants, of both rainy days and total precipitation during both years. Also, the levels of precipitation induced per rainy day are consistent and high, especially in quadrants III and IV where updrafts due to the orographic configuration of quadrant III may be expected, and where overall precipitations are normally low (Table 2). The *fall* period (Table 5) also yields overall positive results, with more scatter from year to year then in the case of summer, probably due to a more unstable meteorological situation during those months. Finally, although the results which deal with *winter* (Table 6) are on the lowest levels of probability, there appears to be sufficient consistency, over the whole area considered, to indicate that a decrease of rainy days occured. Consequently, overall precipitation values may also be expected to diminish despite the small magnitudes of those changes and the insignificant single levels of change of precipitations per rainy day, per quadrant.

Although the method of analysis used in this paper would, offhand, appear to reduce considerably, for any practical purpose, any bias of precipitation values due to elevations of the terrain where those gages are situated [10], changes from quadrant to quadrant may, of course, be expected to occur, not alone because of their orographic

Table 3

*Results related to spring*

Averages are computed from pooled seasonal valued per gage, over $n$ instruments. Student's $t$'s and ratios $R_n$ computed on probability levels indicated, are for $(n-1)$ and departure from zero

| Quadrant | Annual Period | Rainy days | | | | Total precipitation | | | | Precipitation per rainday | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $n$ | $\bar{R}$ | $t$ | $R_{0.1}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.1}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.1}$ |
| 1 | 1 | 20 | 0.036 | 0.550 | – | 20 | −0.823 | −4.887 | −0.291 | 20 | −0.856 | −6.141 | −0.241 |
| | 2 | 19 | 0.064 | 0.964 | – | 19 | −0.347 | −2.915 | −0.207 | 19 | −0.356 | −3.097 | −0.199 |
| | Cumul. | 39 | 0.050 | 1.076 | – | 39 | −0.591 | −5.390 | −0.185 | 39 | −0.612 | −6.227 | −0.166 |
| 2 | 1 | 36 | −0.623 | −5.414 | −0.194 | 36 | −1.043 | −8.034 | −0.219 | 36 | −0.369 | −2.921 | −0.213 |
| | 2 | 32 | −0.257 | −3.300 | −0.132 | 32 | −0.419 | −5.028 | −0.142 | 32 | −0.142 | −2.526 | −0.095 |
| | Cumul. | 68 | −0.450 | −6.089 | −0.124 | 68 | −0.750 | −8.584 | −0.146 | 68 | −0.262 | −3.603 | −0.121 |
| | 1 | 25 | −0.227 | −2.443 | −0.159 | 25 | −0.130 | −1.248 | – | 25 | 0.078 | 0.545 | – |
| | Cumul. | 50 | −0.077 | −1.182 | – | 50 | −0.118 | −1.639 | −0.120 | 50 | −0.044 | −0.536 | – |
| 4 | 1 | 25 | −0.117 | −1.385 | – | 25 | 0.020 | 0.154 | – | 25 | 0.146 | 1.550 | – |
| | 2 | 22 | 0.167 | 3.086 | 0.093 | 22 | −0.199 | −1.410 | – | 22 | −0.382 | −3.185 | −0.206 |
| | Cumul. | 47 | 0.016 | 0.288 | – | 47 | −0.083 | −0.871 | – | 47 | −0.101 | −1.203 | – |
| | | | | | $R_{0.005}$ | | | | $R_{0.005}$ | | | | $R_{0.005}$ |
| Circle | 1 | 106 | −0.286 | −5.114 | −0.160 | 106 | −0.536 | −6.704 | −0.229 | 106 | −0.234 | −3.193 | −0.209 |
| | 2 | 98 | −0.015 | −0.372 | – | 98 | −0.276 | −5.020 | −0.157 | 98 | −0.243 | −5.515 | −0.126 |
| | Cumul. | 204 | −0.156 | −4.303 | −0.101 | 204 | −0.411 | −8.230 | −0.140 | 204 | −0.238 | −5.486 | −0.122 |

Table 4

*Results related to summer*

Averages are computed from pooled seasonal values per gage, over $n$ instruments. Student's $t$'s and ratios $R_n$ computed on probability levels indicated, are for $(n-1)$ and departure from zero

| Quadrant | Annual Period | Rainy days | | | | Total precipitation | | | | Precipitation per rainday | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $n$ | $\bar{R}$ | $t$ | $R_{0.05}$ | $n$ | $\bar{R}$ | $t$ | $\bar{R}_{0.05}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.05}$ |
| | 1 | 20 | 0.708 | 3.072 | 0.482 | 20 | 2.383 | 4.036 | 1.236 | 20 | 1.208 | 2.897 | 0.873 |
| 1 | 2 | 20 | 0.615 | 5.057 | 0.255 | 20 | 0.982 | 3.087 | 0.666 | 20 | 0.132 | 0.875 | – |
| | Cumul. | 40 | 0.661 | 5.135 | 0.260 | 40 | 1.683 | 4.815 | 0.706 | 40 | 0.670 | 2.849 | 0.475 |
| | 1 | 36 | 0.727 | 9.388 | 0.156 | 36 | 0.718 | 4.764 | 0.305 | 36 | −0.101 | −0.783 | – |
| 2 | 2 | 36 | 0.116 | 1.854 | 0.126 | 36 | 0.241 | 2.598 | 0.188 | 36 | 0.106 | 1.358 | – |
| | Cumul. | 72 | 0.421 | 6.877 | 0.122 | 72 | 0.480 | 5.194 | 0.185 | 72 | 0.002 | 0.032 | – |
| | 1 | 24 | 0.438 | 2.537 | 0.358 | 24 | 2.343 | 4.056 | 1.195 | 24 | 1.367 | 3.738 | 0.757 |
| 3 | 2 | 26 | 0.546 | 2.724 | 0.413 | 26 | 1.305 | 3.708 | 0.725 | 26 | 0.418 | 3.346 | 0.257 |
| | Cumul. | 50 | 0.495 | 3.742 | 0.264 | 50 | 1.803 | 5.351 | 0.674 | 50 | 0.874 | 4.432 | 0.394 |
| | 1 | 25 | 0.175 | 2.363 | 0.153 | 25 | 1.865 | 6.212 | 0.620 | 25 | 1.572 | 5.467 | 0.593 |
| 4 | 2 | 25 | 0.979 | 6.354 | 0.318 | 25 | 2.516 | 6.820 | 0.761 | 25 | 0.853 | 4.867 | 0.362 |
| | Cumul. | 50 | 0.577 | 5.643 | 0.204 | 50 | 2.190 | 9.130 | 0.480 | 50 | 1.213 | 6.954 | 0.349 |
| | | | | | $R_{0.005}$ | | | | $R_{0.005}$ | | | $R_{0.005}$ | |
| | 1 | 105 | 0.526 | 7.557 | 0.199 | 105 | 1.680 | 8.238 | 0.583 | 105 | 0.882 | 5.664 | 0.445 |
| Circle | 2 | 107 | 0.515 | 6.955 | 0.212 | 107 | 1.170 | 7.327 | 0.457 | 107 | 0.361 | 5.215 | 0.198 |
| | Cumul. | 212 | 0.520 | 10.260 | 0.142 | 212 | 1.422 | 10.935 | 0.364 | 212 | 0.619 | 7.170 | 0.242 |

Table 5

*Results related to fall*

Averages are computed from pooled seasonal values per gage, over $n$ instruments. Student's $t$'s and ratios $R_n$ computed on probability levels indicated, are for $(n-1)$ and departure from zero.

| Quadrant | Annual Period | Rainy days | | | | Total precipitation | | | | Precipitation per rainday | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $n$ | $\bar{R}$ | $t$ | $R_{0.05}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.05}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.05}$ |
| | 1 | 20 | −0.585 | −3.478 | −0.352 | 20 | −0.399 | −2.038 | – | 20 | 0.196 | 1.831 | – |
| 1 | 2 | 20 | 0.384 | 3.626 | 0.221 | 20 | 1.486 | 5.678 | 0.548 | 20 | 0.822 | 4.809 | 0.358 |
| | Cumul. | 40 | −0.101 | −0.806 | −0.253 | 40 | 0.544 | 2.463 | 0.446 | 40 | 0.509 | 4.567 | 0.225 |
| | 1 | 36 | −0.280 | −5.331 | −0.106 | 36 | −0.274 | −3.925 | −0.141 | 36 | 0.018 | 0.263 | – |
| 2 | 2 | 36 | 0.787 | 5.990 | 0.265 | 36 | 3.288 | 6.000 | 1.108 | 36 | 1.259 | 6.466 | 0.394 |
| | Cumul. | 72 | 0.253 | 2.682 | 0.189 | 72 | 1.507 | 4.353 | 0.693 | 72 | 0.638 | 5.065 | 0.252 |
| | 1 | 26 | −0.434 | −5.284 | −0.169 | 26 | −0.323 | −2.094 | −0.318 | 26 | 0.158 | 1.594 | 0.205 |
| 3 | 2 | 25 | 1.470 | 4.266 | 0.711 | 25 | 2.332 | 3.798 | 1.267 | 25 | 0.316 | 2.393 | 0.272 |
| | Cumul. | 51 | 0.499 | 2.285 | 0.437 | 51 | 0.978 | 2.713 | 0.721 | 51 | 0.235 | 2.869 | 0.164 |
| | 1 | 25 | −0.158 | −1.786 | – | 25 | 0.025 | 0.345 | – | 25 | 0.167 | 2.451 | 0.140 |
| 4 | 2 | 24 | 0.600 | 11.153 | 0.111 | 24 | 2.267 | 6.782 | 0.691 | 24 | 1.082 | 4.519 | 0.495 |
| | Cumul. | 49 | 0.213 | 2.831 | 0.152 | 49 | 1.123 | 4.845 | 0.469 | 49 | 0.615 | 4.462 | 0.278 |
| | | | | | $R_{0.005}$ | | | | $R_{0.005}$ | | | | $R_{0.005}$ |
| | 1 | 107 | −0.346 | −7.266 | −0.136 | 107 | −0.239 | −3.939 | −0.174 | 107 | 0.120 | 2.871 | 0.119 |
| Circle | 2 | 105 | 0.830 | 8.109 | 0.293 | 105 | 2.484 | 9.560 | 0.743 | 105 | 0.911 | 8.873 | 0.294 |
| | Cumul. | 212 | 0.236 | 3.424 | 0.193 | 212 | 1.109 | 6.854 | 0.453 | 212 | 0.512 | 8.348 | 0.172 |

Table 6

*Results related to winter*

Averages are computed from pooled seasonal values per gage, over $n$ instruments. Student's $t$'s and ratios $R_n$ computed on probability levels indicated, are for $(n-1)$ and departure from zero.

| Quadrant | Annual Period | Rainy days | | | | Total precipitation | | | | Precipitation per rainday | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $n$ | $\bar{R}$ | $t$ | $R_{0.1}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.1}$ | $n$ | $\bar{R}$ | $t$ | $R_{0.1}$ |
| 1 | 1 | 19 | −0.223 | −2.802 | −0.138 | 19 | −0.259 | −3.432 | −0.131 | 19 | −0.043 | −0.584 | – |
| | 2 | 19 | −0.496 | −9.512 | −0.090 | 19 | −0.640 | −6.108 | −0.182 | 19 | −0.092 | −1.158 | – |
| | Cumul. | 38 | −0.359 | −6.913 | −0.088 | 38 | −0.450 | −6.334 | −0.120 | 38 | −0.068 | −1.259 | – |
| 2 | 1 | 35 | −0.104 | −1.727 | −0.102 | 35 | −0.003 | −0.034 | – | 35 | 0.115 | 2.225 | 0.088 |
| | 2 | 33 | −0.406 | −6.855 | −0.100 | 33 | −0.138 | −1.677 | – | 33 | 0.269 | 4.186 | 0.109 |
| | Cumul. | 68 | −0.250 | −5.466 | −0.077 | 68 | −0.069 | −1.143 | – | 68 | 0.190 | 4.545 | 0.070 |
| 3 | 1 | 26 | −0.099 | −2.659 | −0.063 | 26 | 0.081 | 1.234 | – | 26 | 0.189 | 3.070 | 0.105 |
| | 2 | 25 | −0.595 | −6.210 | −0.164 | 25 | −0.603 | −3.595 | −0.287 | 25 | 0.036 | 0.322 | – |
| | Cumul. | 51 | −0.342 | −5.589 | −0.102 | 51 | −0.255 | −2.540 | −0.167 | 51 | 0.114 | 1.797 | 0.106 |
| 4 | 1 | 25 | −0.249 | −5.900 | −0.072 | 25 | −3.355 | −4.788 | −0.127 | 25 | −0.089 | −1.375 | – |
| | 2 | 22 | −0.522 | −10.385 | −0.086 | 22 | −0.675 | −7.834 | −0.148 | 22 | −0.099 | −1.458 | – |
| | Cumul. | 47 | −0.377 | −9.942 | −0.064 | 47 | −0.505 | 8.337 | −0.102 | 47 | −0.094 | −2.021<br>−8.337 | −0.078 |
| | | | | | $R_{0.005}$ | | | | $R_{0.01}$ | | | | |
| Circle | 1 | 105 | −0.159 | −5.553 | −0.082 | 105 | −0.112 | −2.612 | −0.113 | 105 | 0.056 | 1.744 | 0.053 |
| | 2 | 99 | −0.497 | −14.218 | −0.100 | 99 | −0.471 | −7.652 | −0.162 | 99 | 0.059 | 1.352 | – |
| | Cumul. | 204 | −0.323 | −12.738 | −0.071 | 204 | −0.287 | −7.312 | −0.102 | 204 | 0.058 | 2.144 | 0.044 |

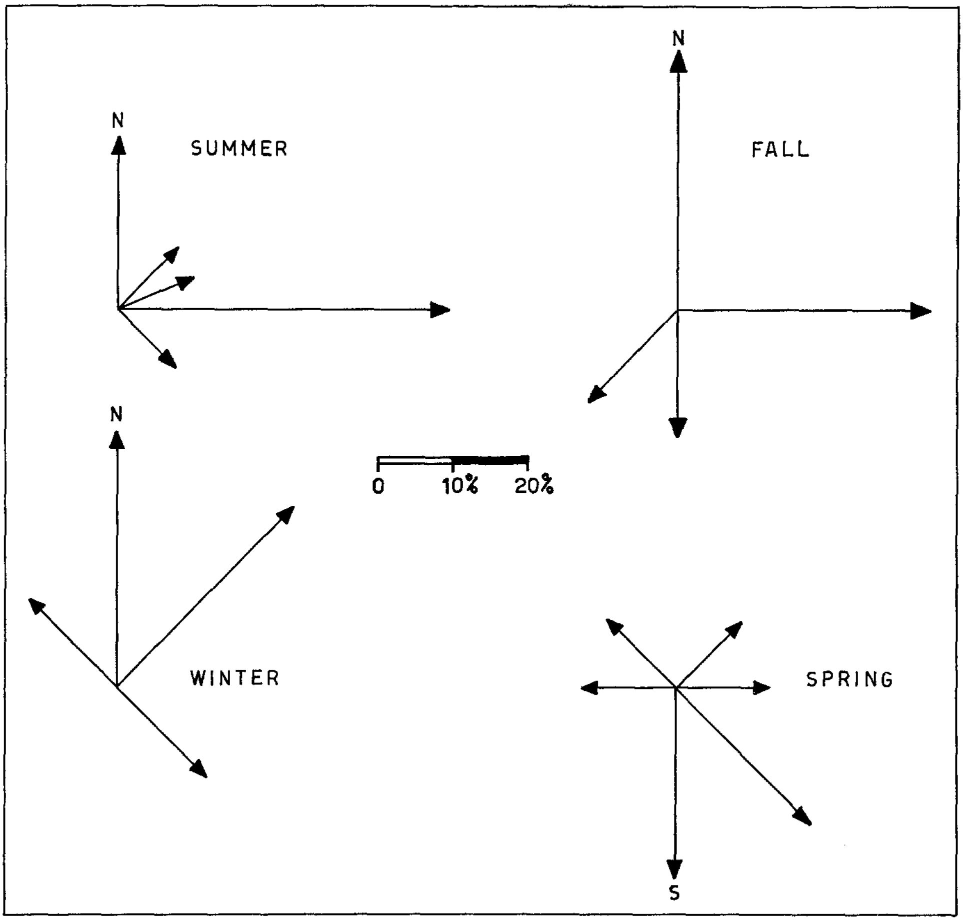


Figure 3
Biannual averages, per season, of wind directions at the Guadagnolo site, during dispersions of nucleants.

configuration and distance from the sea, but primarily also due to the wind directions involved. Overall directions of those motions of air at Guadagnolo, during the experimental runs, are given in Fig. 3. Although those frequencies covered only the wind directions taken during two hours around noontime, they do not appear to contradict our expectations concerning those motions, and they are also in line with what could be anticipated from a lump-sum analysis which follows.

d. *Biennial results, per station*

The periodic effect indicated in Tables 3–6 considerably reduces the weight of any cumulative analysis aimed at individuating areas of significant changes in precipitation

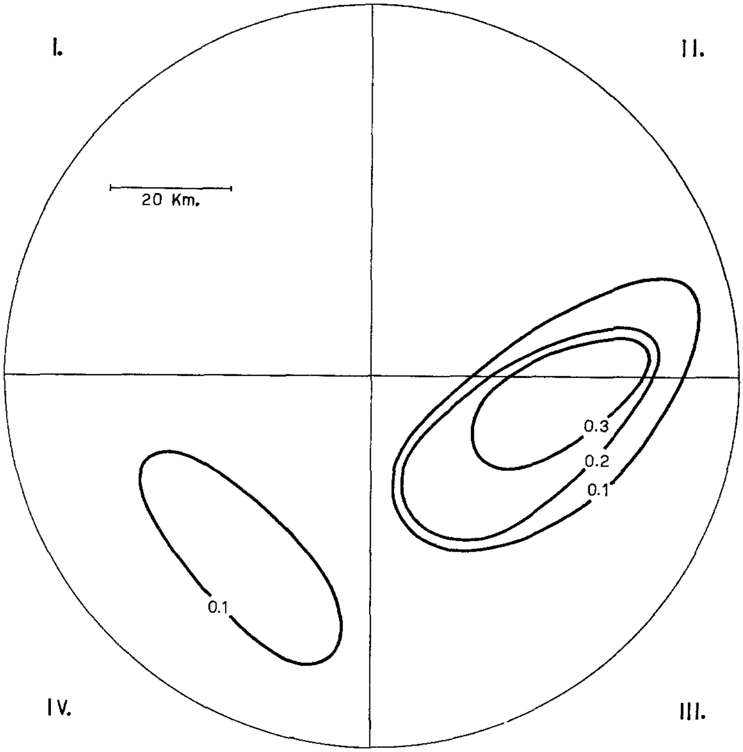


Figure 4
Areas of consistent increase of total annual precipitation; individual values, per station, were computed in terms of $\bar{R}_i$ for eight seasons (see Fig. 5 for significance).

parameters. This applies, in particular, to the evaluation of change of the 'rainy day' variable: biannual poolings of the eight seasonal variables per station yielded, in fact, in this case, levels of change at a mere 0.5 or so. Some very broad trends do, however, emerge with better approximation when both, 'total precipitation' and 'precipitation per rainday', parameters are investigated. Figures 4 and 5 thus show the areas of consistent increase of rainfall per annum and of their probability levels respectively (Student's $t$ for $n=7$) while Figures 6 and 7 illustrate a similar situation in terms of precipitation per rainy day. It is of interest to note that the increases indicated appear to be mostly centered near the operational site and astride a valley opened at both ends and well known for its regularly fast ingathering cumuli.

e. *Estimate of monthly trends*

This estimate may here be done with gross approximation only, since solely two

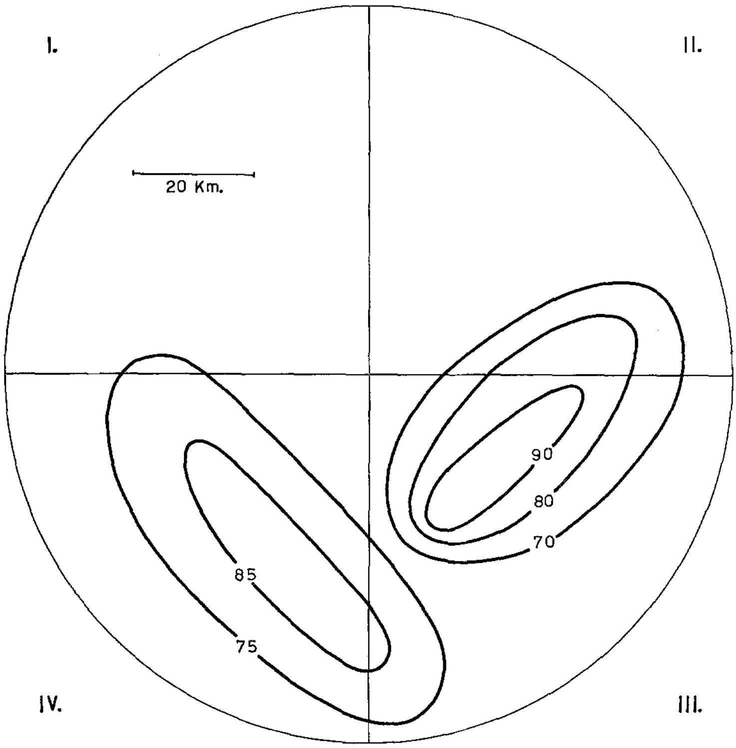


Figure 5
Areas of consistent probability levels (percent) for annual increases of precipitation; individual values, per station, were computed in terms of $t$ coefficients for averages of eight seasonal $R$ indexes (cf. Fig. 4) and a deviation from zero

months are available for the purpose. Results, computed on the basis of the four quadrants *individually*, are found to be of the same general type as the *overall* data illustrated in Figure 8 which is meant merely to give an approximate idea of the qualitative pattern of the process. This notwithstanding its content is in line with the results of Tables 3–6, and is also qualitatively similar to that of Fig. 16, Ref. [19].

## *4. Concluding remarks*

Any persistence (carry-over) effect [21] is to be excluded in the case of the experimentation here described because of:

i. the chemical nature and particulate size of the nucleants used;
ii. the inapplicability of the carry-over effect to every such area where cloud-seeding experiments were done using silver iodide [22].

Occur results indicate, therefore, that consistent and reproducible changes of precipita-

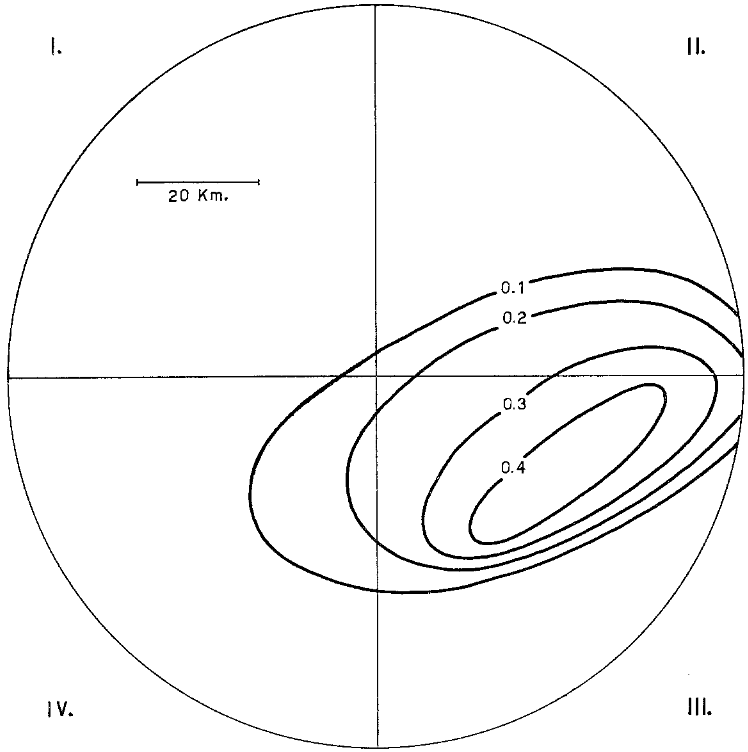


Figure 6
Areas of consistent increase, per annum, computed in terms of $\bar{R}_i$ per station, for eight seasons, on precipitation values per rainy day (see Fig. 7 for significance levels)

tion were obtained over the span of two years, due to seeding, according to the experimental design used.

As stated previously, the objective of this experimentation consisted in testing, for purposes of local rainfall increase, newly conceived nucleator materials which are easy to manipulate, store and transport, and which do not require specialized personnel for their use. A further objective was to assess the practical results obtained by the use of those materials, under weather conditions prevailing in central Italy, during different seasons of the year. A technique useful for future planning of local water resources was thus developed and tried out, and the increase of precipitation obtained in summer has fulfilled the expectations which motivated this project. The experimentation also enabled to test routinely, in the field, means of delivering into the atmosphere of large amounts of giant nuclei of both ice-forming and condensation types, in view of future projects to be carried out on a larger scale both with the aim of rainfall increase and hail-prevention.

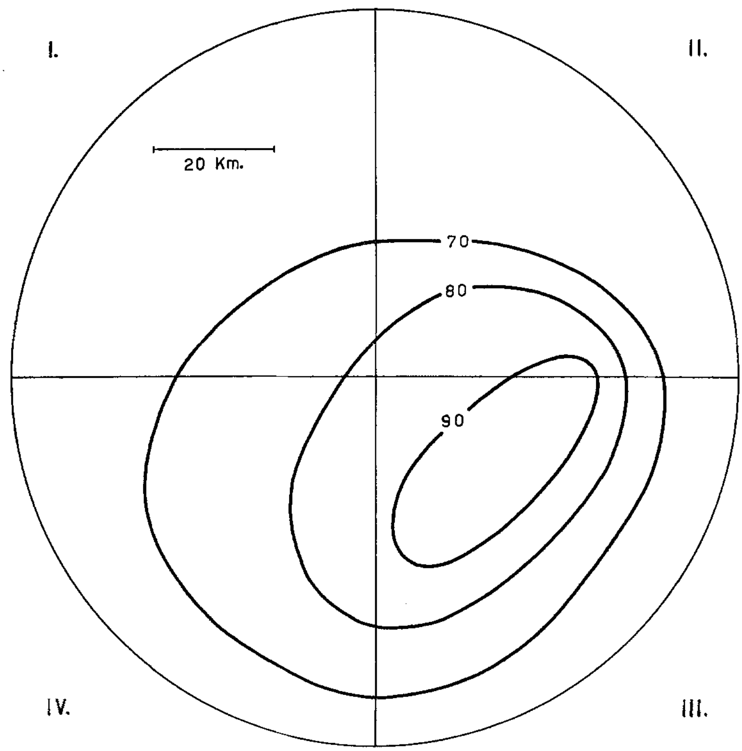


Figure 7
Areas of consistent probability levels (percent) per annum, computed in terms of $t$ coefficients for averages of eight seasonal $R$ indexes, on precipitation values per rainy day (Fig. 6) and a deviation from zero

Much more work of both fundamental and applied nature will, of course, be necessary before the potentialities of the techniques are better assessed and adapted to the variety of existing economical, meteorological and geographical alternatives. It appears to be of interest nevertheless, that injections into the atmosphere, of massive doses of dry, active, giant condensation and ice-forming nuclei, may be expected to increase, under suitable conditions, both precipitation frequencies and volumes in tempered climates. The overall nucleation and growth effects of the condensation aerosol used, obviously also present interesting implications, both practical and fundamental.

## 5. *Acknowledgements*

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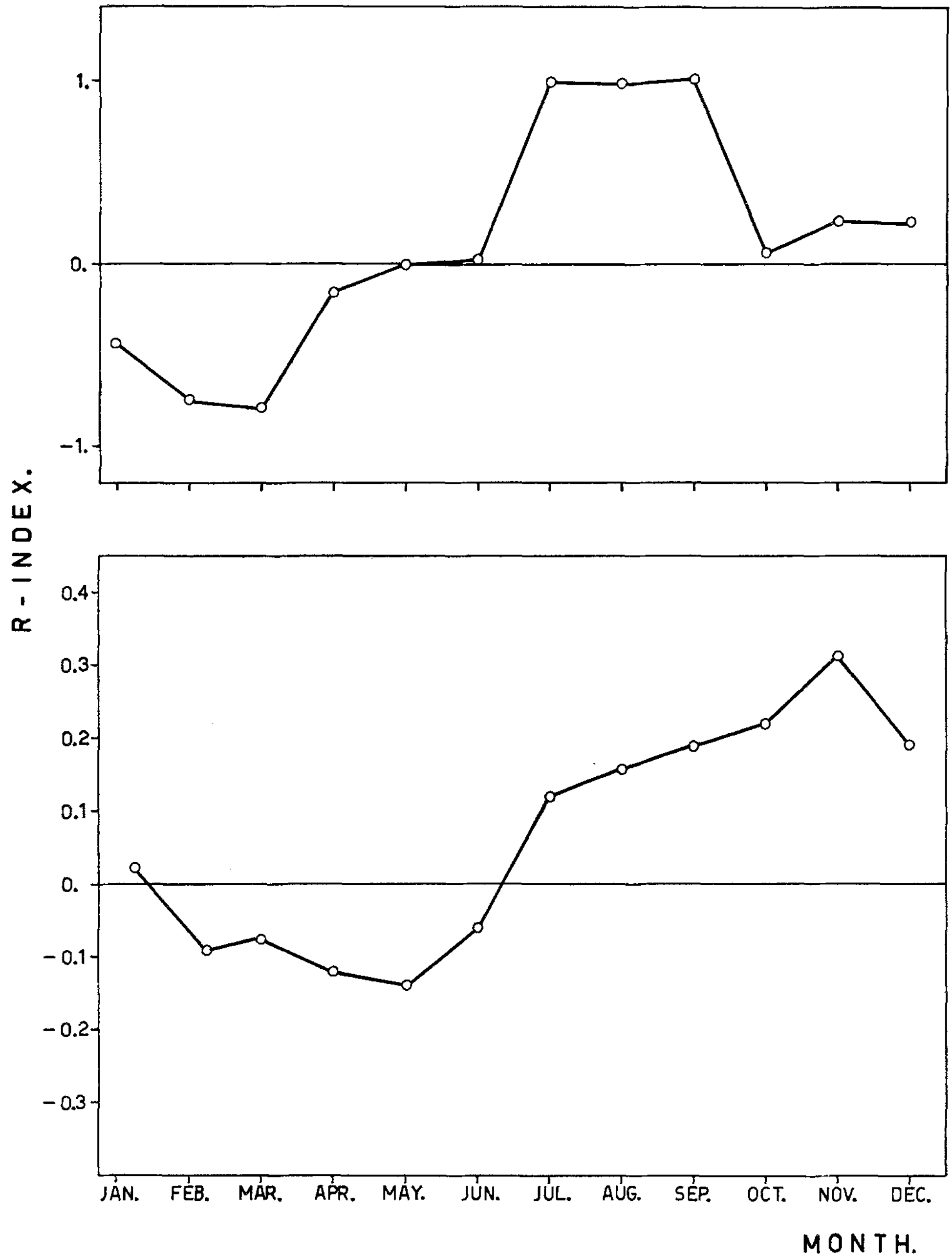


Figure 8
Trimonthly running averages, of mean monthly $R$ indexes, computed from values which were pooled per circle, on precipitation totals (above) and per rainy day (below)

## References

[1] A. C. Montefinale, T. W. Zawidzki, G. L. Petriconi and H. M. Papee, *Combustible compositions for generating aerosols for cloud-modification and weather-control. Note I: Giant condensation nuclei.* Ric. Sci. (Rome) *39* (1970), 828–34.

[2] A. C. Montefinale, T. W. Zawidzki, G. L. Petriconi and H. M. Papee, *Combustible compositions for generating aerosols for cloud-modification and weather-control. Note II: Experiments on dissipation of warm valley-clouds.* Ric. Si. (Rome) *39* (1970), 835–42.

[3] A. C. Montefinale, T. W. Zawidzki, G. L. Petriconi and H. M. Papee, *Combustible compositions for generating aerosols for cloud-modification and weather-control. Note III: Giant $Al_2S_3$ ice-forming nuclei and related preliminary field-tests.* Ric. Sci. (Rome) *39* (1970), 843–9.

[4] L. J. Battan, *Relation between cloud-base and initial radar echo.* J. Appl. Meteor. *2* (1963), 333–6.

[5] K. Isono, M. Komabayashi, T. Takahashi and T. Gonda, *A physical study of solid precipitation from convective clouds over the sea. Part. IV. Importance of giant sea-salt nuclei in formation of solid precipitation.* J. Meteorol. Soc. Japan II *44* (1966), 308–19.

[6] H. G. Houghton, *On precipitation mechanisms and their artificial modification.* J. Appl. Meteorol. *7* (1968), 851–9.

[7] J. E. Jiusto, R. J. Pilie and W. C. Kocmond, *Fog modification with giant hygroscopic nuclei.* J. Appl. Meteor. *7* (1968), 860–9.

[8] E. X. Berry, *Modification of the warm-rain process. Proc. 1st. Natl. Conf. Weather Modif.*(Amer. Meteorol. Soc. Boston (1968), 81–8.

[9] N. A. Peterman, *Hygroscopic treatment of warm-cloud precipitation. Proc. 1st. Natl. Conf. Weather Modif.* (Amer. Meteorol. Soc. Boston 1968), 107–13.

[10] W. E. Howell and M. E. Lopez, *Cloud-seeding in Southern Puerto-Rico, April – July 1965.* J. Appl. Meteorol. *5* (1966), 692–6.

[11] K. R. Biswas, R. K. Kapoor, K. K. Kanuga and Bh. V. Ramana-Murty, *Cloud-seeding experiment using common salt.* J. Appl. Meteor. *6* (1967), 914–23.

[12] Bh. V. Ramana-Murty and K. R. Biswas, *Weather-modification in India. Proc. 1st. Natl. Conf. Weather Modif.* (Amer, Meteorol. Soc. Boston 1968), 71–80.

[13] R. N. Chatterjee, K. R. Biswas and Bh. V. Ramana-Murty, *Results of cloud-seeding experiment at Delhi as assessed by radar.* Indian J. Meteor. and Geophys. *20* (1969), 11–6.

[14] A. C. Montefinale and H. M. Papee, *Preliminary tests on large-scale suppression of warm fog by means of giant monodisperse particulates. Part I. The first Ghedi – Monte Orfano experiment.* Pageoph *83* (1970/VI), 167–172.

[15] G. Suits, *The collected works of Irving Langmuir: Vol. 11. – Cloud Nucleation.* (Pergamon Press, New York 1962), Chapter 4.

[16] G. W. Brier, T. H. Carpenter and D. B. Kline, *Some problems on evaluating cloud-seeding effects over extensive areas – Proc. Vth. Berkeley Symp. Math. Stat. Prob. Vol. V. Weather Modification experiments.* (Univ. Calif. Press, Berkeley (1967), 209–21.

[17] K. J. Brown and R. D. Elliott, *Large-scale dynamic effects of cloud-seeding. Proc. 1st. Natl. Conf. Weather Modif.* (Amer. Meteor. Soc. Boston 1968), 16–25.

[18] J. Neyman and E. Scott, *Further comments on the 'Final Report of the Advisory Committee on Weather Control'* J. Amer. Statist. Assoc. *56* (1961), 580–600.

[19] E. Perez Siliceo, A. Ahumada and P. A. Mosino, *Twelve years of cloud-seeding in the Nexaca watershed, Mexico.* J. Appl. Meteor. *2* (1963), 311–23.

[20] C. A. Bennett and N. L. Franklin, *Statistical Analysis in Chemistry and the chemical Industry* (J. Wiley & Sons Inc. New York 1967), 15.

[21] E. G. Bowen, *Lessons learned from long-term cloud-seeding experiments. – Proc. Internat. Conf. Cloud. Phys. Tokyo, 1965*, pp. 429–33.

[22] K. R. Gabriel, Y. Avichai and R. Steinberg, *A statistical investigation of persistence in the Israeli artificial rainfall stimulation experiment.* J. Appl. Meteor. *6* (1967), 323–5.

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