2.2 SEPARATION BETWEEN CLOUD SEEDING AND AIR POLLUTION EFFECTS

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Abstract
Enhancement of precipitation due to cloud seeding operations has been reported in many studies around the world in the last several decades. On the other hand, suppression of rain and snow due to urban and industrial air pollution recently has been documented and quantified. Here it is shown that both effects are the opposite sides of the same coin, demonstrating the sensitivity of clouds to human anthropogenic aerosols of different kinds. This is done by analyzing the rainfall amounts in northern Israel during the last 53 years and explaining the changes there as the combined opposite effects of precipitation suppression due to air pollution and enhancement due to glaciogenic cloud seeding. Time series based on precipitation from rain gauges were analyzed for seeded and non seeded days and periods in the experimental control and the target areas. The response variable is Ro, t he orographic enhancement factor, which is the ratio of gauge-measured rainfall in inland hilly areas (500-1000 m)to the rainfall at the upwind coasts and plains. The results show that for the whole period of 1950 –2002 the Ro of the hilly areas decreased by 15%.In the early non-seeded period (1950 –1960) Ro was found to be higher than the non-seeded days of the following period, which was the randomized experimental period (1961-1974).This apparently shows the effect of the increasing pollution. Ro had an identical decreasing trend during the seeded days of the experimental period and through the subsequent fully operationally seeded period(1975 –2002).However, the trend line of Ro was shifted upward by 12%for the seeded rain time series compared to the unseeded time series. Thus, the opposite effects of air pollution and seeding appear to have nearly canceled each other in recent years, leading to the false impression that cloud seeding is no longer effective. However, the findings here suggest that if the operational seeding were to stop ,Ro would decrease further by about 12%.The sensitivity of Ro to both seeding and pollution effects was greatest in the areas with the greatest natural orographic enhancement factor and practically non-existent in areas where Ro is near unity. This suggests that the orographic clouds are the most sensitive to air pollution and cloud seeding effects on clouds and precipitation, in agreement with the large susceptibility of precipitation from such short living shallow clouds to aerosols.

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1. Introduction

Previous studies have shown qualitatively that urban and industrial air pollution suppresses precipitation-forming processes in convective clouds (Rosenfeld 1999, 2000). The pollution aerosols serve as small CCN that form large concentrations of small cloud droplets. This in turn suppresses the drops coalescence and the warm rain processes, as well as the ice precipitation (Rosenfeld, 2000, Borys et al., 2003, Andreae et al 2004) and so prolongs the time required to convert the cloud water that exists in small drops into large hydrometeors that can precipitate. Borys et al. (2003) showed that the addition of as little as 1 ug m^{-3} of anthropogenic sulfate aerosols to a clean background can reduce the orographic snowfall rate in the Colorado Rocky Mountains by up to 50%. The suppression is stronger in shallower clouds with warmer top temperatures. Satellite observations showed that pollution can completely shut off precipitation from clouds that have temperatures at their tops > -10ºC (Rosenfeld and Woodley, 2003). Therefore, it is expected to find the greatest rain suppression in regions that are dominated by relatively short living clouds with relatively warm tops downwind of major urban areas. Due to their short life, such clouds are more sensitive to slowing down of the conversion of cloud water to precipitation, whereas long living clouds would eventually convert their water into precipitation regardless of the conversion rate.

Givati and Rosenfeld (2004) quantified the rainfall losses over hills downwind of major coastal urban areas in California and Israel. They expected to find the greatest rain suppression in regions that are dominated by relatively short living clouds with relatively warm tops downwind of major urban areas. Such clouds are more sensitive to slowing down of the conversion of cloud water to precipitation, whereas long living clouds would eventually convert their water into precipitation regardless of the conversion rate. They expected that the effect would be most pronounced downwind of coastal cities with hills inland that receive precipitation mainly during the winter in maritime onshore flow from shallow convective clouds. The main effect would be, therefore, the suppression of the orographic component of the precipitation, which would be manifested as a reduction in the orographic enhancement factor Ro, where Ro is defined as the ratio between the precipitation amounts at the hills and at the upwind lowland. Such conditions are quite abundant, especially on the west coast of continents in the subtropics and mid-latitudes, where the precipitation over the hills is a major source for the scarce water there.

Their main analysis tool was the time series of Ro based on annual precipitation from rain gauges downwind and side wind of major urban areas. The underlying assumption was that small particulate air pollution emissions have increased with the growth of the urban areas, resulting in a decrease in Ro with time. The suppression rate amounts were found to be 15 – 25% of the annual precipitation in hilly areas in California and Israel (Givati and Rosenfeld, 2004). The suppression occurs mainly in the relatively shallow orographic clouds within the cold air mass of cyclones and not in the warm air mass. The side wind Ro time series didn't show any trend with time, and so serve as controls to the polluted areas (for example areas in northern California).

Enhancement of precipitation due to cloud seeding operations has been suggested in many studies around the world in the last half century although scientific proof is still lacking (Silverman, 2001). In terms of cloud microphysical effects, cloud seeding and air pollution are the opposite sides of the same coin. Both are manifestations of the same sensitivity of clouds to human activities. It seems that clouds respond correspondingly to what is added to them. The enhancement and the suppression are caused by addition of ice nuclei and small CCN, respectively. Ice nuclei can enhance precipitation but they can also suppress them (Rosenfeld, 2000). Anthropogenic aerosols of different kinds can have opposite effects.

2. Catachrestic of the study areas

2.1. Microphysical characterization of the clouds in northern Israel

Convective clouds in Israel forms over the sea and most cross the coastline while mature. Because they are not relatively short living, they are not susceptible to aerosol effects like the orographic clouds. The clouds that form inland and are not orographic are usually synoptically forced, and hence deep and long living and therefore not susceptible to aerosols. Little new generation of convection occurs over lowlands, because of the lack of surface heating during the winter storms conditions. Sharon and Kutiel (1986) showed that the rain intensity in Israel decreases when the clouds move inland. Yair and Levin (1994) showed that the number of thunderstorms decrease from the coast inland, regardless to the elevation. Those observations strength the above statement regarding the maturing of the clouds when they move from the coast inland. Lahav and Rosenfeld (2000) characterized the microphysical properties of the clouds in Israel using aircraft measurements and satellite images. They monitored clouds separately over sea and inland, for documenting potential differences between the two areas. They found that maritime convective clouds in relatively clean marine air with low concentration of CCN changes to continental clouds 10-20 km after crossing the coast line. They found in several cases that when the clouds moved inland the drops concentration was higher than over the sea, with local concentration above 1000 drops cm^{-3} near cloud base decreasing with height. Over the sea the concentration varies between 200-350 drops cm^{-3}. According to the satellite the effective radius was smaller by about 2-3 μm for the same depth over the land, as obtained from the temperature relative to cloud base temperature (Lahav and Rosenfeld ,2000). The clouds over the sea exceeded the 14-μm precipitation threshold at -20C isotherm while inland it barely reached it at -11C isotherm. The re decreased moving from sea inland and farther east over Jordan. The clouds at the -10C isotherm exceeded the 14-μm precipitation threshold (Rosenfeld and Gutman, 1994) over sea, barely reached it over Israel, and were mostly below it over Jordan in the case that was examined by them.

2.2. Cloud seeding in Northern Israel

In Israel, two cloud seeding experiments were carried out during the period of 1961–1975 by aircraft seeding with silver iodide acetone burners. The first Israeli experiment (Israel-1, 1961-1967) had a two target cross-over design of north versus center. The seeding was randomized for each day to the north or the south, and was done by a seeder aircraft flying along a seeding line to the west of the coast line (See Fig. 1). The overall result was 15% enhancement in the north and south combined, statistically significant. (Gabriel, 1967; Gagin and Neumann, 1974, 1981; Gabriel and Rosenfeld 1990).

In Israel-2 (1970-1975) the seeding line of the northern target area was shifted eastward to the coast line and a northern control area was defined along the coast line. The center of Israel was named the southern seeded area (S). Either north or south was seeded on each experimental day, according to a random pre-allocation. Analysis of Israel-2 experiment for the north alone showed statistically significant enhancement of 13% (Gagin and Neumann, 1981), while having no effect in the south or when analyzed as a cross-over experiment as was done for Israel-1 (Gabriel and Rosenfeld, 1990). After two experiments achieving positive results in the north, the seeding in northern Israel continued since 1975 in operational mode, i.e., seeding at all days with potential rain clouds. Nirel and Rosenfeld (1995) evaluated this operational seeding and found only a 6% enhancement for the period of 1975 -1990. Their main analysis was based on the assumption of stability in the historical target/control ratio. However, they identified a decreasing trend in that ratio but no physical explanation was offered. (Nirel and Rosenfeld, 1995). When they repeated the analysis of the seeding effect assuming an extrapolated decreasing trend of the not-seeded target/control ratio to the operational seeding period, the operational seeding effect was calculated at 11% (Nirel and Rosenfeld, 1995).

2.3. Air pollution in Israel

Air pollution arrives to the northern Israeli hills on rain days with the airflow from Eastern Europe through the eastern Mediterranean. The flow curves cyclonically and typically arrives to northern Israel at low level as a south-westerly wind that picks considerable air pollution from the Israeli coastal plain. A major pollution source is Haifa bay, densely populated area (over 1.5 millions people) that contains power plants, a refinery and much industry (Israel ministry of environment, 2000). In Israel, as in other places in the world, rapid technological development, improvement in standards of living and increased population density have brought in their wake pollutant emissions from both stationary and mobile sources. Vehicle density has risen from 34 cars per thousand population in 1954 to over 230 today, with the number of cars reaching 2 million. (Israeli Central Bureau, 2004). Emissions of all pollutants have increased since 1980 (Israel's Air Resources Management Program, August 1998). The increase was due primarily to the increasing reliance on diesel fuels for trucks and commercial vehicles (Fletcher et el. 1999). PM10 levels in Tel Aviv and Jerusalem are on a par with, or may even exceed, the average in the Los Angeles region (Fletcher et, 1999).

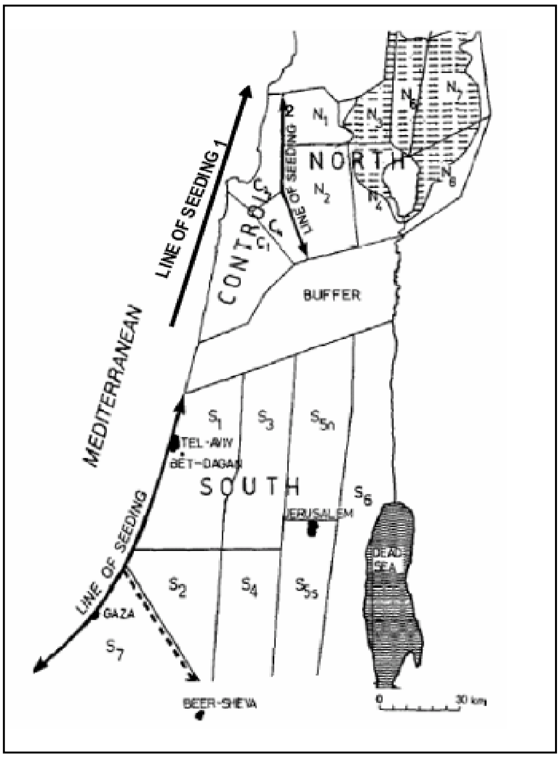


Figure 1: Map of Israel showing the two experimental areas and sub areas for Israel 1, (1961-1969), Israel 2 (1969-1974), the operational seeding in the north (1974-till today) and Israel 3 in the south (start with S, 1975-1995). The target (start with N in the north and control (start with C) areas are divided in sub areas. The seeding line in Israel 2 was moved easterly, in land, in Northern Israel. The broken lines in the north represent the drainage basin of lake Galilee, The main target area in the north.

2.4. Cloud seeding in southern Israel

During Israel-1 and Israel-2 experiments the seeded days in the north were the unseeded days in the south (the southern part of the seeding experiments is actually from geographical point of view the center of Israel. In reference to the north it was called "south" in the seeding experiment). The seeding line in Israel-1 was over the sea parallel to the coast line, from abeam Ashqelon to abeam Natanya (See fig.1).

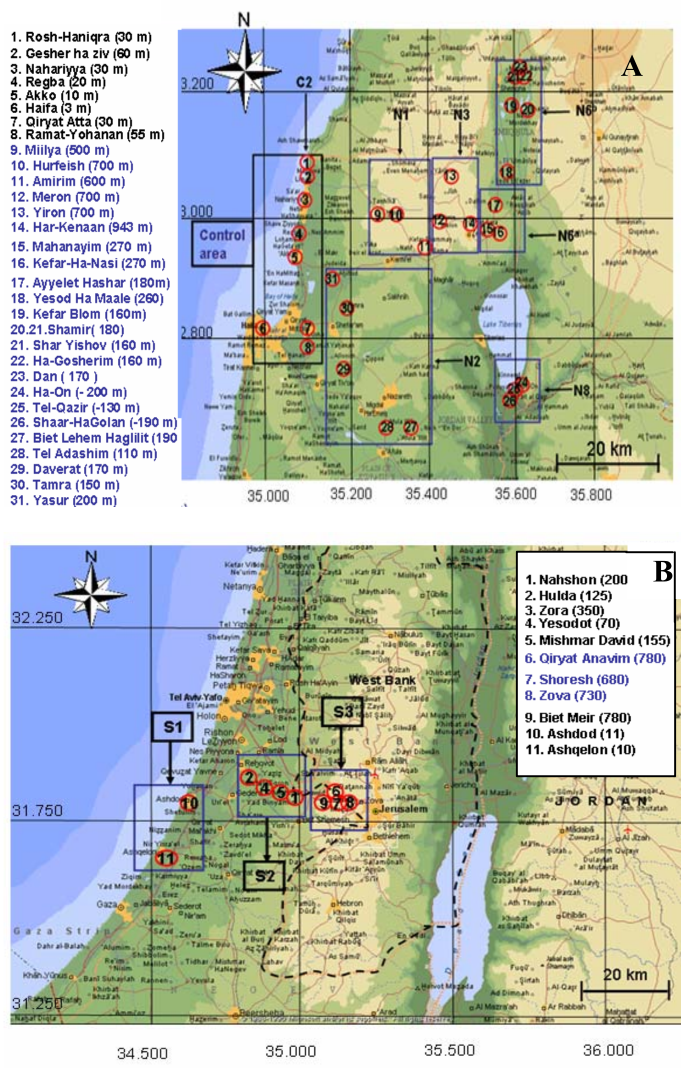


Fig 2: Clusters of homogeneous rain gauges in the targets (in black, start with N for the north and in S for the south) and control (in blue, C2 in the north and S1 in the south) in the northern (A) and southern (B) seeded areas in Israel.

In Israel-2 the seeding line was shifted to the coastline and extended southward to the full length of the Gaza strip. Israel-3 was conducted between 1975 and 1995 as a randomized experiment in the south only. The seeding line at the southern half was shifted eastward to the line of Ashqelon – Beer Sheba. This left S7 as control area (see fig.1).

The statistical analysis for the southern seeding area in Israel indicated that seeding did not enhance the rainfall in the south target area during Israel-2 (Gabriel and Rosenfeld, 1990). The positive effect in Israel-1 for the combined north and south target areas appeared to be contributed from the north, and when the south was considered alone it did not show enhancement (Rosenfeld, 1995). The formal analysis of Israeli-3 experiment resulted in no discernable change of the precipitation due to seeding (Rosenfeld, 1998). Understanding the reasons for the north-south differences of the seeding effects was a prim objective of few studies. Rosenfeld and Farbstein (1992) postulated that the dessert dust, advected from the north African, Sinai and the Negev deserts was responsible to the seeding ineffectiveness in the south, by “seeding” naturally the clouds there by ice nuclei. They have shown that the seeding effect of Israeli-2 north was almost fully obtained during half of the days, in which no dust was observed in the synoptic observation in Israel. Herut et al. (1998) have shown that rainfall in the south was basic, on the average, while it was mostly slightly acid in the north. The basic nature of the rain in the south was caused by the high alkaline content in it. Geochemical analysis pointed to the Sahara, Sinai and Negev desert as the source area of the high alkalinity of the rain. Levi and Rosenfeld (1996) have shown that the content of desert dust in the rain was an order of magnitude larger in the south than in the north. The aerosols brought with southwesterly winds were rich in desert dust, which acted as ice nuclei at relatively high temperature. The south is an area of large gradient of isohyets, which is the climatological manifestation of being affected mainly by the southern margins of the rain clouds systems. The hypothesis that desert dust affected the southern margins of the rain cloud system, but washed down further north, was tested by Rosenfeld and Nirel (1996) , who analyzed the seeding effect in the north, stratified by the southward extent of the rain cloud system. They found that rainfall was enhanced in the north only on situations where it extended to the south part of the south area. That result was found with the highest significant level than any other statistical analysis throughout the Israeli experiments (Rosenfeld and Nirel ,1996).

3. Methodology

3.1. Overall Ro trends

The first step was to quantify the combined effects of air pollution and seeding without attempting to separate them. As was done by Givati and Rosenfeld (2004) in California and in southern Israel (in Judea and Samaria hills, the southern part of the seeing area) highly correlated pairs of hills / coast rain gauges were selected in order to achieve a good representation of the control and the target areas in the north. The stations in each cluster were selected according to the principles of topographical similarity (meaning that the stations in each cluster should be around the same elevation) and equal precipitation measuring periods. The main response parameter that is used is the annual time series of Ro. Northern Israel was divided into six sub target areas and three sub control areas (see fig. 1) as was done in the cloud seeding experiments.

The analysis presents in the next sections first evaluate for northern Israel the combined effects of air pollution and seeding, and then followed by analysis of the separate effects based on time series under seeded and unseeded conditions.

In order to evaluate the trends in Ro, the ratio of precipitation between clusters of hilly rain gauges and clusters of upwind lowland rain gauges was measured. Therefore, the clusters of stations used here in the south are the same clusters that were used to evaluate the trends in the orographic enhancement factor (Ro) in Givati and Rosenfeld (2004) but they do not mach exactly to the clusters that were used in the formal evaluation of the cloud seeding experiments.

3.2. Separation between seeded and unseeded trends

As was mentioned before, the seeding line was to the west of the coast line in Israel-1, on the coast line in Israel-2 for the south, and east of the coast line in Israel-2 for the north and the southern portion of Israel-3. According to this, the coastal plain stations could have been under the influence of seeding only during the 6 years of Israel 1 in the north. When we excluding this period the trends for the seeded and unseeded conditions didn’t change, but due to the small quantity of the seeding years it won’t be right to exclude this. Instead, we assume that the seeding effect on the coastal plain stations during Israel 1 is negligible with respect to the effect on the hilly stations. Any deviation from this assumption would only decrease the apparent seeding effects on Ro. Therefore, when suspecting that seeding might have enhanced the precipitation at the coastal plain, the results should be considered the lower bound of the seeding effect on Ro. Therefore we can say that the coastal stations that we used for the control areas are not likely to have been affected by local pollution or by seeding of Israel-1 because they were near the seeding line, and obviously not by seeding of Israeli-2 and the operational seeding.

Givati and Rosenfeld (2004) showed that the orographic clouds were the most sensitive to the precipitation suppression effects of the air pollution, as quantified by the trends in the orographic enhancement factor, Ro. They showed that no change was evident in the lowland stations both in Israel and California (for example – no change was evident between the lowland stations of San

Bernandino and Los Angeles, Sacramento and San Francisco and pairs of lowland stations in Israel). We suggest here that rain enhancement by cloud seeding is the other side of the same coin of the sensitivity of the precipitation efficiency of orographic clouds to aerosols. The lack of the apparent pollution effects in the lowlands suggest that the precipitation there occur from clouds that are not as sensitive to the aerosols source over land, because they were originated by convection or synoptic forcing over sea, and are relatively mature when advected from sea inland.

The years between 1950 and 1960 were the pre experimental years and so were considered as the non-seeded period. The years between 1975 until today are the operational period and so considered as seeded. During the period of 1961 – 1975 (Israel 1 and 2 experiments) some of the days were seeded and some unseeded, according to a random allocation that was inherent to the experiment. The separate time series contain annual precipitation amounts for the seeded and unseeded days separately (from November to April each year).

4. Results

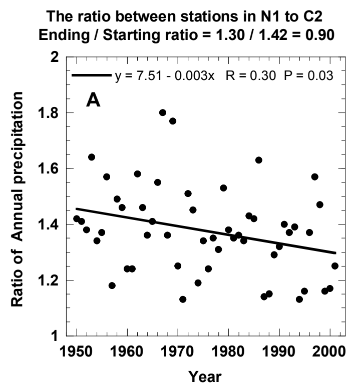
4.1. overall Ro trends

Fig. 3 displays the time series of Ro (the ratio of target-control annual rainfall) for the hilly clusters of N1 (A) and N3 (B) against the plains cluster of C2 (see locations in fig. 2A). The control area of C2 has the highest daily and annual correlation with the clusters of N1 and N3 so this is why this specific cluster was used for measuring the hill / plains ratio for the north. The high correlation is required for using the coastal station to predict the “natural” rainfall in the hilly station. The high correlation is also essential for assuring that the mountain station that was selected is indeed downwind to the costal station.

The coastal area of C2 was downwind of the seeding line during the Israel 1 experiment (see the seeding line in fig. 1), but upwind of it during Israel 2, when it became a control area. Givati and Rosenfeld (2004) showed that low, non- orographic clouds are not sensitive to air pollution. They present a topographic cross-section from the costal area of San Francisco, through the plain of Sacramento to the Sierra Nevada range and show that no trend occurred between the polluted plain to the coast area. Only the western slopes showed a decrease in the ratio between them to the coast or plain. If we accept this finding and the idea of the insensitivity of the non-orographic clouds to anthropogenic effects, we can allow our self to consider the coastal area of C2 as a control area, despite the fact it was seeded part of the time.

The hilly clusters are located downwind of the pollution sources in the bay of Haifa. It can be seen in figure 3 that a decreasing trend of 10%-15% in the Ro occurred along the years in those target areas. The decrease is statistically significant. This decrease in Ro is similar to those found in hilly areas in central Israel and in California (Givati and Rosenfeld, 2004). In contrast, little change was found in the target/control ratio for the low elevation clusters of stations in the areas of N2. This is line with the lack of orographic enhancement factor between these sub areas and the upwind coastal control clusters. This is evident in fig. 5, where the absence in the orographic enhancement is associated with lack of significant trend in the Ro in those areas along the years.

Trends in the cross-hill component of the low tropospheric wind velocity and moisture flux during rain events are the most likely alternative explanation for the reduction in Ro. Givati and Rosenfeld (2004) applied a radiosonde regression model to predict the daily rain amounts in hilly stations. The model showed no difference between the measured rain and the predicted rain in central Israel (the southern seeded area). Essentially, this reflects that the relevant meteorological conditions during rain days did not change systematically along the years, and the observed trends in Ro are likely caused by non-meteorological reasons, such as anthropogenic air pollution.



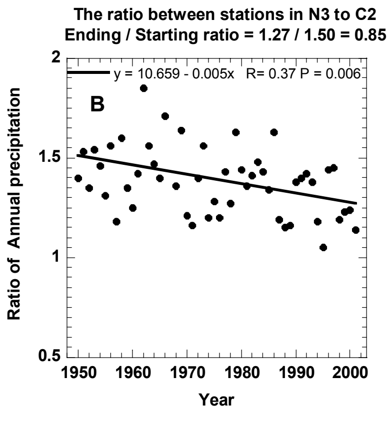


Fig. 3: Overall change in the target/control annual ratio of precipitation during the last 54 years, for a cluster of rain gauge cluster at elevations of 600 to 800 m in sub-area N1 (upper panel), and for a

cluster at elevation of 750-950 m at sub-area N3 (lower panel). Note the statistically significant decrease of 10%-15% in the ratios with respect to C2 control area.

Figures 4 display the time series of Ro for the plain and valley clusters of N2 against the control areas of C2. No significant trend in the Ro under seeded and unseeded conditions was found between the low elevation target cluster to the control areas of C2. The ratio was stable along the years since the 50's until today. The effect of cloud seeding and air pollution in the low elevation areas is more limited due to the lack of an orographic enhancement to the rainfall. This strengthens the suggestion that orographic clouds are the most susceptible for precipitation enhancement due to cloud seeding and to precipitation suppression due to air pollution.

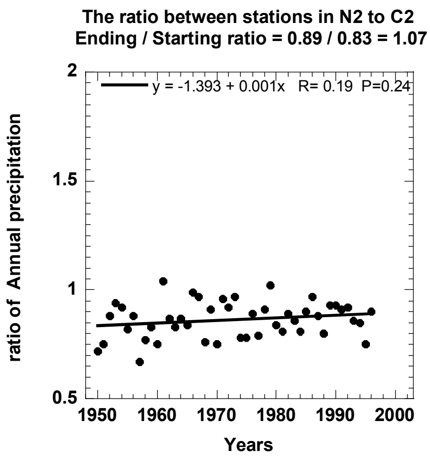


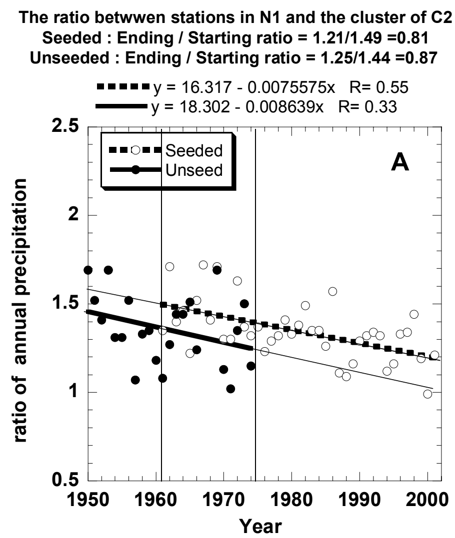
Fig. 4: Lack of orographic enhancement factor between the low elevation clusters in the targets areas N2 (B, 27 m) with respect to the control areas of C2. No significant trend in the Ro along the years

4.2. Trend analysis under seeded and unseeded conditions – Northern Israel

Fig. 5 shows the trend lines under seeded (the broken line and empty points) and unseeded (the solid line and full points) conditions for the ratio between the clusters of stations in N1 (A) and N3 (B) against the coastal cluster of C2. Both the seeded and the unseeded trend lines in the two clusters decreased along the years, but the broken line that represents the ratio under seeded conditions is shifted upward by 12% to 14% with respect to the solid line that represents the unseeded condition. During the randomized seeding period of 1961-1975 the target/control ratio of the seeded days was greater by 12.4% than for the not seeded days in N1 and by 14.4% in N3 (The calculation for the distance between the lines was made according to the average value of the periods 1961 – 1974). Adding the years before 1961 to the unseeded regression and the years after 1975 to the seeded regression did not change much the regression lines. The regressions shown in Fig. 5 are for these full seeded and unseeded datasets. Implementation of the Student T test (statistical test for difference between groups) shows that the differences between the seeded and unseeded regression trend lines are significant at the level of 3% for N1 and at 7% for N3. This means that without cloud seeding the precipitation amount in those two target areas would have been 12% to 14% less of what they are today, or a loss of about 100 mm/year in the hilly areas with annual precipitation amount near 800 mm. The increase in the orographic enhancement factor due to cloud seeding does not fully compensate for the continuing decrease due to air pollution. Cloud seeding for rain enhancement is aimed at accelerating the conversion of cloud droplets into precipitation particles, whereas air pollution has the opposite effect of suppressing the coalescence of cloud droplets into raindrops and the formation of ice hydrometeors. Rosenfeld (2000) showed the pollution suppression effect on ice formation in places like Australia.

As it can be seen in fig. 5 the ratio for the seeded conditions at the end of the measured period is still lower by 14-15% than the unseeded ratio at the beginning of the measurement period. This is in agreement with the overall ratio for all days without partitioning by seeding, as shown in Fig. 3.

Fundamentally, cloud seeding can increase precipitation amount above the natural values, as was actually done in the early randomized cloud seeding experiments. After all, this was the original purpose of these experiments. If we assume that the natural conditions have not changed during the research period, as suggested by the radiosonde analysis (Givati and Rosenfeld, 2004), a decrease of a given amount in precipitation efficiency due to air pollution implies a same percentage increase in the rain enhancement potential by introduction of aerosols that have the counter-effect. In such case, there is at least a potential of additional 14% for rain enhancement in order to restore to the values of the natural ratio that was in the early 50's. This further implies that cloud seeding as practiced in Israel is far from being optimal, by targeting and/or microphysical effects.



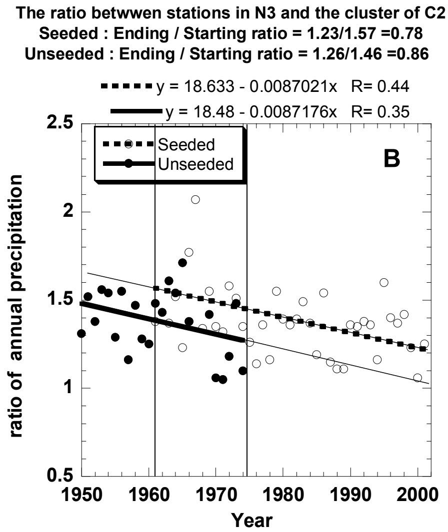
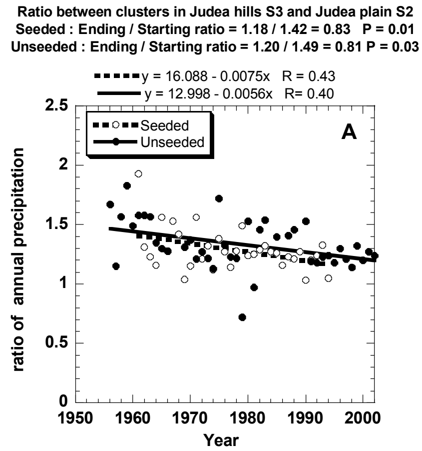


Fig. 5: change in the target/control annual ratio of precipitation during the last 54 years for the seeded (broken line and empty points) and unseeded (solid line and full points), between stations in the targets areas of N1 in the upper panel (western upper Galilee) and N3 in the lower panel (upper Galilee) to the control area C2 (northern coast). The seeded trend line is shifted upward with respect to the unseeded line by 12.4% in N1 and by 14.2% in N3.

4.3. Trend analysis under seeded and unseeded conditions – southern Israel

Fig 6 shows the trend lines for the ratio under seeded and unseeded conditions in the southern seeded area of Israel between hilly clusters of stations of Judea hills (S3 in Fig. 2) against the Judea plains (S2 in Fig. 2) and cluster at the coastal plain further upwind (S1 in Fig. 2).

As was found in Givati and Rosenfeld (2004), the Ro between the hilly cluster to the plains and coast is decreasing, but in can be seen in fig. 6 that unlike what is shown in fig 5, here there are almost no differences between the trend lines that represent the seeded and the unseeded conditions. No trend was found for the ratio between the Judea plains to the coastal plain under seeded and unseeded conditions and also no difference was found between the lines. These results suggest that the seeding did not appear to have affected the clouds either over the plain or over the hills downwind the seeding line. Those findings fit the statistical evidence for Israel 1 (Rosenfeld, 1997), 2 (Gabriel and Rosenfeld, 1990) and 3 (Rosenfeld et al. 1998) that showed no rainfall enhancement in the south target area.



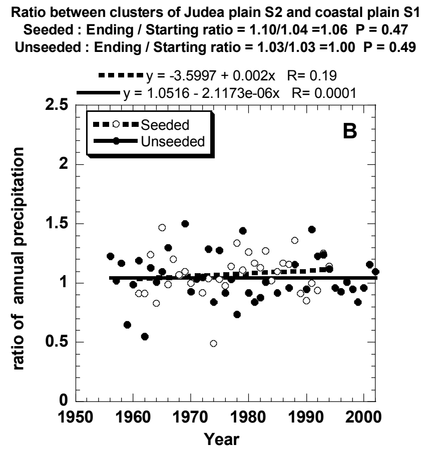


Fig. 6: Trend lines under seeded and unseeded conditions for the ratio between (A) the cluster of rain gauges over the hills of Jerusalem, 600-800 m (S3) versus the upwind plain just to the west of the hills, 100-200 m (S2) and this plain cluster against cluster of station in the coast (B). No relative trends occurred between S2 and S1. It can be seen that although the Ro between the hill to the plain, unlike in northern Israel (fig. 3) here there is no difference between the lines that represents seeded conditions (broken line and empty points) and unseeded conditions (solid line and full points). It suggests that cloud seeding did not enhance precipitation in the hills over central Israel.

5. Conclusions

The results presented in this paper show for the first time the opposite effects of deliberate and inadvertent human actions to alter precipitation processes. The effect of growing urban and industrial air pollution since the 1950's has caused an inadvertent decrease in the ratio in the orographic enhancement factor between hilly areas and plain areas upwind from them (as was found in Israel and California). Without the air pollution no trend would have probably occurred in the ratio (as was found in relatively pollution-free areas in Israel and California). Cloud seeding with sliver iodide was found to enhance the precipitation especially where the orographic enhancement factor was the largest. Likewise, the pollution effects reduced the precipitation by the greatest amount in the same regions. Shallow and short-living orographic clouds are particularly susceptible to such impacts. They respond in an opposite way to the different materials that we add to them. Because of that, it seems that the attempts to alter winter precipitation should be concentrated on orographic clouds. This suggests that the conceptual model on which the Israeli cloud seeding experiments was based is not exactly as postulated. The seeding aimed mainly at increasing the rate of precipitation forming processes at the convective clouds forming over sea and coastal plains by glaciogenic seeding that is aimed to formed graupel earlier in the cloud lifecycle (Gagin and Neumann, 1974). However, it appears that cloud seeding did not enhance the convective precipitation, but rather increased the orographic precipitation, apparently by the Bergeron Findeisen process (Friedman 1982). The meaning of the results that are presented here is that statistical evaluations of seeding efficacy on orographic precipitation without taking into account the pollution effects will lead to erroneous results and misleading conclusions. This fact can explain why such models that estimated the seeding effects in northern Israel based on historical comparisons (Nirel and Rosenfeld, 1995) showed decreases in apparent seeding effect along the years. The case study that was analyzed here is not unique. Many places in the world are influenced by those opposite effects. The effect of air pollution on the orographic precipitation was document and quantified but it wasn't separate from the positive effect of decades of glaciogenic cloud seeding of the orographic clouds. Similar analysis can be done in other places in the world where we have the physical basis to expect that such confounding effects occurred, and have quality precipitation data in the hilly areas available to us. Based on previous studies and on the results of this paper we suggest that our proposed mechanism is the most likely explanation to the observations, and no alternative explanations were found probable. Certainly additional research is required.

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