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Cloud microphysical background for the Israel-4 cloud seeding experiment

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ABSTRACT

The modest amount of rainfall in Israel occurs in winter storms that bring convective clouds from the Mediterranean Sea when the cold post frontal air interacts with its relatively warm surface. These clouds were seeded in the Israel-1 and Israel-2 cloud glaciogenic seeding experiments, which have shown statistically significant positive effect of added rainfall of at least 13% in northern Israel, whereas the Israel-3 experiment showed no added rainfall in the south. This was followed by operational seeding in the north since 1975.

The lack of physical evidence for the causes of the positive effects in the north caused a lack of confidence in the statistical results and led to the Israel-4 randomized seeding experiment in northern Israel. This experiment started in the winter of 2013/14. The main difference from the previous experiments is the focus on the orographic clouds in the catchment of the Sea of Galilee. The decision to commence the experiment was partially based on evidence supporting the existence of seeding potential, which is reported here.

Aircraft and satellite microphysical and dynamic measurements of the clouds document the critical roles of aerosols, especially sea spray, on cloud microstructure and precipitation forming processes. It was found that the convective clouds over sea and coastal areas are naturally seeded hygroscopically by sea spray and develop precipitation efficiently. The diminution of the large sea spray aerosols farther inland along with the increase in aerosol concentrations causes the clouds to develop precipitation more slowly. The short time available for the precipitation forming processes in super-cooled orographic clouds over the Golan Heights farthest inland represents the best glaciogenic seeding potential.

1. Introduction

Glaciogenic cloud seeding has been conducted in Israel since the early 1960s by seeding silver iodide (AgI) from acetone burners both from aircraft that fly along seeding lines upwind of the target areas and from ground generators. The seeding efficacy was evaluated by three randomized experiments (Israel-1: 1961–67, Israel-2: 1969–75 and Israel-3: 1975–95). Subsequently, operational seeding in the north of Israel was carried out between 1975 and 2013. The statistical analyses of the first two randomized experiments (Israel-1 and 2) showed precipitation enhancement of 15% and 13%, respectively. The indicated effects were larger at a distance of 25–50 km from the seeding line (Gabriel and Rosenfeld, 1990; Gagin and Neumann, 1974, 1981). The third experiment (Israel-3) was conducted in the south of Israel and showed no significant effect (Rosenfeld and Farbstein, 1992). These results have been debated and a few studies have claimed that the reported enhancement in precipitation was actually a result of meteorological bias or statistical errors (Levin et al., 2010; Rangno and Robbs,

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1995), despite the statistically significant positive results in the first two experiments. These claims have to be weighed against the mathematical fact that the likelihood of this to happen twice in a row for experiments with significance level < 5% is < $0.05^2 = 0.0025$ (Ben-Zvi et al., 2011).

The seeding, in the first two experiments, was focused on convective clouds over the Mediterranean Sea and the coast of Israel. The heat flux from the relatively warm sea energizes these convective clouds. The main target area, however, was the hilly areas inland, where orographic clouds also form. Subsequent studies found that the convective clouds over the Mediterranean Sea are naturally seeded hygroscopically by sea spray and hence not very prone to enhancement by seeding silver iodide (Lahav and Rosenfeld, 2000; Levin et al., 1996). The explanation given to the lack of positive seeding effect in Israel-3 was the frequent presence of desert dust in southern and central Israel that seeded the clouds naturally by serving as ice nuclei (Levi and Rosenfeld, 1996; Rosenfeld and Farbstein, 1992; Rosenfeld and Nirel, 1996).

Additional statistical analyses showed that the orographic precipitation responded most sensitively to the seeding experiments (Givati and Rosenfeld, 2005). These hilly areas receive higher rainfall than the coastal plain. They constitute the main catchment for the Sea of Galilee, which serves as a major water reservoir for Israel. Therefore, presently, seeding is carried out with a similar technique as was done since 1961, but with additional seeding lines farther east and augmented with ground generators targeting the orographic clouds over the upper Galilee and the Golan Heights (see Fig. 1).

The relatively short life time of cloud droplets in orographic clouds makes them more sensitive to aerosol effects (Givati and Rosenfeld, 2005, 2009; Rosenfeld and Givati, 2006). Cloud physics research flights have been conducted in Israel for further elucidating the hypothesis that orographic clouds might be more suitable for seeding than the convective clouds, and that previous indicated enhanced rainfall might have been contributed mostly by them (Givati and Rosenfeld, 2005). The main objective of these measurements was to characterize the Israeli winter clouds and the environment in which they develop, in order to evaluate their seeding potential. The cloud microstructure was documented with an instrumented research aircraft. The insights from aircraft measurements were expanded to the regional scale by satellite retrievals of cloud microphysical properties. The results, which are reported in the next sections, were sufficiently encouraging to support a fourth randomized cloud seeding experiment. The Israel-4 experiment is focused at evaluating the seeding effect over the catchment of the Sea of Galilee. Most of the water running to the lake comes from precipitation falling over the Golan Heights and Mount Hermon (Fig. 1), which receive considerable amounts of orographic precipitation.

The randomized experimental temporal unit of Israel-4 is 24-hours, delimited at 08:00 (local time), in accordance with the definition of a rain-day. A set of criteria for definition of a suitable experimental unit is defined, and when they are

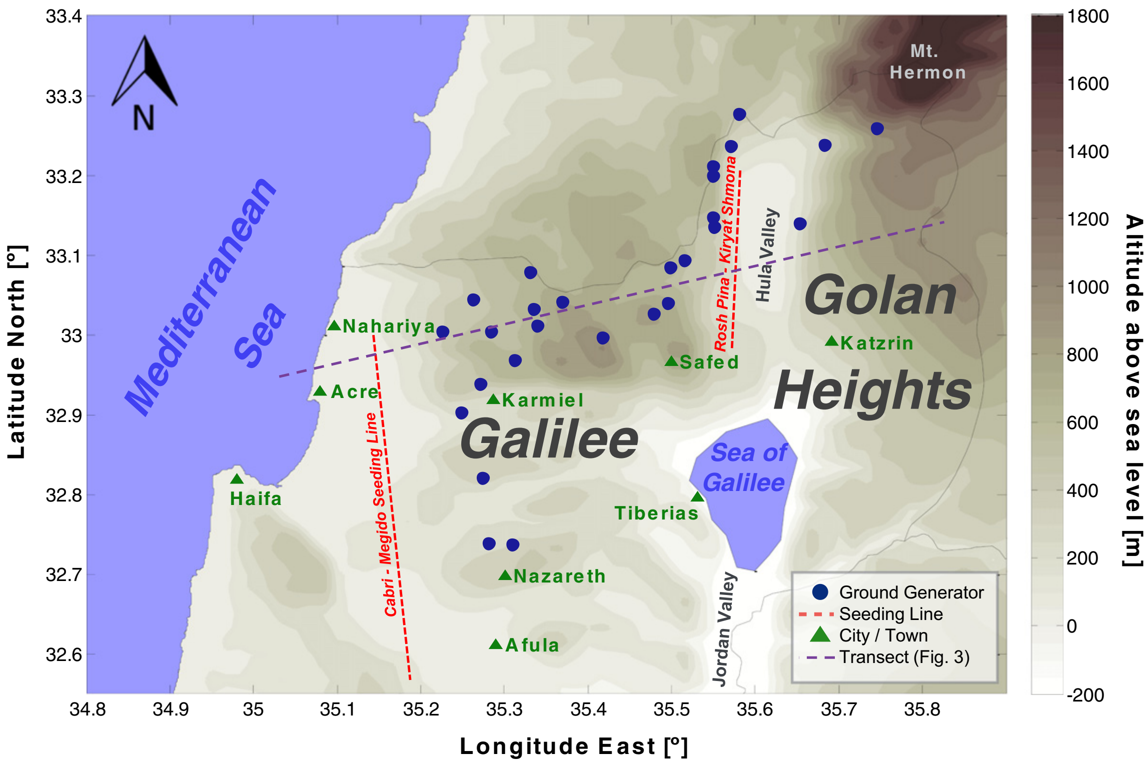

Fig. 1. A physical map of northern Israel showing the spatial distribution of the silver iodide ground generators (blue filled circles) as well as the seeding tracks of the aircraft of the Israeli rain enhancement program (red dashed lines). The purple dashed line denotes the approximate location of the topographic cross-section shown in Fig. 3.